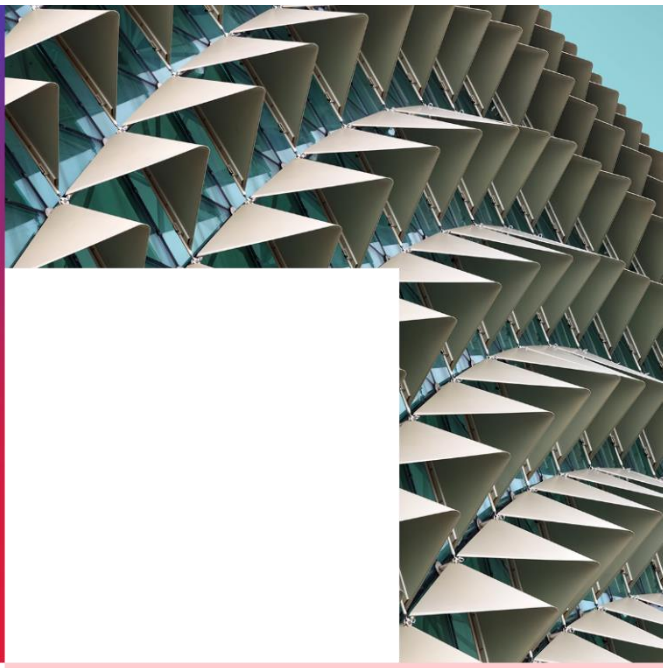

Combination Load Profiles (WP3-D1)

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Amendment History

Date	Issue	Status
31/03/2023	1.0	Initial version
16/04/2023	1.1	Version after review
17/04/2023	2.0	Baselined final version
26/04/2023	3.0	Graph colours updated
27/04/2023	4.0	Graph colours updated

Contents

1 Introduction

1.1 Background

This report focuses on the estimation of feeder and secondary substation load profiles. Headroom within the LV networks is a particular concern with the adoption of LCTs such as electric vehicles, especially where secondary substations do not have full monitoring installed and reliance is placed on maximum demand indicators alone. MDIs require resetting, measure against the sub-station rather than individual feeders, and do not specifically indicate when a peak demand occurred. The Feeder Load Profiles Use case described here calculate an estimate of the individual Feeder and secondary substation loads, and then compare these with the measured data from the secondary substation monitoring. The estimates are at a half hour time granularity and it is anticipated the profiles will be utilised in advancing LV planning and associated network capacity optimisation. The load estimation algorithms are suggested to be useful in business as usual to identify priority areas of network where headroom is coming under pressure and the installation of sub-station monitoring could be targeted. In a pragmatic sense the relative loading rather than an absolute value can still yield this prioritisation.

Four different main algorithms are used to calculate the feeder/secondary sub-station load, with a variant on each concerning if connectivity data from Crown is updated from Electric Office. The data used to provide estimates is based on data available to the DNO and other assumptions.

Please note that only the real power load is estimated. Assumptions on power factor can be made to estimate the total kVA load.

1.2 Aims

The aim of the analysis is to

1. Compare the accuracy of the different estimation methods against the measured data at both Substation and Feeder level
2. Identify key data issues
3. Discover if accuracy is dependent on the relative coverage of smart meters, dumb meters and Half-hour meters.

1.3 Document structure

The remaining sections of the document are set as follows

Section 2 provide a summary of the analysis.

Section 3 describes the estimation algorithms. As well as an overview of the main algorithms, includes a description of the default values used and the key factors to be used in assessing the quality of each estimation algorithm

Section 4 describes the approach of how the analysis was performed. It steps through how the initial data issues were identified, performing the initial analysis to identify erroneous data and identification of “good” feeders/substations, then an assessment of the core “good" feeders/substations as well as commentary on the “outlier” feeder/substations.

1.4 Abbreviations

Term	Definition
BaU	Business as Usual
CIM	(IEC 61970/61968/62325) Common Information Model for the electricity industry.
CSV	Comma-Separated Value
CROWN	NGED's asset register and work management system
DCC	Data Collection Company (for SM data)
DMS	Distribution Management System (such as GE PowerOn)
DNO	Distribution Network Operator
EAC	Estimated Annual Consumption
EAM	Enterprise Asset Management (such as ARM, SAP or Oracle)
EO	Electric Office (NGED's GIS)
GIS	Geographic Information System (such as ESRI or GE Electric Office/Smallworld)
HH	Half-Hourly
HV	High Voltage
LV	Low Voltage
INM	Integrated Network Model
JSON	JavaScript Object Notation
LCT	Low-Carbon Technology e.g. heat pumps, electric vehicles or photovoltaic generation
MDI	Maximum Demand Indicator
MPAN	Meter Point Administration Number (core – the 13-digit format)
NGED	National Grid Electricity Distribution
NHH	Non-Half-Hourly
NOP	Normally Open Point
ODS	Operational Data Store
OGC	Open Geospatial Consortium
RMS	Root Mean Square (= $\sqrt{\frac{1}{n}\sum x^2}$)
RMU	Ring Main Unit
SCADA	Supervisory Control and Data Acquisition
SM	Smart Meter
SMITN	Smart Meter Innovations and Test Network
SS	Secondary Substation
SSC	Standard Settlement Class
SQL	Structured Query Language
TPR	Time Pattern Regime
Tx	Transformer

2 Summary

2.1 Overview of process

The estimation process applied is a bottom up process where an estimate is made for individual MPANs (based on the MPAN type and attributes) and this data aggregated up to a feeder or substation level.

The most critical data was getting the correct association between an MPAN and its associated Feeder/substation. This was partially assisted by doing some analysis of the electric office data to identify whether that provided a better connectivity association. This improved the situation in some cases.

The next critical issue was to remove erroneous smart meter aggregation data here some rules were developed for the assessment. (See section 4.3)

Having filtered out the worst performing substations/feeders (see section 4.4) a comparison of the estimation techniques as performed against the three important planning and operation requirements of

- Daily peak
- Annual Peak
- Half Hour profile

These are described in more detail in section 3.3

Four estimation techniques were trialled (NHH1, NHH2, NHH3 and NHH4). These are described in section 3. Broadly NHH1 and NHH2 use electricity market profile coefficients for estimation whilst NHH3 and NHH4 uses Smart Meter data as a proxy for the non-smart meter MPANs.

Each estimation is compared against the substation metering.

2.2 Summary of Results

In general substation level estimations were better than feeder level estimations. This was expected as the MPAN associations on a substation were not affected about an incorrect association with a feeder. Also the greater number of MPANs played well into any averaging estimation method.

The assessment is shown below for both feeders and substations for the three key criteria. The assessment is based on the RMS across all the category 1[1] feeders/substations.

- The daily peak accuracy was found to be between 5%-20% for feeders and 5%-15% for substations.

- The annual peaks mostly within ±20%. It was noted that for Annual Peaks NHH1 and NHH2 tend to under-estimate whilst NHH3 and NHH4 tend to over-estimate.

- NHH1 and NHH2 half-hourly profiles was found to be better than NHH3 and NHH4.

[1] Selection of Category 1 feeders/substations is described in section 4.4. It removes outliers where the issues are probably due to MPAN connectivity data.

- Errors generally similar throughout days of the week and months of the year

NHH3 estimation technique is always the worst error. From these results the NHH1 estimation technique performs the best. The table below shows the overall results providing an average across all the category 1 feeders/substations.

Table 1 - Summary of results

	Daily Peak	Annual Peak	HH Profile
Substation	NHH1 (9.5%) NHH2 (9.9%) NHH4 (13.4%) NHH3 (15.1%)	NHH1 (10.7%) NHH4 (11.7%) NHH2 (13.2%) NHH3 (15.6%)	NHH1 (14.0%) NHH2 (14.5%) NHH4 (18.6%) NHH3 (21.0%)
Feeder	NHH1 (13.5%) NHH2 (14.4%) NHH4 (23.6%) NHH3 (26.3%)	NHH1 (14.1%) NHH2 (15.6%) NHH4 (27.5%) NHH3 (29.2%)	NHH1 (21.6%) NHH2 (22.6%) NHH4 (27.9%) NHH3 (28.9%)

3 Methods

3.1 Estimation algorithms

There are four different estimation algorithms trialled to calculate the feeder/secondary sub-station loads. Estimation is calculated on an MPAN level and then based on the assignment of the MPAN to feeder/substation, the aggregate for the feeder substation is determined.

MPANs are categorised into three types namely

- Half Hourly Metered MPANs
- MPANs with Smart Meters
- Non-Half Hour (NHH) MPANs (non- Smart Meter) (also referred to as Dumb MPANs)

Half Hour MPANs are those MPANs with half-hour metering and which are not collected via the DCC. The data is available for each MPAN on a half-hour granularity.

Smart Meter MPANs have data collected on a half-hour granularity but are only available as an aggregate of at least three MPANs. In our exercise the data used is an aggregate of all smart meter for each feeder.

Consumption for Dumb Meters is provided at an annual level. This data is be converted to Half-hour granularity by the use of profile coefficients.

The four estimation techniques are referred to as NHH1, NHH2, NHH3 and NHH4 as the variation in the techniques are mainly about how to estimate the NHH MPANs. The different techniques are summarised in the table below:

Algorithm Name	HH Customer Demand	Smart meter aggregated demand	NHH customer estimation
NHH1	An accurate reflection of the demand taken (Subject to the accuracy of the metered volumes).	An accurate reflection of the demand taken (Subject to errors in allocation customers to substations/feeders and the accuracy of the metered volumes).	Utilise EAC and day specific profile coefficients for each day profile class, SSC, TPR. If not available use alternative data from Crown or use defaults
NHH2	As above	As above	Utilise EAC and general seasonal profile coefficients for each profile class.
NHH3	As above	As above	Use smart meter data as a proxy for the NHH customers
NHH4	As above	As above	Use smart meter data to create profile coefficients (for each profile class). Apply these to NHH EACs

Table 2 - Estimation techniques trialled

Unmetered customers, losses and reactive power were not estimated, and left for follow-on work.

Acronyms:

- SSC – Standard Settlement Configuration. Assigned to an MPAN by the electricity market and is available to Network operators.

- TPR – Time Pattern Regime. These are sub-elements of an SSC.

- EAC – Estimated Annual Consumption. Every Smart MPAN and NHH MPAN have an EAC assigned to it by the electricity market for each TPR assigned to the MPAN. These are provided or updated to the Network Operator every 3 months in a DTN dataflow P0222.

- Where the EAC is not available in the NGED systems then an EAC may have been calculated for an MPAN and stored in Crown by NGED. The Crown EAC is used when the P0222 EAC is unavailable.

- Where there is neither a P0222 nor Crown EAC available for an MPAN then a default EAC for each Profile Class is available and is used. The default EAC is a value for each Profile Class / SSC used in the electricity market where the EAC has not yet been calculated.

- Where the Profile Class of an MPAN is unknown then the MPAN is assigned a Profile Class of 1 and SSC of 393. This is the standard domestic profile/SSC.

3.2 Aggregations

Crown assigns each MPAN to a specific feeder at each substation. As actual measurements are available at both Feeder and substation level the MPANs is aggregated at both these levels for comparison and testing purposes.

NGED’s GIS system, Electric Office (EO), also provides system MPAN to Feeder/substation connectivity. Not all MPANs have a service connection drawn in EO. The MPAN assignment based on EO is therefore established by two methods

1. Where the service connection is shown in EO, the MPAN is traced to the relevant feeder and substation.
2. Where the service connection is not shown in EO, a proximity algorithm is used to find the nearest feeder to the MPAN.

In Summary there are 4 types of aggregations which are assessed (and these are done for the four algorithms)

A. Feeder level using Crown MPAN assignments
B. Substation level using Crown MPAN assignments
C. Feeder level using EO MPAN assignments
D. Substation level using EO MPAN assignments

3.3 Assessment Key attributes

To assess the quality of each algorithm for each aggregation the following key indicators are used

1. Daily Average kW differences/ percentage differences
2. Daily Peak kW differences/ percentage differences
3. Daily Half Hour profile comparison using normalised root mean squares
4. Annual Peak kW differences/ percentage differences

The daily values (items 1, 2 & 3 above) have been calculated for each feeder/substation for each day. These were then averaged across all days to provide a single value for each feeder.

3.3.1 Daily Average differences

Daily values are calculated to provide an average kW value for each Feeder/Substation for the day

Feeder/Substation half hour kW value (F_{hhp}) for profile p is calculated as

$$F_{hhp} = \sum_{M}^{F} kW_M$$

Where $\sum_M^F kW_M$ is the sum of each MPANs kW half-hour estimate (kW_M) for MPANs assigned to that Feeder/Substation (F) for the relevant profile p (NHH1, NHH2, NHH3, NHH4)

The Feeder/Substation daily average kW value (F_{dp}) for profile p for day d is calculated as

$$F_{dp} = \sum_{48}^{d} hhp/48$$

Similar the average daily feeder measurement is

$$F_{dm} = \sum_{48}^{d} kW_{Ahh}/48$$

Where kW_{Ahh} is the Feeder measurement kW value for each half hour period of day d

The daily average difference is calculated as

$$Fdiff_{dp} = F_{dm} - F_{dp}$$

The percentage daily average difference is calculated as

$$Fdiffpc_{dp} = Abs(\frac{F_{dm} - F_{dp}}{F_{dm}})$$

3.3.2 Daily Peak differences

The Feeder/Substation daily peak kW value (FP_{dp}) for profile p for day d is calculated as

$$FP_{dp} = \max_d(F_{hhp})$$

Where $\max_d$ is the maximum value across all half hour periods in day d

Similar the daily peak feeder measurement (FP_{dm}) is

$$FP_{dm} = \max_d(kW_{Ahh})$$

The daily peak difference is calculated as

$$FPdiff_{dp} = \; FP_{dm} - \; FP_{dp}$$

The percentage daily average difference is calculated as

$$FPdiffpc_{dp} = \; Abs(\frac{FP_{dm} - \; FP_{dp}}{FP_{dm}})$$

3.3.3 Half Hour root mean squared

The comparison for a day uses the root sum square method.

$$\sqrt{\frac{\sum_{1}^{48}\left(\frac{E_{hh} - M_{hh}}{\sum_{1}^{48} M_{hh}/48}\right)^{2}}{48}}$$

Where

- E_{hh} is the estimated value for the half hour period (using one of the estimation algorithms NHH1, NHH2, NHH3,NHH4)
- M_{hh} is the measured value for the feeder for the half hour period

3.3.4 Annual Peak differences

The Feeder/Substation annual peak kW value (FPA_{dp}) for profile p for day d is calculated as

$$FPA_{yp} = \max_{all}(F_{hhp})$$

Where $\max_{all}$ is the maximum value across all half hour periods in all days

Similar the daily peak feeder measurement (FP_{dm}) is

$$FPA_{ym} = \max_{all}(kW_{Ahh})$$

The daily peak difference is calculated as

$$FPAdiff_{dp} = \; FPA_{ym} - \; FP_{yp}$$

The percentage daily average difference is calculated as

$$FPAdiffpc_{dp} = \; Abs(\frac{FP_{ym} - \; FP_{yp}}{FP_{ym}})$$

4 Analysis Results

4.1 Approach

The assignment of MPANs to feeders is critical for all the estimation techniques. The following high level process was used for the analyses.

1. Determine the MPAN assignment (later know as Crown or Electric Office (EO))
2. Identify any day which has erroneous data
3. Perform initial analysis to determine the preferred assignment to use for each feeder/substation.
4. Categorise the quality of each feeder/substation (based on average minimum daily error)
5. Compare the different estimation techniques.

4.2 MPAN network assignment

The default MPAN assignment to a feeder/substation was taken from the CROWN data. However there is some differences between the MPAN assignments in CROWN and Electric Office (GIS system.

In areas where meter information has been populated in EO as well as their service connections to the main cables, we were able to assign substation and feeder number to each meter using the information that exist in the EO cables (“connectivity approach”). The feeder and the substation number for each meter which obtained using the “connectivity” approach was compared with the CROWN data.

In areas where the meter information is not available in EO, we used the meter coordinates from CROWN data. A distance function was used to find the distance for each meter to its closest LV feeder. Each meter is assigned a feeder using the “proximity” approach, and this information is compared with the CROWN data.

4.3 Identifying Erroneous data

4.3.1 Smart Meter Errors

There are occasional errors in the collected kW values from smart meter aggregation groups. These are identified and recorded for each feeder/substation-day so that those feeder/substation-days are excluded from any analysis.

Smart Meter data errors are identified as a day

- with any period with a value greater than 500kW (SMerror)
- average kW for a day is less than -10kW (SM_error2)
- average kW for a day is greater than 200kW (SM_error2)

Note highest average daily kW export for a SM aggregation group was 1.1kW which did not have a SM error.

4.3.2 GridKey Errors

GridKey Feeder measurements are provided at a time granularity of 1 minute. These are averaged to create 30 min data (Half Hour period)

GridKey errors are identified for any day for the feeder/substation

- where there are less than 20 minutes in any Half Hour period (GK_minutes)
- where there are less than 1360 minutes in a day (GK_min_day)
- Where the measurement is less than 1 W and greater than -1 W (this identifies feeder measurements for a feeder where fuses are removed) (GK_Spur)
- Where there is a negative flow on the feeder (GK_Negat)

4.3.3 Half Hour Meter data missing

There appears to be some missing half hour MPAN data. This identifies days for a feeder where there is some Half Hour data for an MPAN sometime in the year but the data is missing for a day. (HH_Miss)

4.3.4 Erroneous data identified - Feeder

The number of errors found are shown in the table below

Error	**Feeder/Days**
GK_min_day	836
GK_minutes	1,002
GK_Negat	176
GK_Spur	9,497
HH_Miss	161
SM_error2	242
SMError	419

Table 3 - Feeder Data Errors

4.3.5 Erroneous data identified - Substation

Error	**Substation/Days**
Clock_ch	129
GK_min_day	260
GK_minutes	313
GK_Spur	12,584
HH_Miss	149
SM_error2	223
SMError	418

Table 4 - Substation Data Errors

4.4 Initial Analysis

The initial analysis was executed to

1. Decide on whether to use the Electric office or Crown connectivity
2. Filter out feeder/substations which appear to have poor data quality which has not been eliminated by removing the identified erroneous data as described in section 4.3.

This has been done prior to assessing the accuracy of the four estimation algorithms.

The selection process for feeders and substations was done separately.

The initial analysis uses all four assessment attributes as set out in section 3.3. For each Substation/Feeder for each estimation algorithm, the four assessment attributes have been calculated and for the daily values averaged over the days available. The values for each of the estimation techniques (NHH1, NHH2, NHH3, NHH4) are then summarised into an average, maximum and minimum value. Thus, this gives us 12 values for each feeder namely

- Average of Daily Average (section 3.3.1)
- Minimum of Daily Average (section 3.3.1)
- Maximum of Daily Average (section 3.3.1)
- Average of Daily Peak (section 3.3.2)
- Minimum of Daily Peak (section 3.3.23.3.1)
- Maximum of Daily Peak (section 3.3.2)
- Average of Daily HH RMS (section 3.3.3)
- Minimum of Daily HH RMS (section 3.3.3)
- Maximum of Daily HH RMS (section 3.3.3)
- Average of Annual Peak (section 3.3.4)
- Minimum of Annual Peak (section 3.3.4)
- Maximum of Annual Peak (section 3.3.4)

This is done for both Electric Office and Crown assignments. Each of these 12 values from Electric Office and Crown are compared and the least value is credited with the assignment to use.

The table below shows the analysis of the above and includes an indicator of the quality of the feeder minimum daily average value for the selected connectivity.

The indicator of the number of in and out transfers uses the Crown assignment as the starting configuration.

4.4.1 Substation Initial Analysis

The table below shows the analysis of the above and includes an indicator of the quality of the Substation minimum daily average value for the selected connectivity.

The list has been sorted into substations with daily minimum values less than 10%, substations between 10-20% and over 20%. These are referred to as Category 1, 2 and 3 respectively.

Overall analysis has been done for the substations with less than 10% (Category 1) and examples of substations with between 10-20% (category 2) are also provided.

There are 34 Category 1 substations (75%), 8 Category 2 substations (18%) and 3 Category 3 substations (7%)

Of the 34 Category 1 substations, 15 substations are with EO connectivity and 19 substations with Crown connectivity.

Substation	Daily average			Daily Peak			HH RMS			Annual Peak			Assigned Connect	Daily Min	Cat	MPAN Transfers		
	Av	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn				Out	In	Net
941916	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	CR	EO	CR	2%	1	7	0	-7
942369	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	EO	CR	CR	2%	1	7	0	-7
942681	CR	CR	CR	EO	CR	EO	CR	CR	CR	CR	CR	CR	CR	2%	1	2	3	1
942756	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	3%	1	107	0	-107
942037	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	EO	CR	CR	3%	1	4	0	-4
942687	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	3%	1	4	1	-3
940337	EO	EO	CR	EO	EO	CR	EO	EO	CR	EO	CR	EO	EO	3%	1	1	0	-1
942368	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	3%	1	0	0	0
945113	CR	CR	CR	EO	EO	CR	EO	EO	CR	CR	CR	CR	CR	4%	1	23	0	-23
942647	EO	EO	EO	EO	EO	CR	EO	EO	EO	CR	CR	EO	EO	4%	1	3	4	1
941988	EO	EO	EO	EO	EO	EO	EO	CR	EO	CR	CR	EO	EO	4%	1	6	0	-6
942978	CR	CR	EO	CR	EO	CR	EO	CR	EO	CR	CR	CR	CR	4%	1	5	1	-4
940458	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	4%	1	3	1	-2
942683	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	CR	EO	CR	4%	1	2	0	-2
942651	CR	CR	EO	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	4%	1	5	7	2
942757	CR	CR	CR	CR	CR	EO	CR	CR	CR	EO	CR	EO	CR	5%	1	6	0	-6
944922	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	EO	CR	5%	1	4	2	-2
942086	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	5%	1	2	0	-2
942661	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	5%	1	2	0	-2
942649	EO	CR	CR	EO	EO	EO	EO	CR	EO	CR	CR	EO	EO	5%	1	4	1	-3
942840	EO	CR	EO	EO	EO	EO	EO	CR	EO	CR	CR	EO	EO	5%	1	31	0	-31
941987	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	5%	1	0	0	0
940717	CR	EO	EO	CR	EO	CR	EO	EO	EO	CR	EO	EO	EO	5%	1	3	4	1
942695	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	5%	1	8	3	-5
942856	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	5%	1	4	0	-4
942774	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	CR	EO	5%	1	11	0	-11
942878	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	6%	1	4	0	-4
942084	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	7%	1	None		
942855	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	7%	1	1	2	1
942071	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	7%	1	4	0	-4
942839	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	7%	1	0	3	3
945237	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	8%	1	0	1	1
942755	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	9%	1	17	0	-17
942842	EO	EO	CR	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	10%	1	None		
942680	EO	EO	EO	EO	CR	EO	EO	CR	EO	EO	EO	EO	EO	11%	2	3	1	-2
941985	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	CR	CR	CR	12%	2	4	2	-2
942979	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	12%	2	1	2	1
942950	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	12%	2	5	3	-2
942693	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	13%	2	33	0	-33
942814	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	13%	2	4	0	-4
942843	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	13%	2	9	0	-9
942877	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	13%	2	8	0	-8
945487	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	21%	3	0	21	21
942876	CR	CR	CR	CR	CR	EO	CR	CR	CR	EO	EO	CR	CR	22%	3	1	0	-1
942367	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	25%	3	0	0	0

Table 5 - Substations: Selected connectivity and Categorisation

Note: In the MPAN transfer columns, the number shown is the MPAN transfers from one substation to another. Where there is a MPAN transfer from one feeder to another within the substation then this is not counted as a transfer. There are two substations (92084 and 942842) where there are no transfers (including no transfers between feeders in those substations.

The assignment where there are no transfers in or out of the substations mean that there is no difference between EO and CR. The assignment is therefore based on rounding differences, but this will have no effect on the results as either choice is valid.

4.4.2 Feeder Initial Analysis

The table below shows a similar analysis for feeders.

The list has been sorted into feeders with daily minimum values less than 15%, feeders between 15-25% and over 25%. These are referred to as Category 1, 2 and 3 respectively.

Overall analysis is done for the feeders with less than 15 % (Category 1) and examples of feeders with between 15-25% (Category 2) are also provided.

There are 87 Category 1 feeders (79%), 17 Category 2 feeders (15%) and 6 Category 3 feeders (6%)

Of the 87 Category 1 feeders, 46 feeders are with EO connectivity and 41 feeders with Crown connectivity.

Feeder	Daily average			Daily Peak			HH RMS			Annual Peak			Assigned Connect	Daily Min	Cat	MPAN Transfers		
	Av	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn				Out	In	Net
941987:1	CR	CR	CR	CR	CR	EO	CR	CR	CR	EO	CR	CR	CR	3%	1	0	58	58
942978:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	CR	EO	3%	1	None		
944922:2	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	EO	CR	3%	1	4	0	-4
941916:4	CR	CR	CR	EO	EO	CR	CR	CR	CR	EO	EO	CR	CR	3%	1	5	52	47
941916:1	CR	CR	EO	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	3%	1	7	52	45
945113:2	EO	CR	EO	EO	EO	CR	EO	EO	EO	EO	EO	EO	EO	3%	1	8	0	-8
942681:3	EO	CR	EO	EO	EO	CR	EO	EO	EO	EO	EO	EO	EO	3%	1	1	52	51
942369:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	3%	1	8	52	44
942086:2	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	CR	CR	CR	3%	1	2	52	50
942369:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	4%	1	0	52	52
942681:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	4%	1	2	52	50
942756:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	CR	EO	4%	1	None		
942756:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	4%	1	62	0	-62
942683:4	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	CR	EO	CR	4%	1	2	58	56
945237:4	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	CR	EO	CR	4%	1	6	0	-6
942855:3	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	4%	1	None		
942756:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	4%	1	49	0	-49
942856:2	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	4%	1	1	0	-1
945113:4	EO	EO	EO	EO	EO	CR	EO	EO	EO	CR	CR	CR	EO	4%	1	1	0	-1
942649:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	5%	1	145	58	-87
942687:2	EO	EO	CR	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	5%	1	None		
942687:1	EO	CR	EO	CR	EO	CR	EO	EO	EO	CR	CR	CR	CR	5%	1	4	52	48
940337:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	5%	1	None		
942878:3	EO	CR	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	5%	1	None		
945487:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	5%	1	1	0	-1
942755:3	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	EO	CR	5%	1	1	0	-1
945113:3	CR	CR	CR	EO	EO	CR	EO	EO	EO	CR	CR	CR	CR	5%	1	17	0	-17
942978:4	EO	EO	CR	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	5%	1	None		
942774:4	CR	CR	EO	EO	EO	CR	EO	EO	EO	EO	CR	EO	EO	5%	1	2	0	-2
941985:4	EO	EO	CR	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	5%	1	2	52	50
941987:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	CR	EO	5%	1	1	58	57
942755:2	CR	CR	CR	EO	EO	EO	CR	CR	EO	EO	CR	EO	CR	6%	1	1	0	-1
944922:4	CR	CR	EO	CR	CR	CR	CR	EO	CR	CR	EO	CR	CR	6%	1	1	0	-1
942367:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	6%	1	0	52	52
942978:1	EO	EO	EO	EO	EO	CR	EO	EO	EO	EO	EO	EO	EO	6%	1	3	0	-3
942681:5	CR	CR	EO	CR	CR	EO	EO	EO	EO	EO	EO	CR	EO	6%	1	1	58	57

Feeder	Daily average			Daily Peak			HH RMS			Annual Peak			Assigned Connect	Daily Min	Cat	MPAN Transfers		
	Av	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn				Out	In	Net
942661:4	EO	EO	CR	CR	CR	EO	EO	EO	EO	EO	EO	CR	EO	6%	1	2	52	50
942367:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	6%	1	None		
941988:3	CR	CR	CR	CR	CR	EO	CR	CR	EO	EO	EO	CR	CR	6%	1	0	52	52
940337:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	EO	EO	6%	1	2	0	-2
942661:2	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	6%	1	11	52	41
942037:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	6%	1	2	52	50
942661:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	6%	1	3	58	55
942855:4	EO	EO	EO	CR	CR	CR	EO	EO	CR	CR	CR	CR	CR	6%	1	None		
942369:2	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	CR	CR	CR	6%	1	1	58	57
942651:3	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	EO	CR	6%	1	1	52	51
942084:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	7%	1	None		
942839:2	EO	EO	EO	EO	CR	EO	EO	EO	EO	CR	CR	CR	EO	7%	1	None		
942683:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	7%	1	None		
941985:3	CR	CR	CR	CR	CR	EO	CR	CR	CR	CR	EO	CR	CR	7%	1	4	58	54
942086:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	7%	1	15	58	43
942369:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	7%	1	7	52	45
945487:5	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	7%	1	73	0	-73
942683:3	EO	EO	CR	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	7%	1	2	52	50
942855:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	7%	1	4	0	-4
942647:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	7%	1	27	52	25
942840:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	7%	1	27	0	-27
942695:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	8%	1	8	0	-8
942037:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	8%	1	0	52	52
941916:2	CR	CR	CR	CR	CR	CR	EO	CR	EO	EO	EO	EO	CR	8%	1	2	52	50
945237:1	CR	CR	CR	CR	CR	EO	CR	CR	CR	EO	EO	CR	CR	8%	1	None		
942695:1	EO	EO	EO	EO	CR	EO	EO	EO	EO	CR	CR	CR	EO	9%	1	2	0	-2
942757:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	9%	1	10	0	-10
942071:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	9%	1	3	52	49
942368:4	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	EO	CR	9%	1	0	58	58
941988:4	CR	CR	CR	EO	CR	EO	EO	EO	CR	EO	EO	CR	CR	9%	1	1	52	51
942842:1	CR	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	10%	1	None		
942839:3	CR	CR	CR	CR	CR	EO	EO	CR	CR	CR	EO	CR	CR	10%	1	None		
940337:3	EO	EO	EO	CR	CR	EO	CR	CR	CR	CR	EO	CR	CR	10%	1	0	52	52
942774:1	CR	CR	CR	EO	EO	CR	CR	CR	CR	CR	CR	CR	CR	10%	1	None		
942681:1	CR	EO	CR	EO	EO	EO	CR	EO	CR	EO	EO	EO	EO	11%	1	2	52	50
942774:2	EO	CR	EO	CR	CR	CR	EO	CR	EO	EO	EO	CR	CR	11%	1	16	0	-16
942037:2	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	11%	1	0	58	58
942368:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	12%	1	None		
942856:4	CR	CR	CR	CR	EO	CR	EO	CR	EO	EO	EO	EO	CR	12%	1	4	0	-4
942681:4	CR	CR	CR	CR	EO	CR	EO	EO	CR	CR	CR	CR	CR	12%	1	3	58	55
942978:3	CR	CR	CR	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	12%	1	7	0	-7
942037:5	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	EO	CR	CR	13%	1	3	52	49
942693:2	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	EO	CR	CR	13%	1	1	52	51
942843:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	13%	1	9	0	-9
942814:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	13%	1	4	0	-4
942877:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	13%	1	8	0	-8
942950:2	CR	CR	CR	EO	EO	CR	CR	EO	CR	EO	CR	EO	CR	14%	1	4	0	-4
942757:3	CR	CR	CR	EO	EO	CR	CR	CR	CR	EO	EO	CR	CR	15%	1	11	0	-11
942755:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	15%	1	11	0	-11
942647:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	15%	1	13	52	39
942368:2	EO	EO	CR	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	15%	1	None		
942647:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	16%	2	78	52	-26
940458:3	EO	EO	EO	EO	EO	CR	EO	EO	EO	EO	CR	EO	EO	17%	2	1	58	57
942680:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	17%	2	None		
942680:3	CR	EO	CR	CR	EO	CR	EO	CR	EO	CR	CR	EO	CR	17%	2	3	52	49
940337:2	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	17%	2	13	58	45
942979:2	CR	CR	EO	CR	EO	CR	EO	CR	EO	CR	CR	CR	CR	18%	2	9	0	-9
942693:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	19%	2	33	58	25
942071:3	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	20%	2	7	52	45
942071:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	EO	EO	20%	2	1	52	51
942774:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	CR	CR	CR	EO	21%	2	6	0	-6
942368:3	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	22%	2	1	58	57

Feeder	Daily average			Daily Peak			HH RMS			Annual Peak			Assigned Connect	Daily Min	Cat	MPAN Transfers		
	Av	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn	Ag	Mx	Mn				Out	In	Net
942876:1	CR	CR	CR	CR	CR	EO	CR	EO	CR	EO	EO	CR	CR	22%	2	1	0	-1
942651:2	EO	EO	EO	EO	CR	EO	EO	EO	EO	CR	CR	EO	EO	22%	2	2	52	50
940458:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	23%	2	0	52	52
944922:3	CR	CR	CR	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	23%	2	1	0	-1
942840:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	25%	2	5	0	-5
942755:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	25%	2	14	0	-14
942950:3	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	27%	3	5	0	-5
942367:2	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	47%	3	4	58	54
942649:1	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	54%	3	71	52	-19
942878:4	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	67%	3	4	0	-4
941988:1	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	261%	3	9	52	43
942950:1	CR	EO	CR	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO	1009%	3	5	0	-5

Table 6 - Feeders: Selected connectivity and Categorisation

Feeders where there are no transfers in or out are shown with a null value.

The assignment where there are no transfers in or out of a feeder mean that there is no difference between EO and CR. The assignment is therefore based on rounding differences, but this will have no effect on the results as either choice is valid.

4.5 Results

4.5.1 Results – Assessment Criteria

This Results section concentrates on the Category 1 substation/feeders. It uses the following key assessment attributes as these are the most useful for a DNO for either network reinforcement or for managing flexibility.

1. Daily Peak kW differences/percentage differences (see section 3.3.2)
2. Annual Peak kW differences/percentage differences (see section 3.3.4)
3. Daily Half Hour profile comparison using normalised root mean squares (see section 3.3.3)

It compares the accuracy of the estimation techniques at both an individual Feeder/Substation and across all Category 1 Feeders/Substations.

The assessment initially calculates the percentage error as set out in section 3.3 for each day for the Daily Peak and Daily HH profile.

For Daily Peak and Daily HH profile for each substation/feeder the daily errors are averaged across all valid days using a simple average and an RMS value.

For Annual Peak there is only a single value for each Feeder and so no further averaging is required. (Note the data in our analysis does not include a full year. It only includes data from 1st Jan 2022 to the 30th Sept 2022)

Both the Average and the RMS values for individual feeders are used to create and Average and RMS across all Feeders.

Consequently, for Daily Peak and Daily HH profile there are 4 sets of results are calculated for the overall assessment

- The Average across all substation/feeders of the Average of individual substation/feeders

- The RMS across all substation/feeders of the Average of individual substation/feeders
- The Average across all substation/feeders of RMS of individual substation/feeders
- The RMS across all substation/feeders of RMS of individual substation/feeders

For Annual peak there are only 2 sets of results namely

- The Average across all substation/feeders
- The RMS across all substation/feeders

4.5.2 Results – Substation comparisons

There are 34 Category 1 substation which have a Daily Average kW error for at least one of the estimation techniques of less than 10% (see section 4.4.1). An indication of the Category 2 substations is also provided.

4.5.2.1 Results – Substation Daily Peak

The daily peak error for each substation is summarised across all the valid days of measurement using:

1. Simple average
2. Root Mean Square (RMS)

The number of substations in each error band is shown in the table below.

Category 1 - Number of substations with Average and RMS Daily peak error in each error band								
Band	RMS				Average			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
<5.0%	1	0	0	0	5	4	0	1
<7.5%	15	11	6	4	17	18	9	10
<10.0%	21	23	13	12	28	27	19	21
<12.5%	28	29	20	22	33	32	25	28
<15.0%	33	31	25	27	33	33	29	31
All	34	34	34	34	34	34	34	34

Table 7 - Substation Category 1 Daily Peak Error bands

A graphical form of this table is shown below.

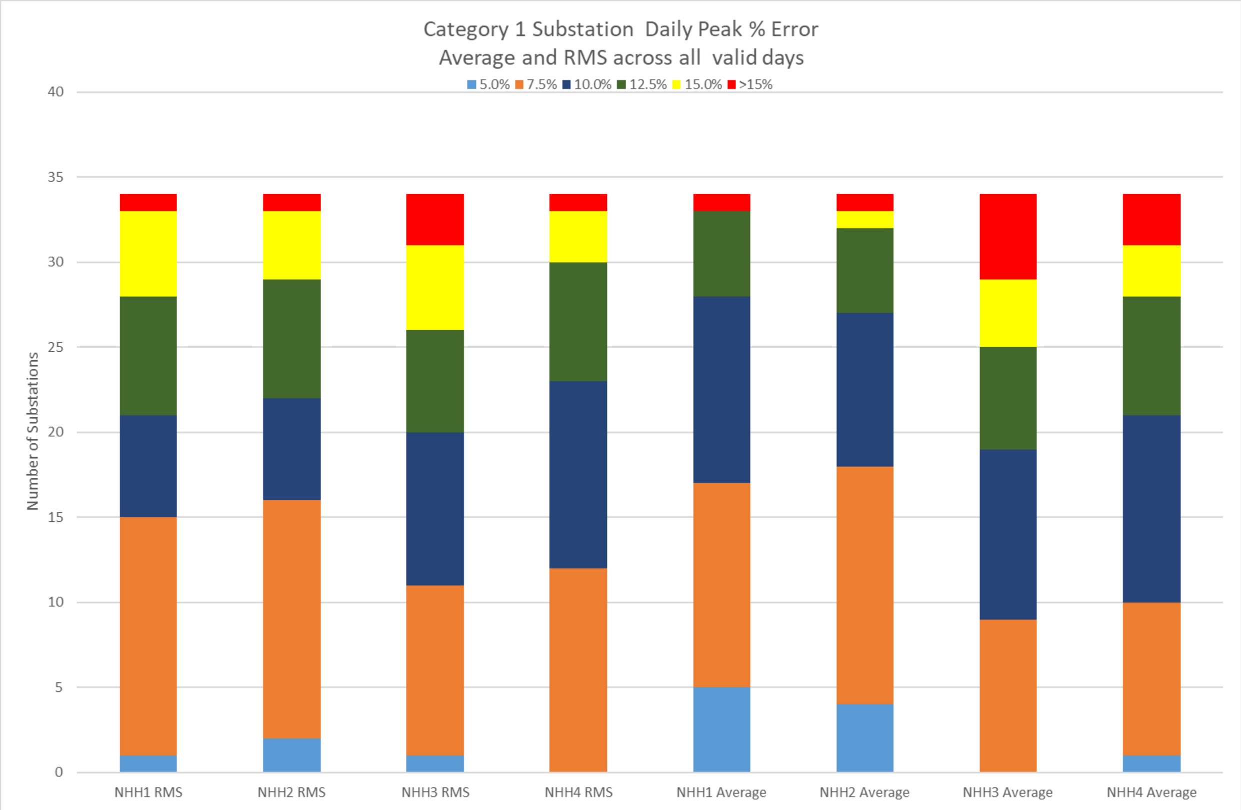


Figure 1 - Substation Category 1 Daily Peak Error bands graph

Another view of the data is to look at a graph of the daily peak error for each substation for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Average and RMS values.

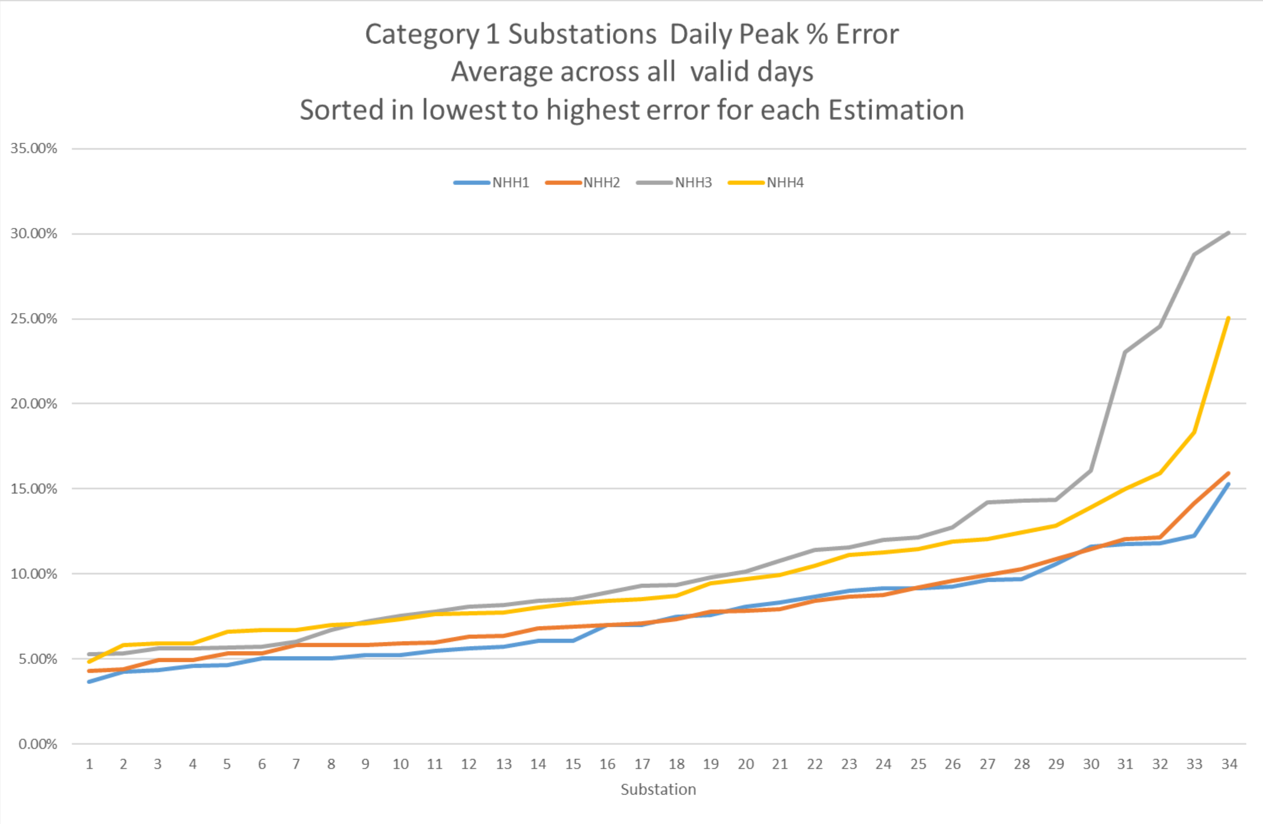


Figure 2 Substation Category 1 Average Daily Peak Error

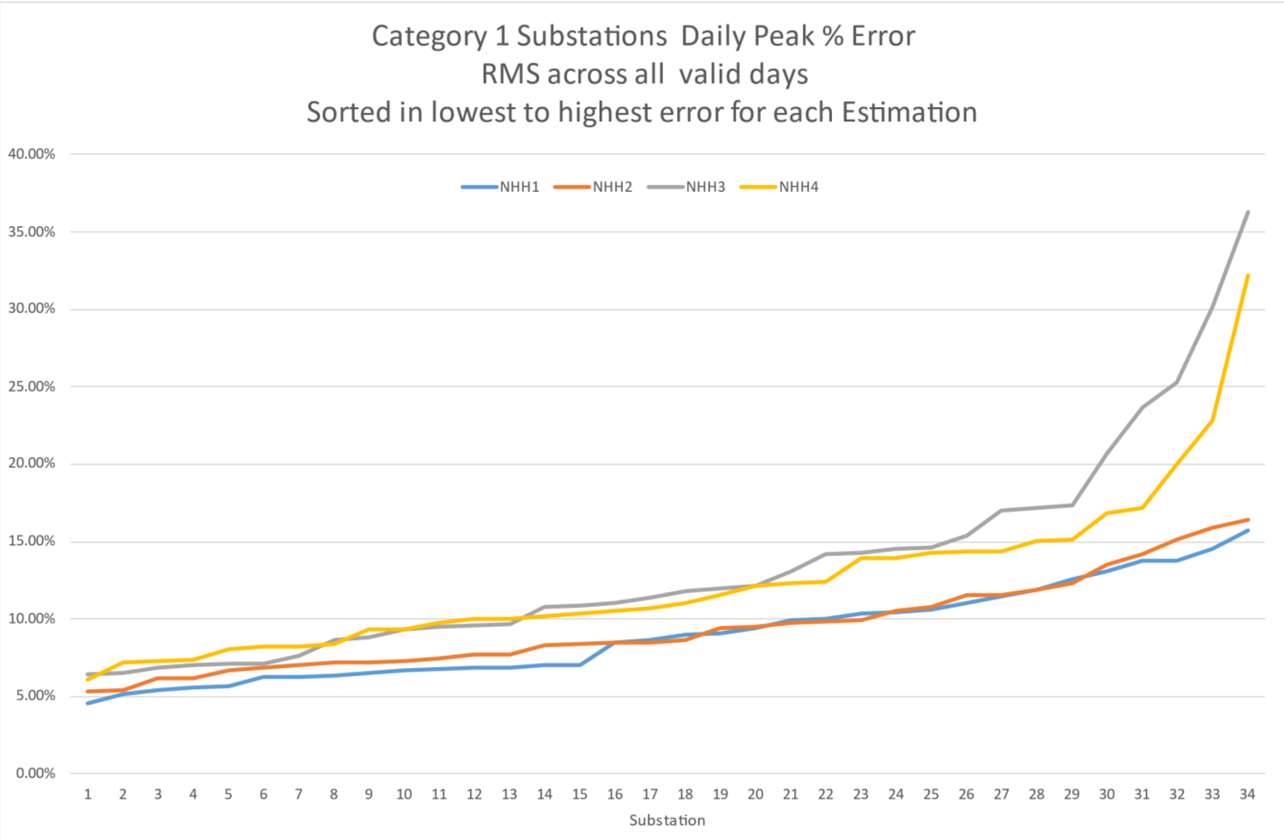


Figure 3 - Substation Category 1 RMS Daily Peak Error

The data is also summarised across all substations to provide an average error and RMS error for each estimation technique. This is done using average, RMS and also calculating the standard deviation.

Category 1 Daily Peak % error								
RMS, Average and Stdev across all substations	Substation RMS across all days				Substation Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	9.5%	9.9%	15.1%	13.4%	8.1%	8.5%	13.0%	10.8%
Average	9.0%	9.5%	13.5%	12.4%	7.6%	8.0%	11.3%	10.0%
Standard Deviation	3.0%	3.0%	6.9%	5.1%	2.8%	2.8%	6.4%	4.1%

Table 8 - Daily Peak Error: All Category 1 substations

These results show that the NHH3 is the least accurate and with NHH1 and NHH2 are the best technique.

There are 8 Category 2 Substations (Minimum Daily average error between 10-15%)

Category 2 Daily Peak % error								
RMS, Average and Stdev across all substations	Substation RMS across all days				Substation Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	16.7%	19.7%	38.8%	42.2%	13.9%	16.3%	33.4%	36.2%
Average	16.3%	19.2%	36.4%	39.9%	13.5%	15.9%	30.9%	33.9%
Standard Deviation	4.1%	4.6%	14.5%	14.7%	3.7%	3.9%	13.5%	13.6%

Table 9 - Daily Peak Error: All Category 2 substations

The Category 2 substations show NHH1 and NHH2 are the best estimation techniques.

4.5.2.2 Results – Substation Annual Peak

The Annual Peak for each substation is provides a single error value for each substation. The error can be negative (over estimate) or positive (under estimate). The assessment includes the error magnitude.

Band	Category 1 - Number of substation with Annual peak error magnitude in each error band			
	NHH1	NHH2	NHH3	NHH4
<5.0%	7	5	16	15
<7.5%	15	11	18	18
<10.0%	22	16	22	23
<12.5%	25	21	23	27
<15.0%	30	24	26	29
All	34	34	34	34

Table 10 - Substation Category 1 Annual Peak Error bands

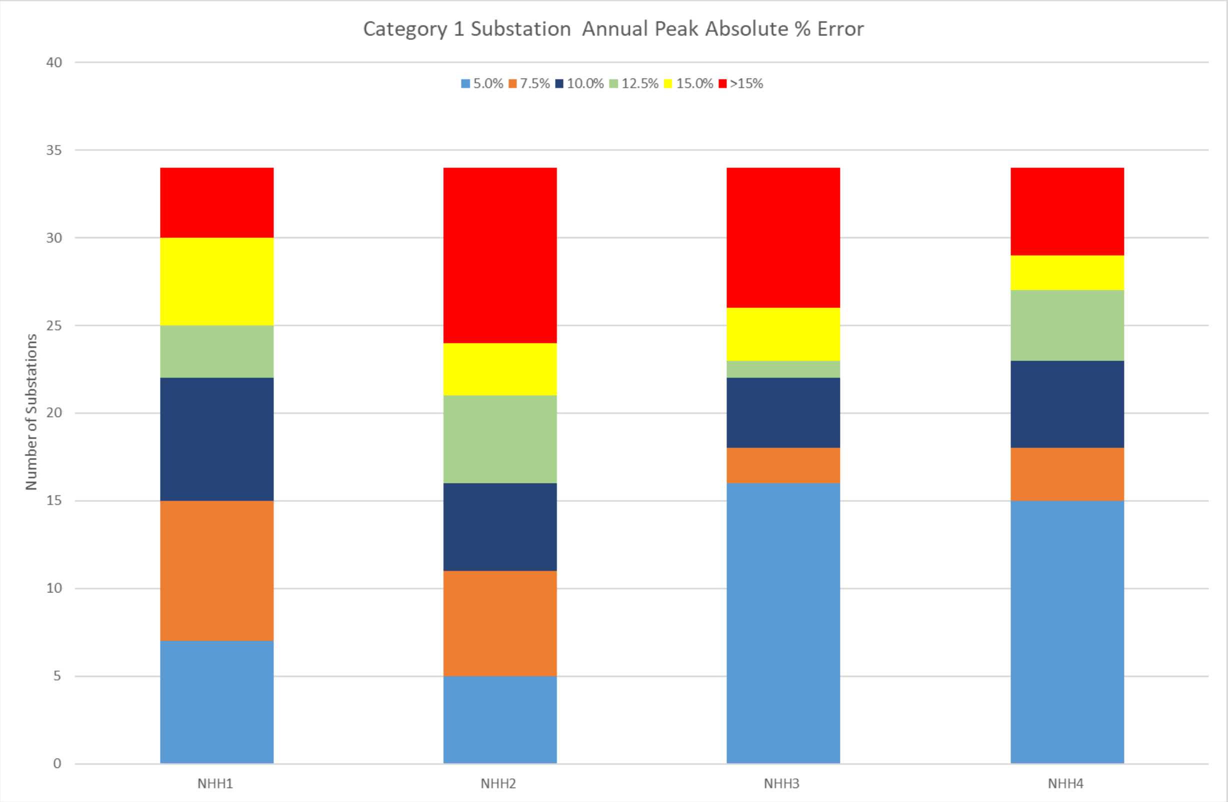


Figure 4 - Substation Category 1 Annual Peak Error bands graph

Another view of the data is to look at a graph of the Annual peak error for each substation for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Error Magnitude (ignore sign) and Actual error (including sign).

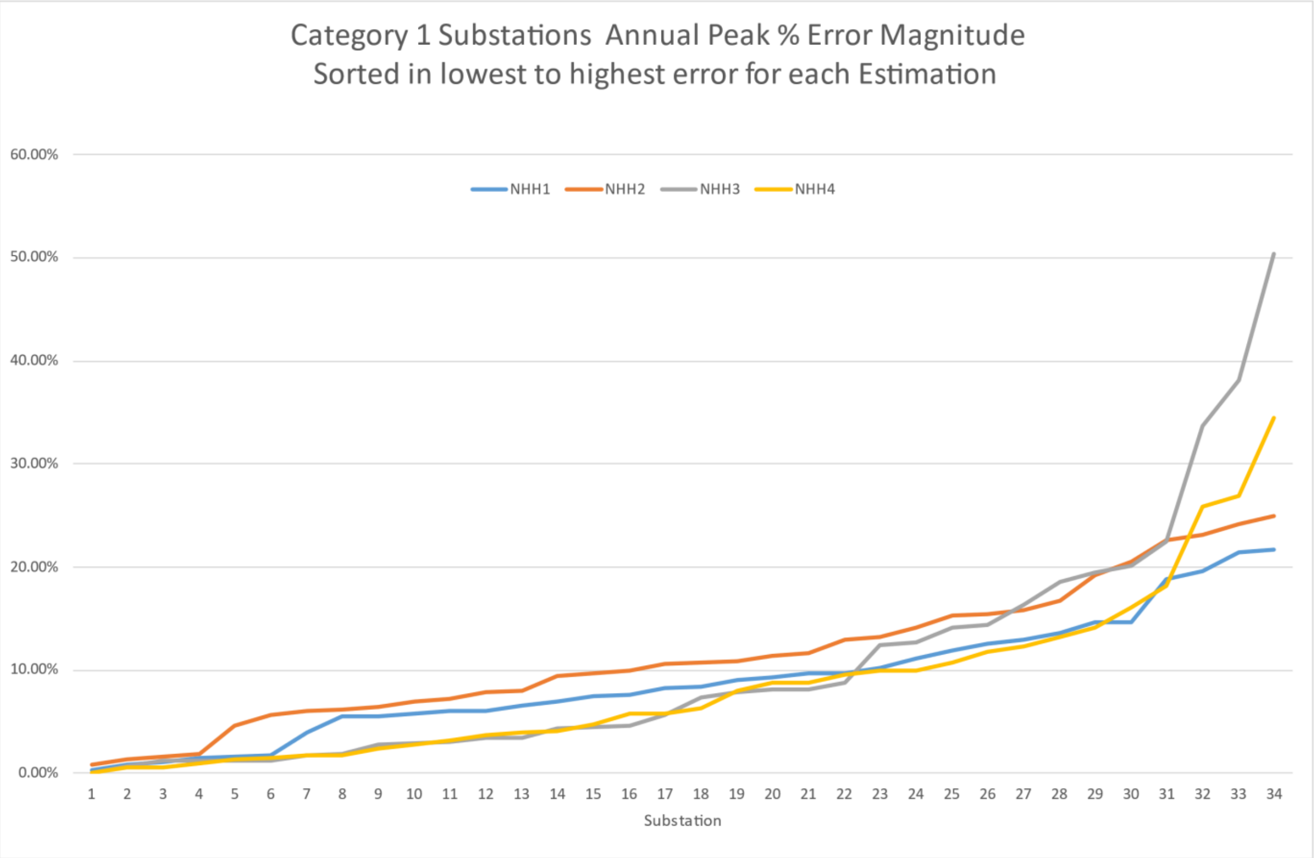


Figure 5 - Substation Category 1 Annual Peak Error Magnitude

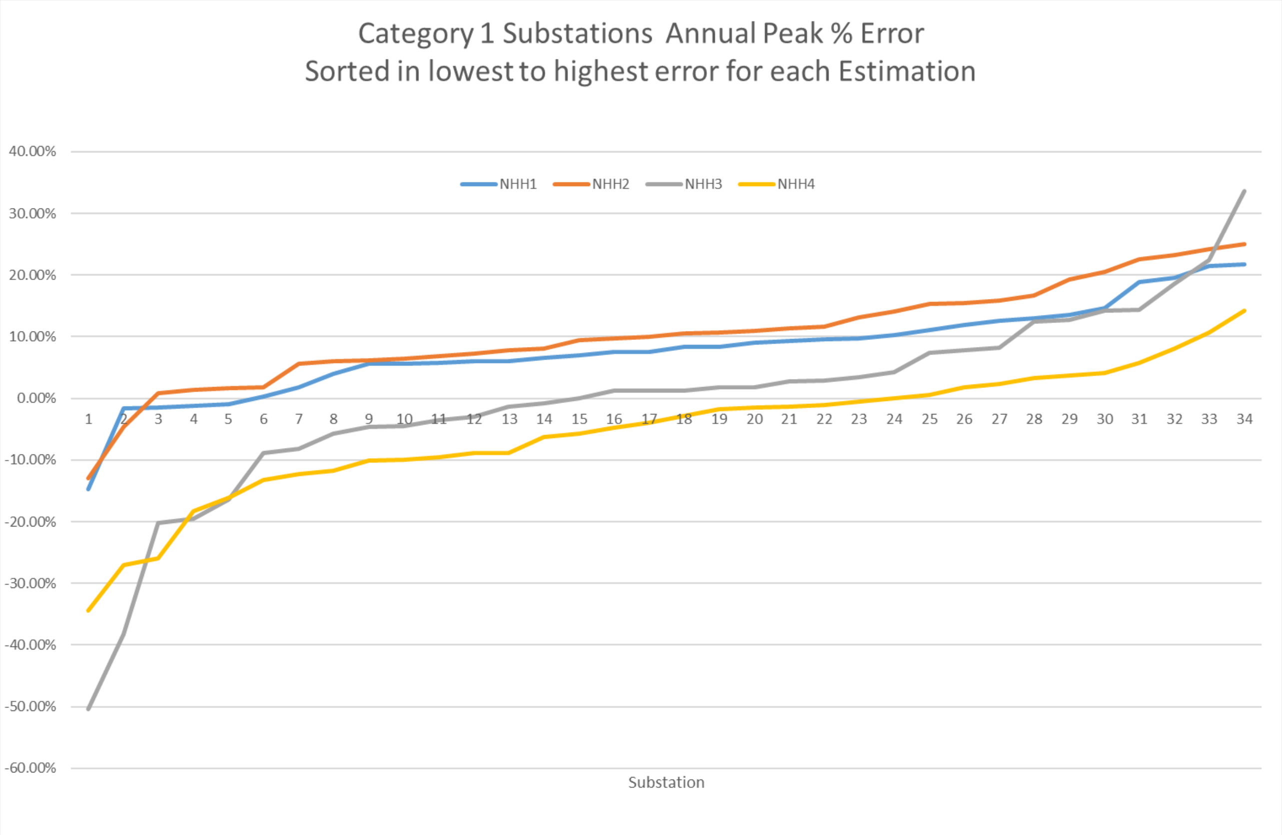


Figure 6 - Substation Category 1 Annual Peak Error

The NHH1 and NHH2 estimation techniques appear on average to underestimate whist NHH3 and NHH4 have small average overestimates. One reason that this may occur is that houses with smart meters may be newer housing stock or older houses with energy aware residents. This would generally mean that they have lower energy consumption and lower peak consumption and therefore do not represent the older housing stock.

The data is also summarised across all substations to provide an average error and an average error magnitude for each estimation technique. This is done using average and RMS as well as calculating the standard deviation.

Category 1 Annual Peak % error								
RMS, Average and Stdev across all substations	Error magnitude				Actual error			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	10.7%	13.2%	15.6%	11.7%	10.7%	13.2%	15.6%	11.7%
Average	9.0%	11.4%	10.5%	8.5%	7.9%	10.4%	-0.4%	-5.3%
Standard Deviation	5.8%	6.7%	11.6%	8.2%	7.4%	8.2%	15.8%	10.6%

Table 11 - Annual Peak Error: All Category 1 substations

Category 2 Annual Peak % error								
RMS, Average and Stdev across all substations	Error magnitude				Actual error			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	19.3%	22.6%	37.5%	36.2%	19.3%	22.6%	37.5%	36.2%
Average	15.8%	19.7%	27.0%	29.4%	11.6%	14.7%	-18.6%	-28.9%
Standard Deviation	11.9%	11.8%	27.8%	22.6%	16.5%	18.3%	34.8%	23.2%

Table 12 - Annual Peak Error: All Category 2 substations

The Category 2 substations show NHH1 is the best estimation technique.

4.5.2.3 Results – Substation Half Hour profile

The HH profile error for each day for a substation is calculated as described in section 3.3.3.

The HH Profile error for each substation is summarised across all the valid days of measurement using

1. Simple average
2. Root Mean Square (RMS)

The number of substation in each error band is shown in the table below.

Category 1 - Number of substation with Average and RMS HH profile error in each error band								
Band	RMS				Average			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
< 10%	7	4	0	1	8	4	1	1
< 12.5%	13	14	6	6	15	15	6	6
< 15%	22	23	12	14	23	24	12	15
< 17.5%	29	28	15	20	29	29	16	20
< 20%	33	32	20	24	34	33	21	25
All	34	34	34	34	34	34	34	34

Table 13 - Substation Category 1 HH Profile Error bands

A graphical form of this table is shown below.

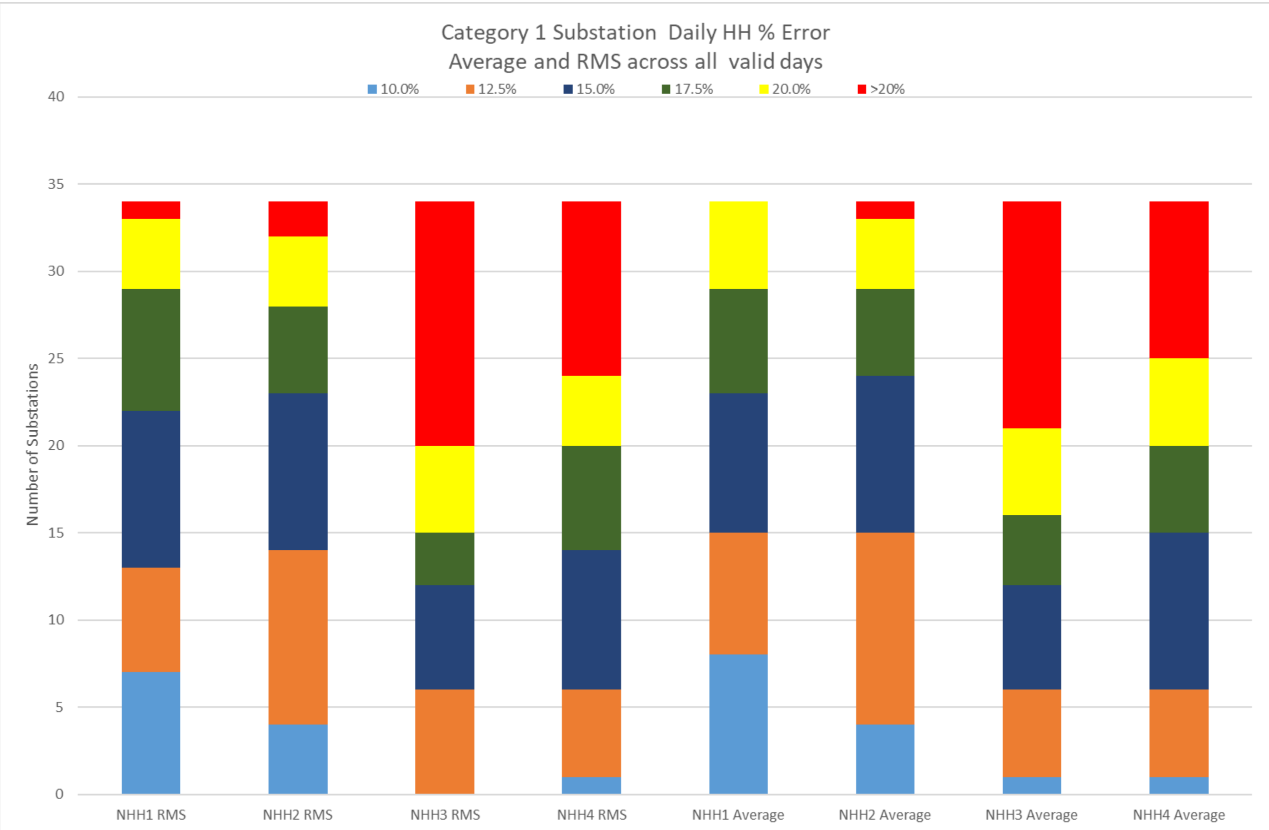


Figure 7 - Substation Category 1 HH Profile Error bands graph

Another view of the data is to look at a graph of the daily HH error for each substation for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Average and RMS values.

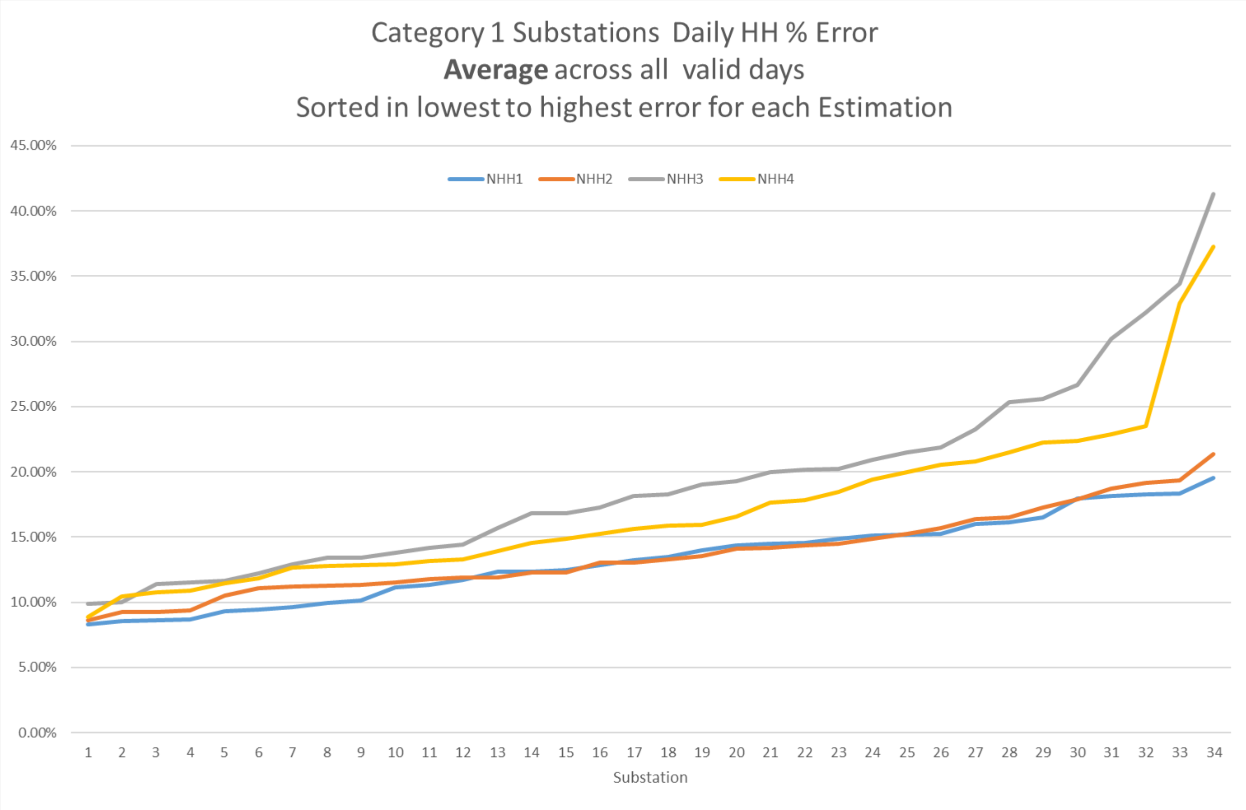


Figure 8 - Substation Category 1 Average HH Profile Error

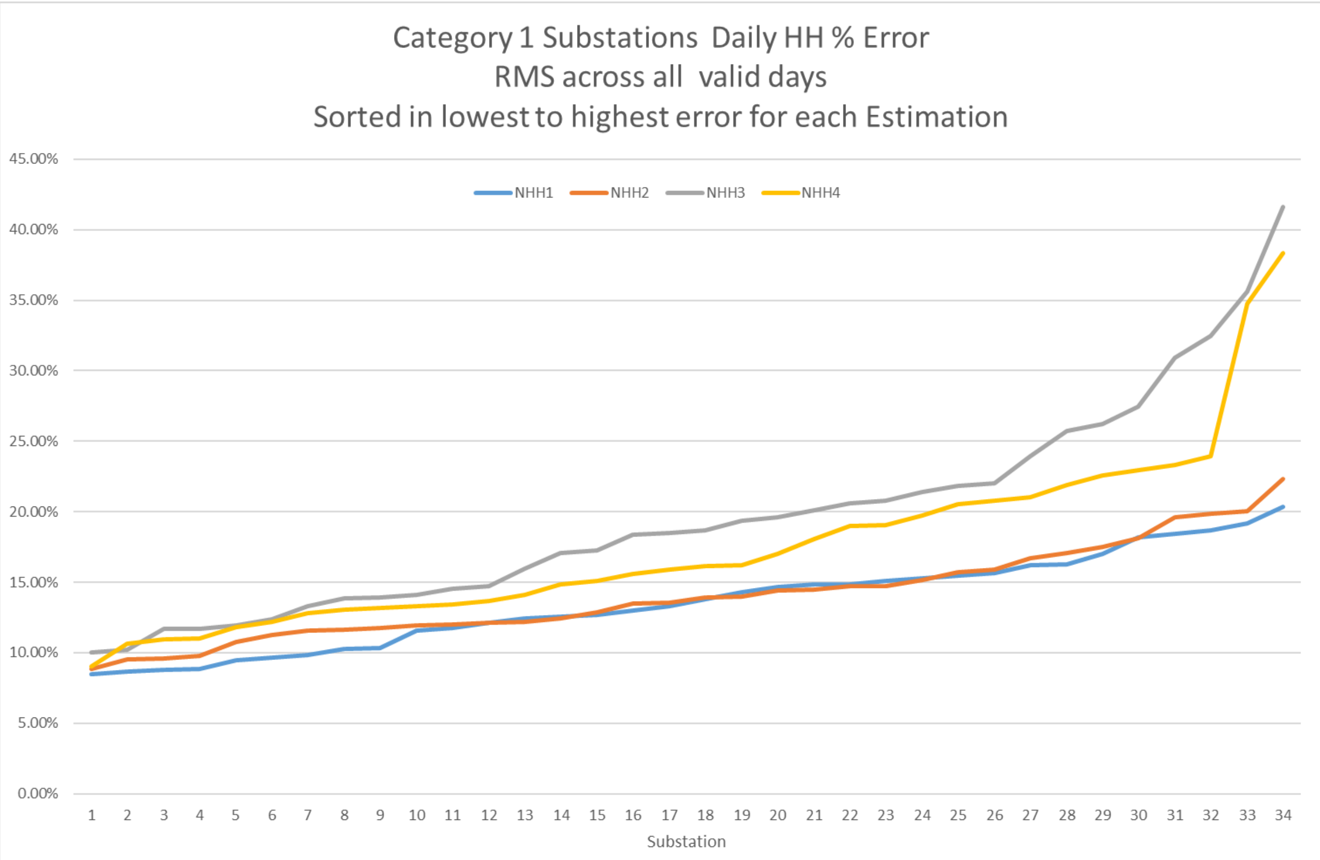


Figure 9 - Substation Category 1 RMS HH Profile Error

The data is also summarised across all substations to provide an average error and RMS error for each estimation technique. This is done using average, RMS and also calculating the standard deviation.

Category 1 Daily HH % error								
RMS, Average and Stdev across all substations	Substation RMS across all days				Substation Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	14.0%	14.5%	21.0%	18.6%	13.7%	14.1%	20.6%	18.1%
Average	13.6%	14.1%	19.6%	17.5%	13.3%	13.7%	19.2%	17.1%
Standard Deviation	3.3%	3.3%	7.5%	6.4%	3.2%	3.2%	7.4%	6.1%

Table 14 - HH Profile Error: All Category 1 substations

These results show that NHH1 and NHH2 are the best estimation techniques.

There are 8 Category 2 Substations (Minimum Daily average error between 10-15%)

Category 2 Daily HH % error								
RMS, Average and Stdev across all substations	Substation RMS across all days				Substation Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	32.1%	33.0%	44.0%	42.4%	31.1%	31.5%	42.7%	41.4%
Average	31.1%	31.8%	41.8%	40.2%	30.1%	30.3%	40.6%	39.2%
Standard Deviation	8.2%	9.4%	14.7%	14.2%	8.2%	9.2%	14.2%	14.2%

Table 15 - HH Profile Error: All Category 2 substations

The Category 2 substations show NHH1 and NHH2 are the best estimation techniques.

4.5.3 Results – Feeder comparisons

There are 74 Category 1 feeders which have a Daily Average kW error for at least one of the estimation techniques of less than 10% (see section 4.4.1). An indication of the Category 2 feeders (21) is also provided.

4.5.3.1 Results – Feeder Daily Peak

The daily peak error for each substation is summarised across all the valid days of measurement using:

1. Simple average
2. Root Mean Square (RMS)

The number of substation in each error band is shown in the table below.

Category 1 - Number of substation with Average and RMS Daily peak error in each error band								
Band	RMS				Average			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
< 5%	0	0	0	0	1	1	0	0
< 10%	25	23	9	9	38	37	17	15
< 15%	53	50	23	25	63	65	39	41
< 20%	69	68	43	44	72	69	55	54
< 25%	72	71	55	55	73	71	60	63
All	74	74	74	74	74	74	74	74

Table 16- Feeder Category 1 Daily Peak Error bands

A graphical form of this table is shown below.

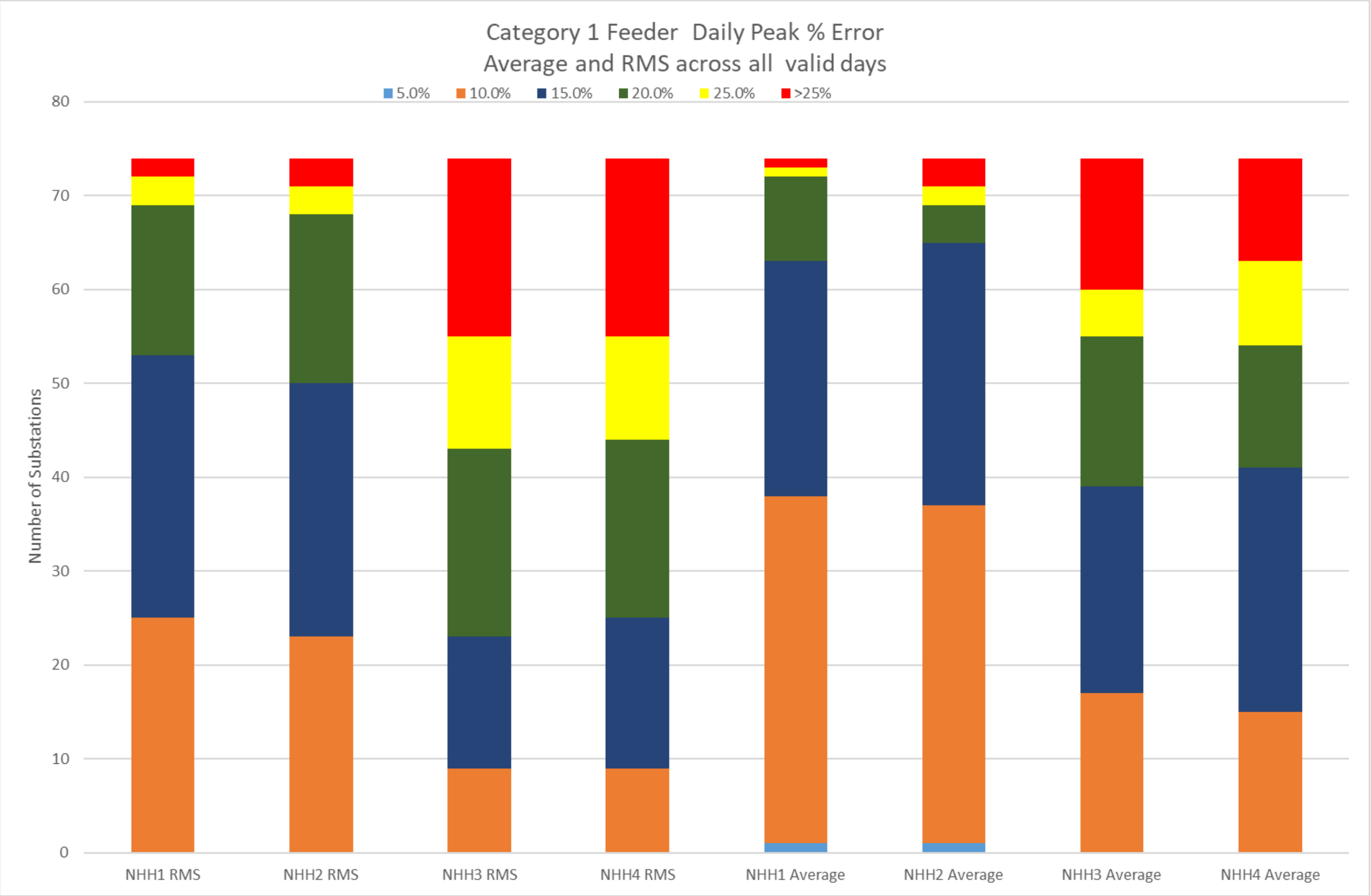


Figure 10 - Feeder Category 1 Daily Peak Error bands graph

Another view of the data is to look at a graph of the daily peak error for each Feeder for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Average and RMS values.

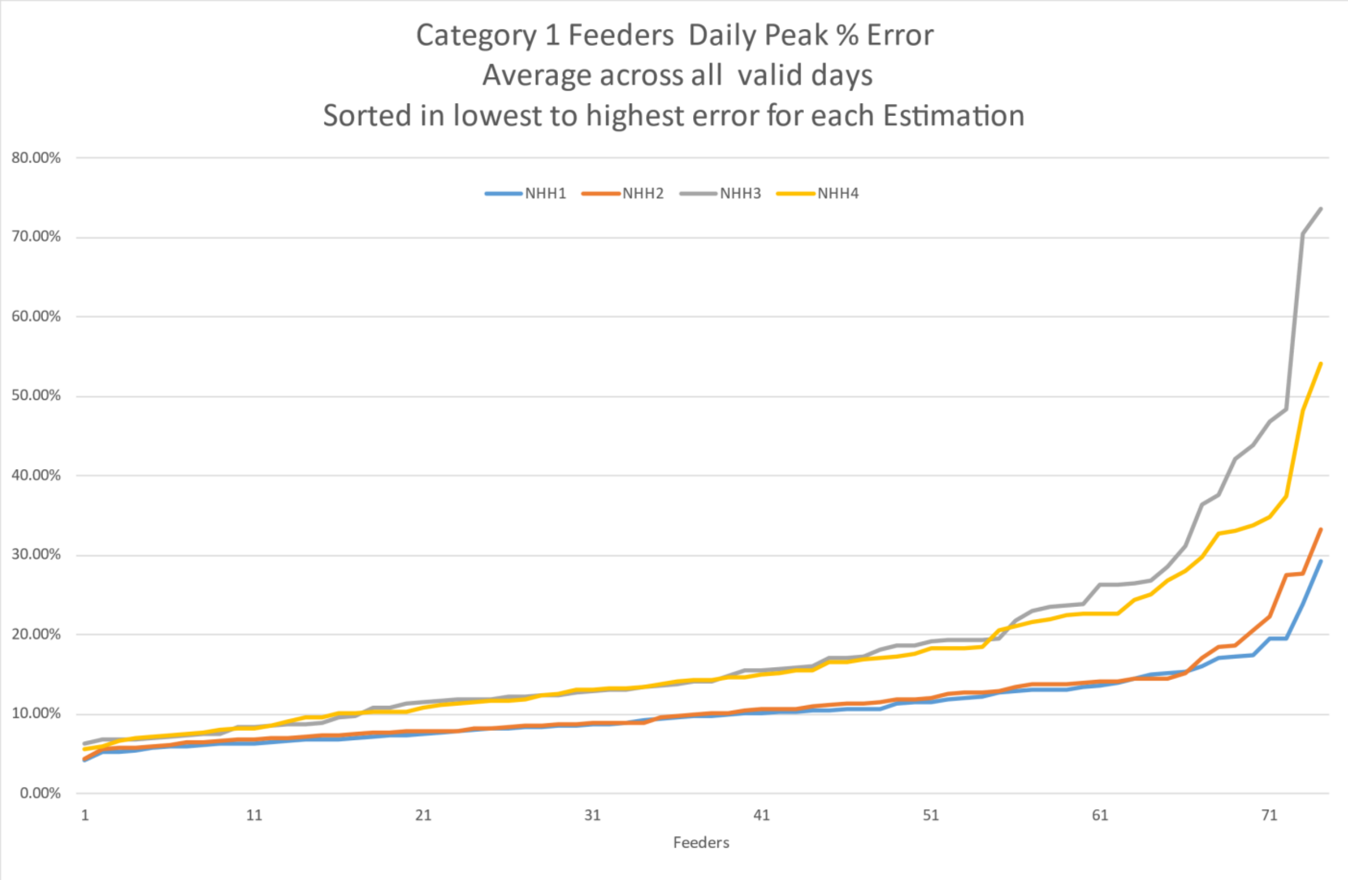


Figure 11- Feeder Category 1 Average Daily Peak Error

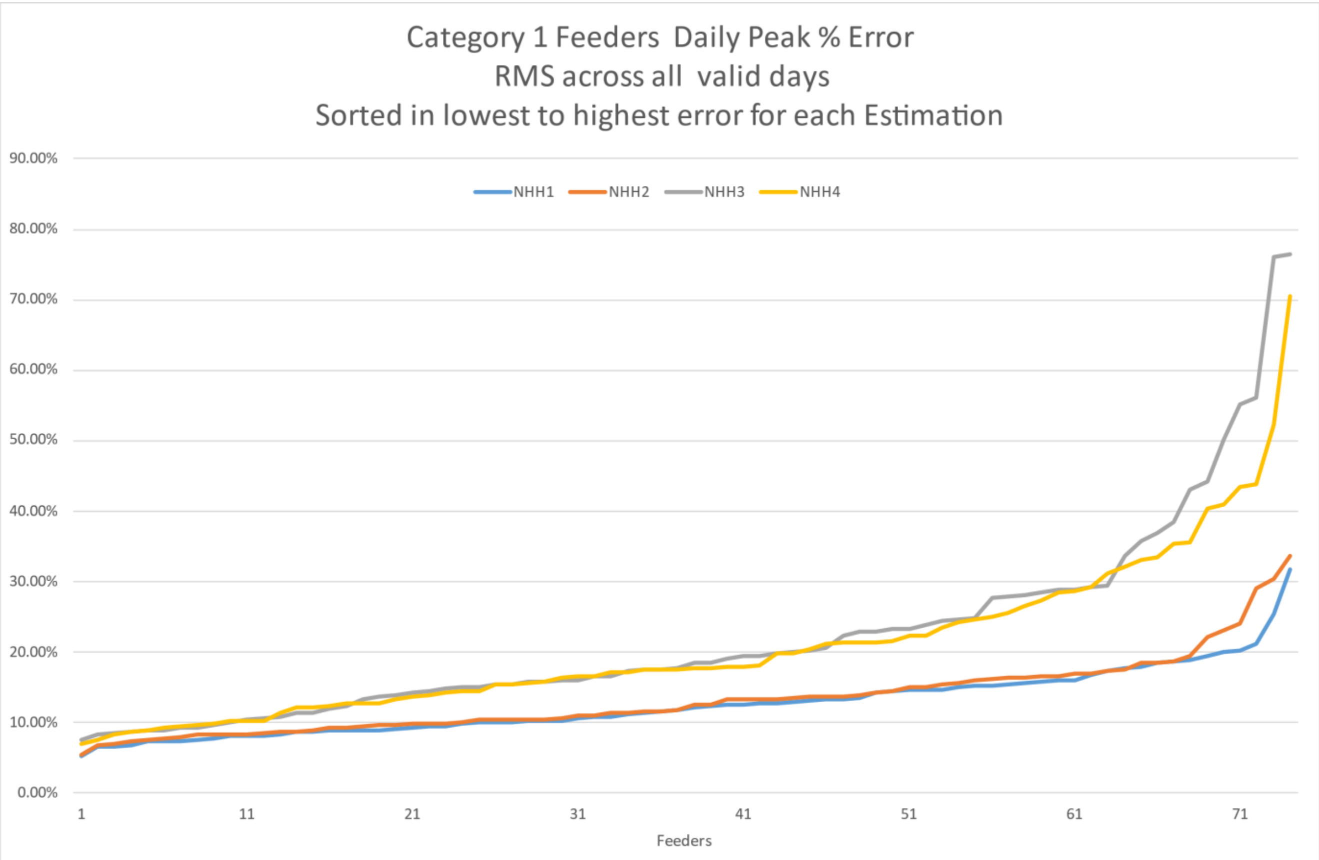


Figure 12 - Feeder Category 1 RMS Daily Peak Error

The data is also summarised across all feeders to provide an average error and RMS error for each estimation technique. This is done using average, RMS and also calculating the standard deviation.

Category 1 Daily Peak % error								
RMS, Average and Stdev across all Feeders	Feeder RMS across all days				Feeder Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	13.5%	14.4%	26.3%	23.6%	11%	12%	23%	19%
Average	12.7%	13.4%	22.2%	20.8%	10.6%	11.2%	18.6%	16.8%
Standard Deviation	4.7%	5.4%	14.1%	11.3%	4.5%	5.3%	13.2%	9.4%

Table 17- Daily Peak Error: All Category 1 Feeder

These results show that the NHH1 and NHH2 have the least error for Category 1 feeders.

There are 21 Category 2 Feeders (Minimum Daily average error between 15-25%)

Category 2 Daily Peak % error								
RMS, Average and Stdev across all feeders	Feeder RMS across all days				Feeder Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	21.8%	22.5%	40.9%	39.6%	19%	20%	37%	35%
Average	20.5%	21.4%	34.8%	33.7%	17.9%	18.9%	30.5%	29.1%
Standard Deviation	7.5%	7.3%	22.0%	21.3%	7.5%	7.5%	21.3%	19.4%

Table 18 - Daily Peak Error: All Category 2 Feeders

These results show that the NHH1 and NHH2 have the least error for Category 2 feeders.

4.5.3.2 Results – Feeder Annual Peak

The Annual Peak for each feeder is provides a single error value for each feeder. The error can be negative (overestimate) or positive (underestimate). The assessment includes the error magnitude.

Band	Category 1 - Number of feeders with Annual peak error magnitude in each error band			
	NHH1	NHH2	NHH3	NHH4
< 5%	19	15	13	15
< 10%	36	31	29	27
< 15%	52	50	38	39
< 20%	66	60	47	45
< 25%	70	68	53	52
All	74	74	74	74

Table 19- Feeder Category 1 Annual Peak Error bands

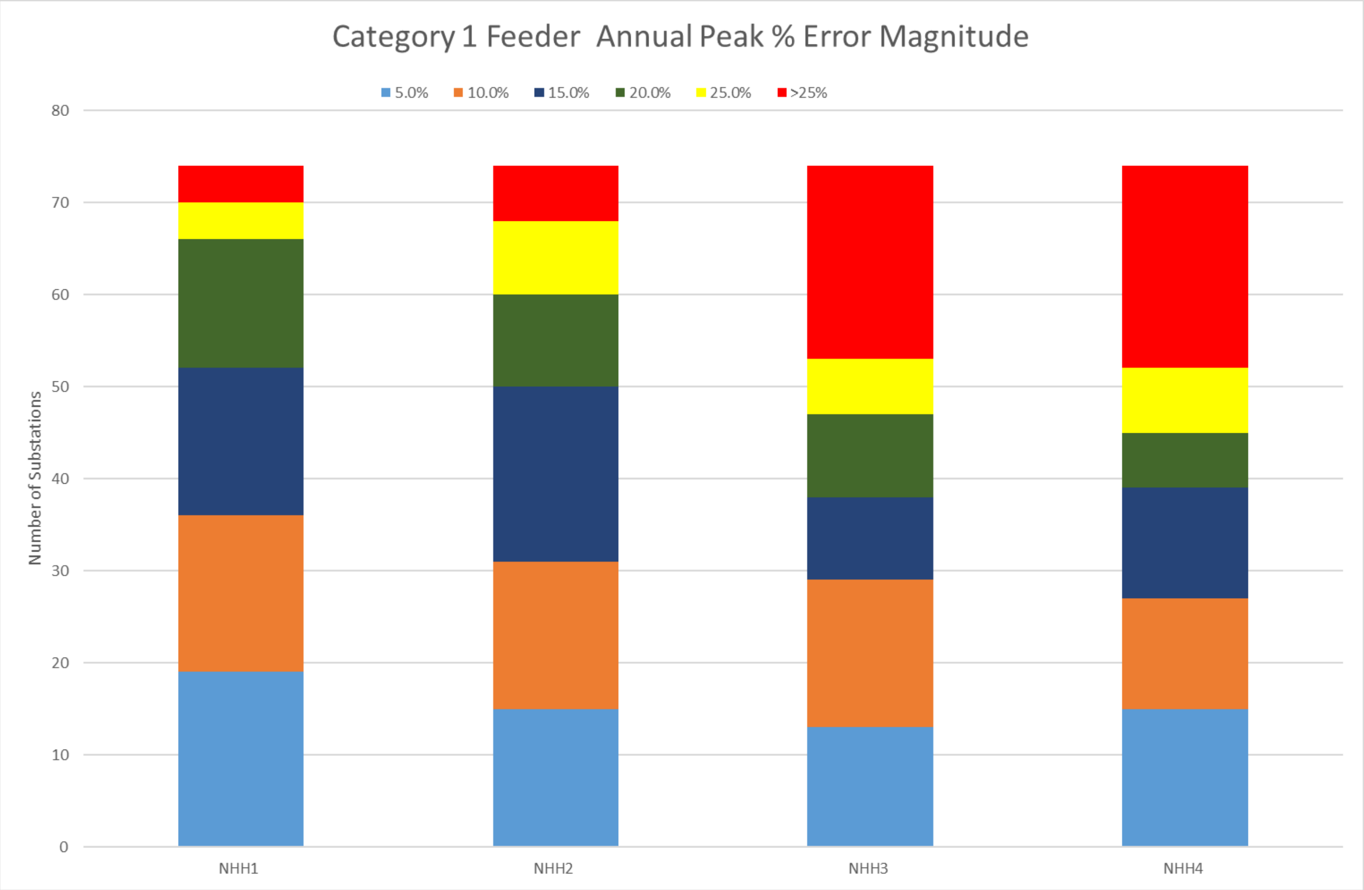


Figure 13- Feeder Category 1 Annual Peak Error bands graph

Another view of the data is to look at a graph of the Annual peak error for each substation for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Error Magnitude (ignoring sign) and Actual error (including sign).

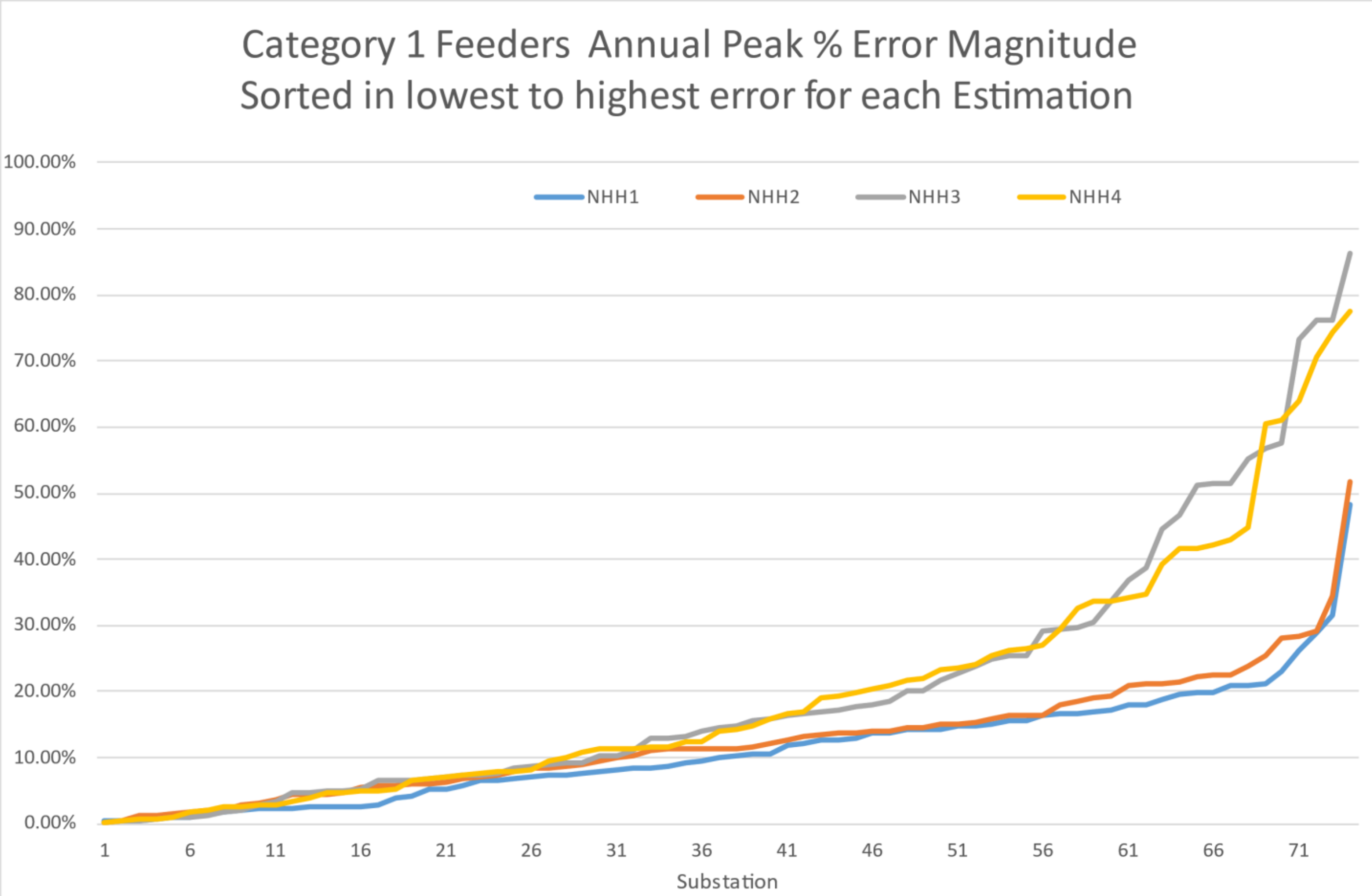


Figure 14 - Feeder Category 1 Annual Peak Error magnitude

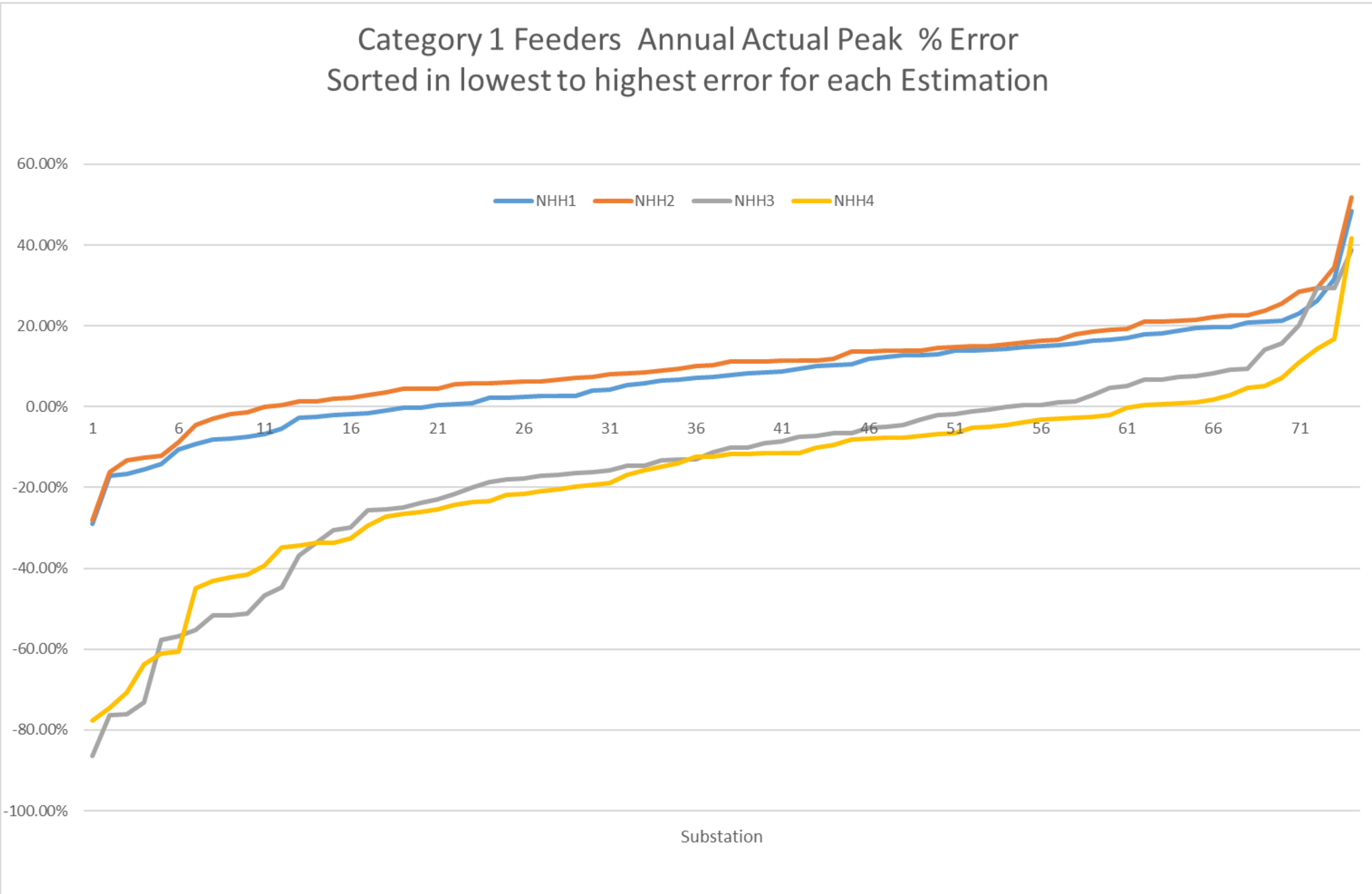


Figure 15 - Feeder Category 1 Annual Peak Error

The data is also summarised across all feeders to provide an average error and an average error magnitude for each estimation technique. This is done using average and RMS as well as calculating the standard deviation.

Category 1 Annual Peak % error								
RMS, Average and Stdev across all feeders	Error Magnitude				Actual Error			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	14.1%	15.6%	29.2%	27.5%	14.1%	15.6%	29.2%	27.5%
Average	11.2%	12.7%	20.9%	20.2%	6.9%	10.0%	-15.0%	-17.3%
Standard Deviation	8.6%	9.0%	20.5%	18.8%	12.4%	12.0%	25.2%	21.6%

Table 20 - Annual Peak Error: All Category 1 Feeders

These results show that the NHH1 and NHH2 have the least error for Category 1 feeders.

Category 2 Annual Peak % error								
RMS, Average and Stdev across all feeders	Error Magnitude				Actual Error			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	24.6%	26.8%	46.9%	56.4%	24.6%	26.8%	46.9%	56.4%
Average	21.4%	23.5%	34.2%	37.3%	7.8%	10.8%	-19.9%	-26.7%
Standard Deviation	12.4%	13.2%	32.8%	43.4%	23.9%	25.2%	43.5%	50.9%

Table 21 - Annual Peak Error: All Category 2 Feeders

These results show that the NHH1 and NHH2 have the least error for Category 2 feeders.

4.5.3.3 Results – Feeder Half Hour profile

The HH profile error for each day for a feeder is calculated as described in section 3.3.3.

The HH Profile error for each feeder is summarised across all the valid days of measurement using

3. Simple average
4. Root Mean Square (RMS)

The number of feeder in each error band is shown in the table below.

Category 1 - Number of feeder with Average and RMS HH profile error in each error band								
Band	RMS				Average			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
< 10%	1	1	0	0	1	1	0	0
< 15%	20	19	6	5	21	21	6	6
< 20%	40	39	22	26	44	43	24	30
< 25%	62	59	40	41	65	62	41	42
< 30%	69	67	54	53	69	68	55	54
All	74	74	74	74	74	74	74	74

Table 22 - Feeder Category 1 HH Profile Error bands

A graphical form of this table is shown below.

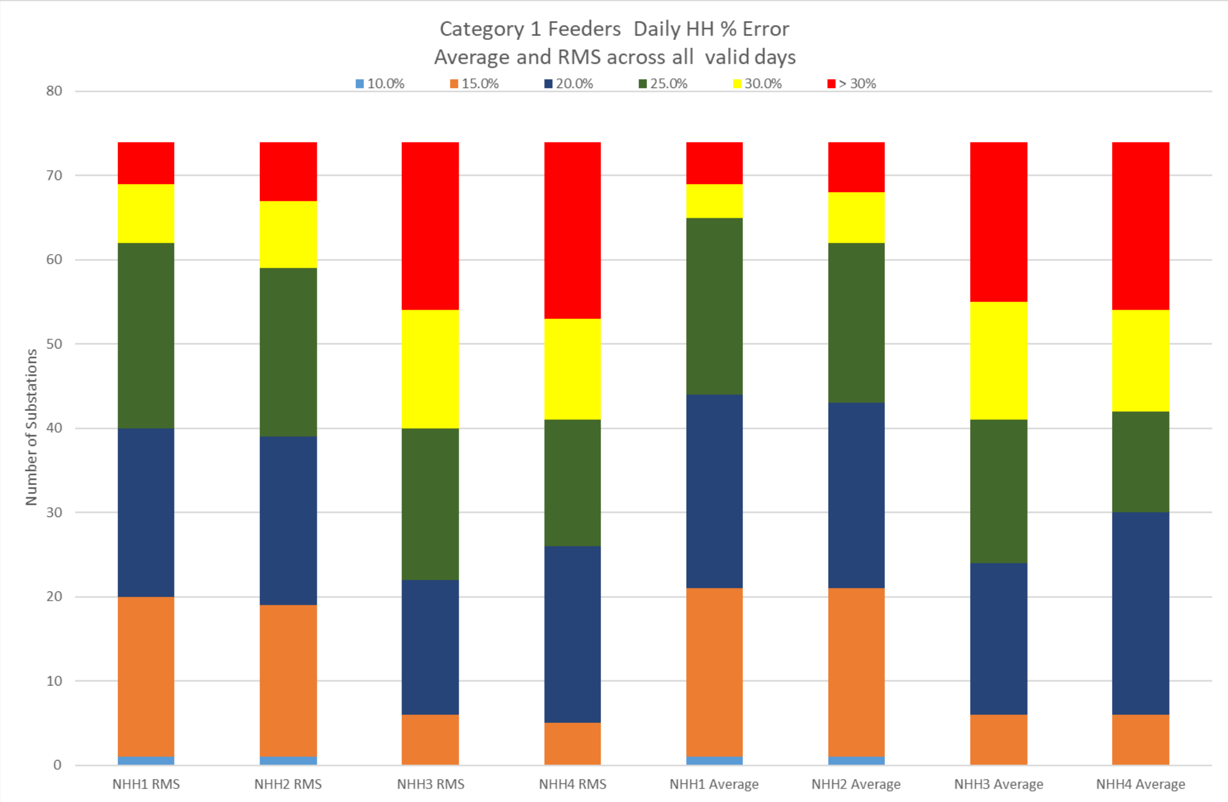


Figure 16 - Figure Category 1 HH Profile Error bands

Another view of the data is to look at a graph of the daily HH error for each feeder for estimation technique sorted into best to worst for each estimation technique. Separate graphs are shown for Average and RMS values.

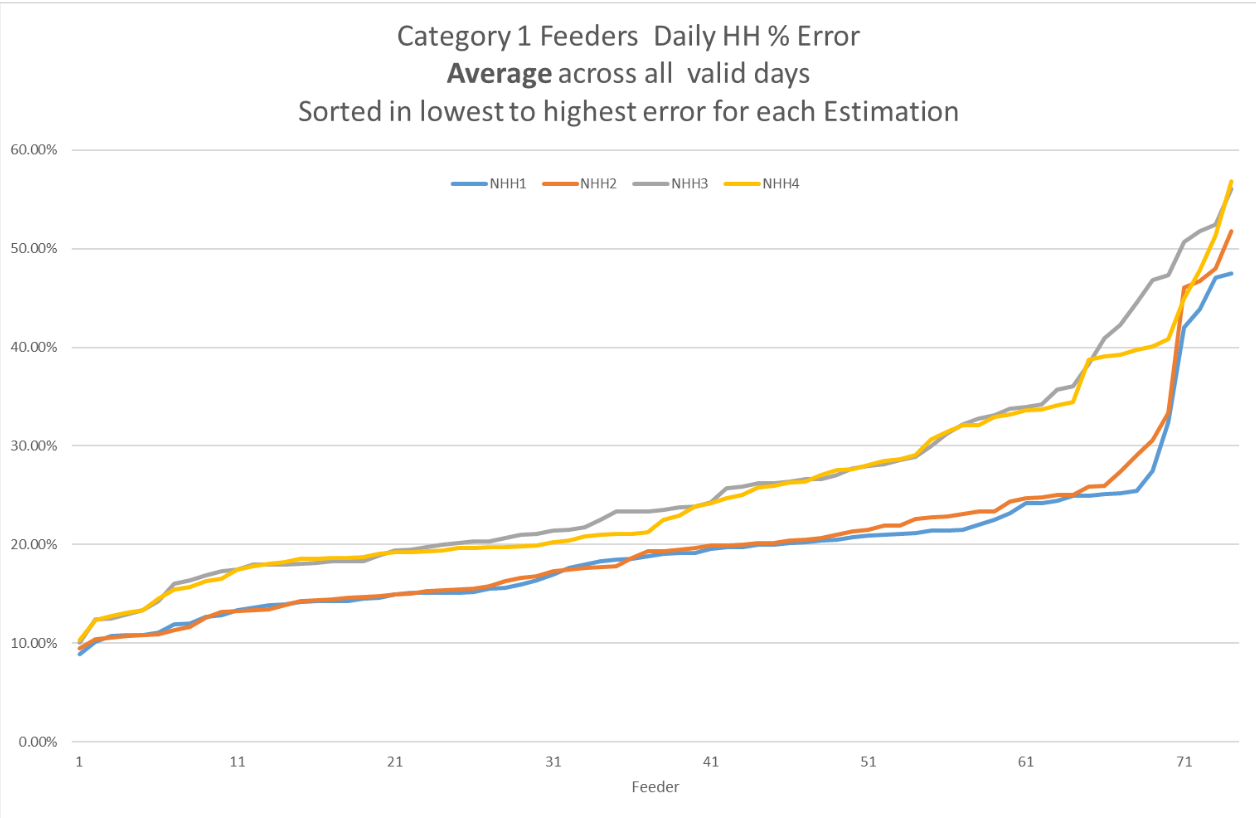


Figure 17 - Feeder Category 1 Average HH Profile Error

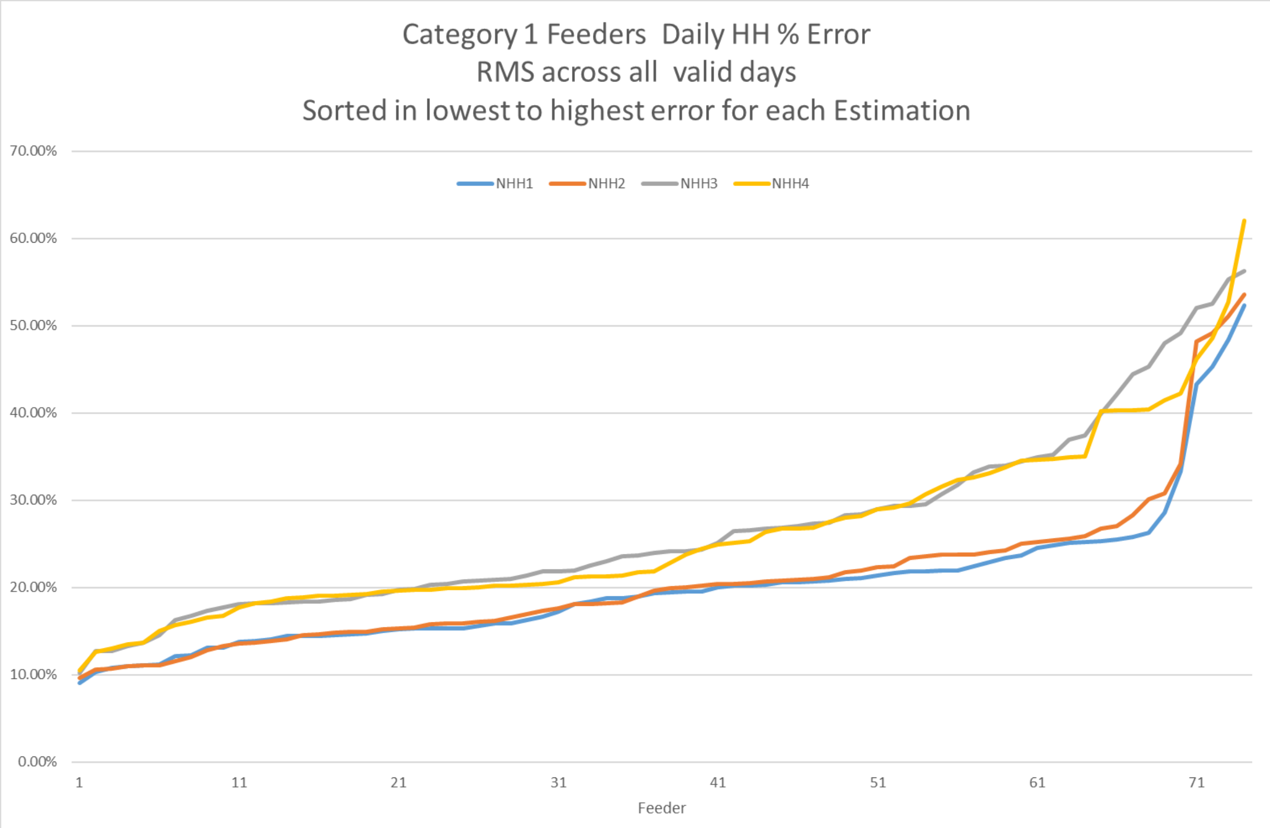


Figure 18 - Feeder Category 1 RMS HH Profile Error

The data is also summarised across all feeders to provide an average error and RMS error for each estimation technique. This is done using average, RMS and also calculating the standard deviation.

Category 1 Daily HH % error								
RMS, Average and Stdev across all feeders	Feeder RMS across all days				Feeder Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	21.6%	22.6%	28.9%	27.9%	21.0%	21.8%	28.1%	27.1%
Average	20.1%	20.7%	26.8%	26.1%	19.6%	20.1%	26.1%	25.4%
Standard Deviation	8.2%	8.9%	10.7%	10.1%	7.7%	8.5%	10.4%	9.6%

Table 23 - HH Profile Error: All Category 1 Feeder

These results show that NHH1 and NHH2 are the best estimation techniques.

There are 21 Category 2 Feeders (Minimum Daily average error between 15-25%)

Category 2 Daily Peak % error								
RMS, Average and Stdev across all feeders	Feeder RMS across all days				Feeder Average across all days			
	NHH1	NHH2	NHH3	NHH4	NHH1	NHH2	NHH3	NHH4
RMS	31.1%	31.3%	46.1%	39.7%	30.1%	30.4%	44.4%	38.4%
Average	30.0%	30.4%	41.9%	37.5%	29.1%	29.5%	40.6%	36.3%
Standard Deviation	8.5%	7.9%	19.8%	13.4%	7.8%	7.6%	18.5%	12.7%

Table 24 - HH Profile Error: All Category 2 Feeder

The Category 2 feeders show NHH1 and NHH2 are the best estimation techniques.

4.5.4 Results – Daily Profiles Examples

In this section we provide a weekly winter and summer profile for a range of substations based on the daily average error in section 4.4.1 for substations and section 0 for feeders.

Graphs are displayed for NHH1 and NHH4 estimation techniques for a winter week and a summer week where there is a complete week of valid data.

The examples show a clear difference in HH profile match when the daily error reaches 10% for substations.

4.5.4.1 Substation Daily Profiles Examples

4.5.4.1.1 Substation 941916 – Daily Error 2%

The calculated average annual HH profile error for substation 941916 is 1.3% (NHH1), 1.4% (NHH2), 2.0% (NHH3) and 1.9% (NHH4)

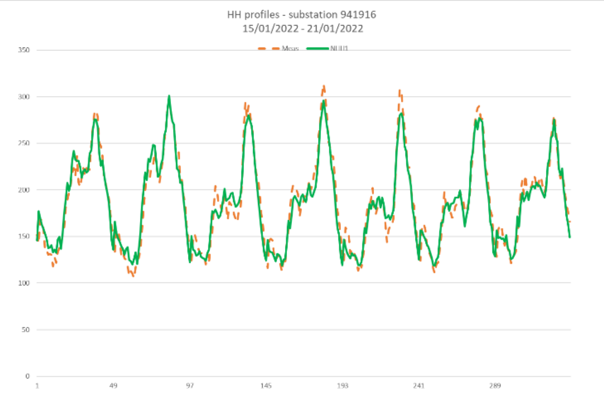


Figure 19 - SS 941916 Winter week HH Profile - NHH1

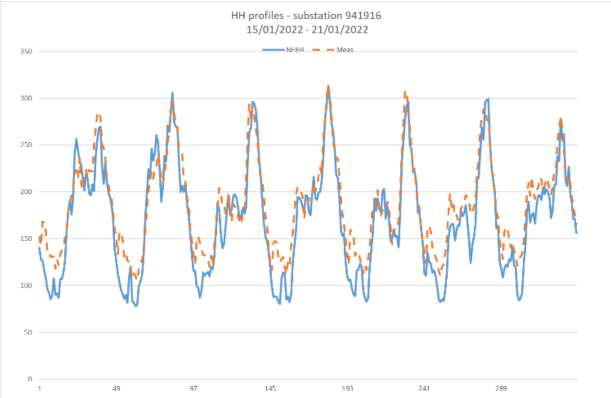


Figure 20 - SS 941916 Winter week HH Profile - NHH4

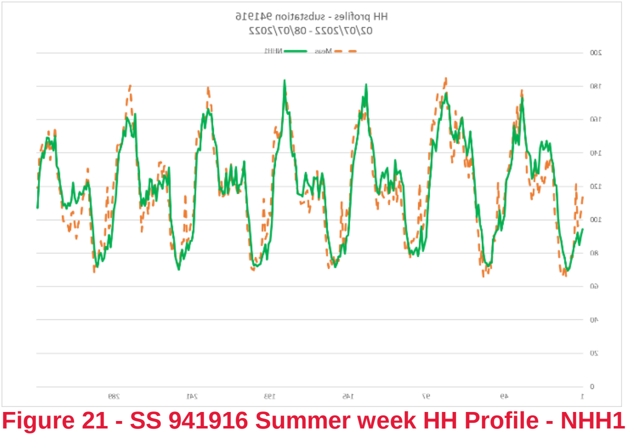


Figure 21 - SS 941916 Summer week HH Profile - NHH1

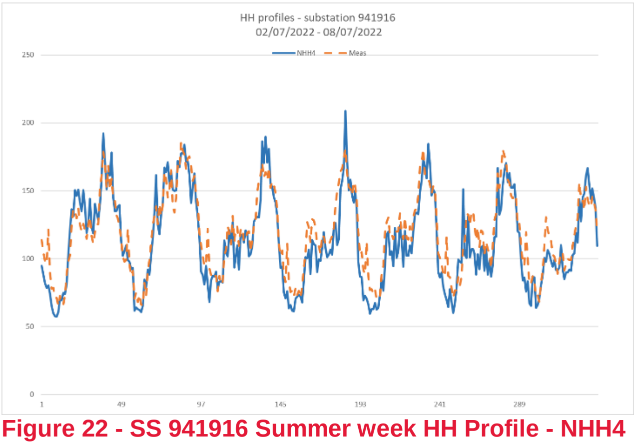


Figure 22 - SS 941916 Summer week HH Profile - NHH4

4.5.4.1.2 Substation 942084 – Daily Error 7%

The calculated average annual HH profile error for substation 942084 is 2.2% (NHH1), 1.9% (NHH2), 3.1% (NHH3) and 2.8% (NHH4)

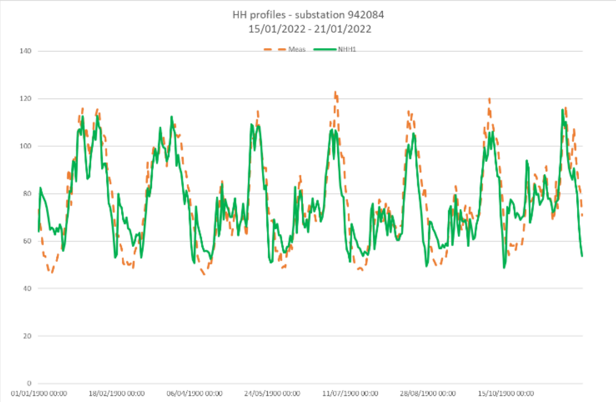


Figure 23 - SS 942084 Winter week HH Profile - NHH1

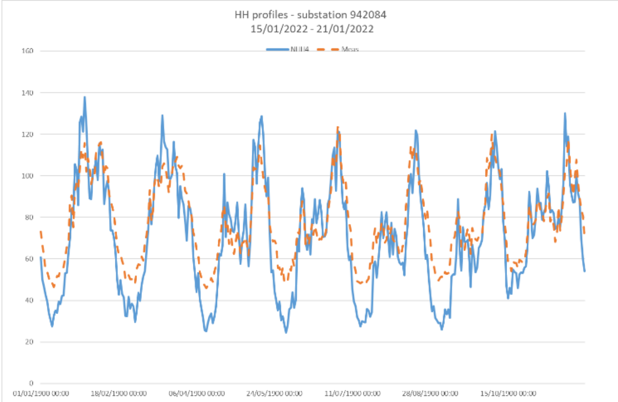


Figure 24 - SS 942084 Winter week HH Profile - NHH4

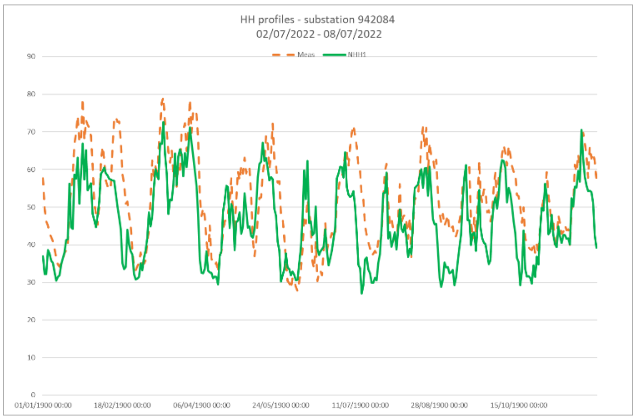


Figure 25 - SS 942084 Summer week HH Profile - NHH1

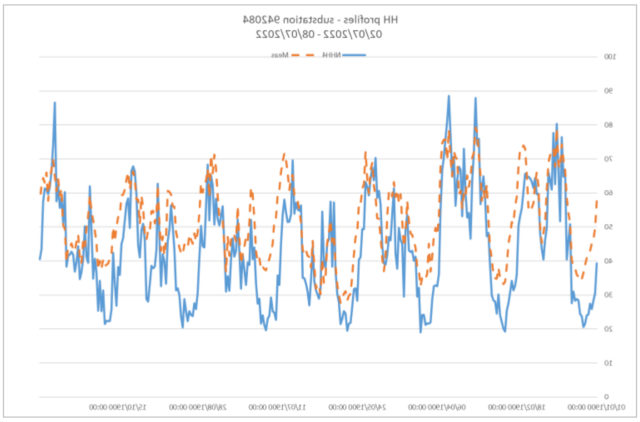


Figure 26 - SS 942084 Summer week HH Profile - NHH4

4.5.4.1.3 Substation 942842 – Daily Error 10%

The calculated average annual HH profile error for substation 942842 is 3.1% (NHH1), 3.3% (NHH2), 4.1% (NHH3) and 4.8% (NHH4)

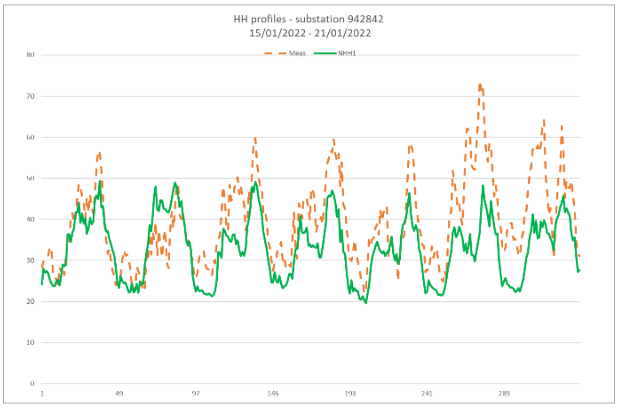


Figure 27 - SS 942842 Winter week HH Profile - NHH1

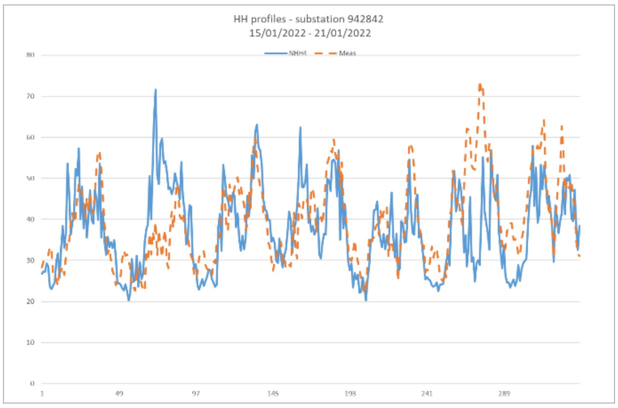


Figure 28 - SS 942842 Winter week HH Profile - NHH4

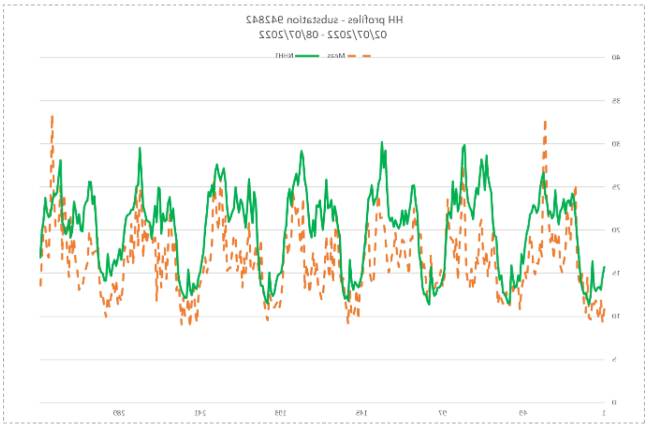
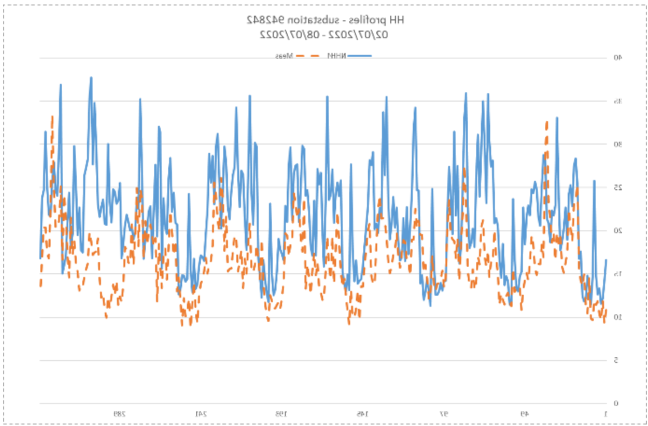
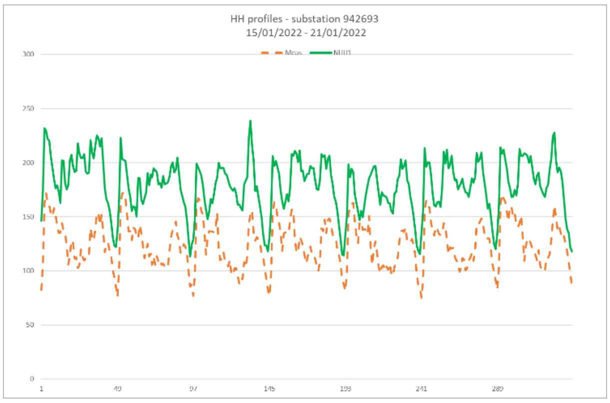
 

Figure 29 - SS 942842 Winter week HH Profile - NHH1

Figure 30 - SS 942842 Summer week HH Profile - NHH4

4.5.4.1.4 Substation 942693 – Daily Error 13%

The calculated average annual HH profile error for substation 942693 is 4.5% (NHH1), 5.1% (NHH2), 3.7% (NHH3) and 3.5% (NHH4)



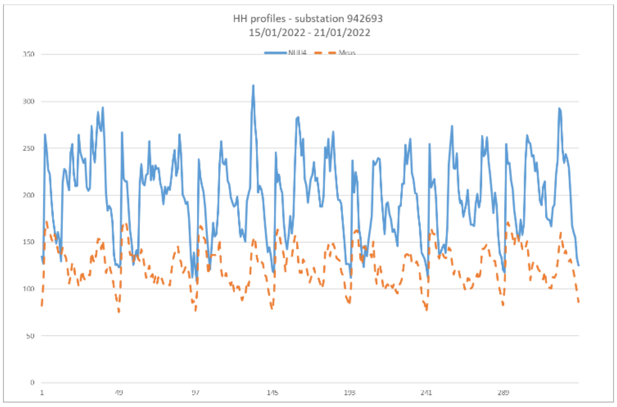
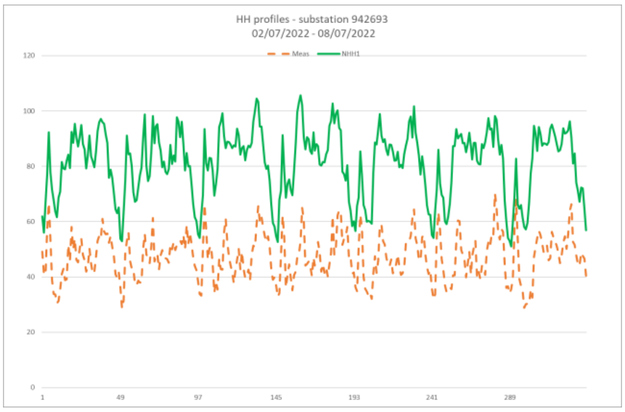


Figure 31 - SS 942693 Winter week HH Profile - NHH1

Figure 32 - SS 942693 Winter week HH Profile - NHH4



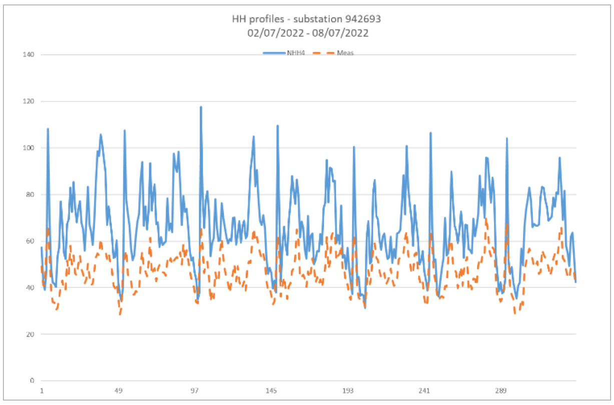


Figure 33 - SS 942693 Summer week HH Profile - NHH4

Figure 34 - SS 942693 Summer week HH Profile - NHH1

4.5.4.2 Feeder Daily Profiles Examples

4.5.4.2.1 Feeder 941987:1 – Daily error 3%

The calculated average annual HH profile error for Feeder 941987:1 is 1.6% (NHH1), 1.6% (NHH2), 2.3% (NHH3) and 2.2% (NHH4)

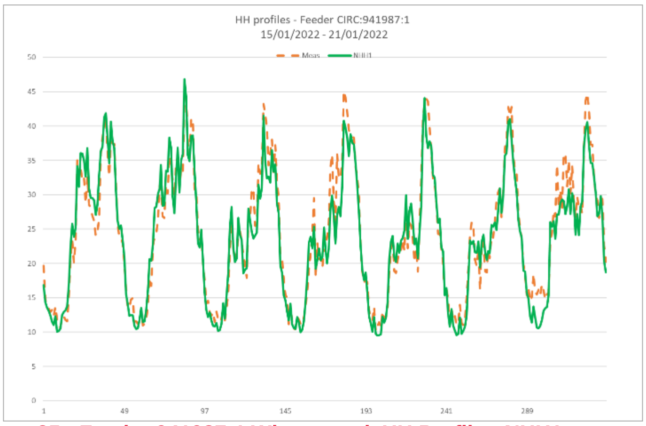


Figure 35 - Feeder 941987:1 Winter week HH Profile - NHH1

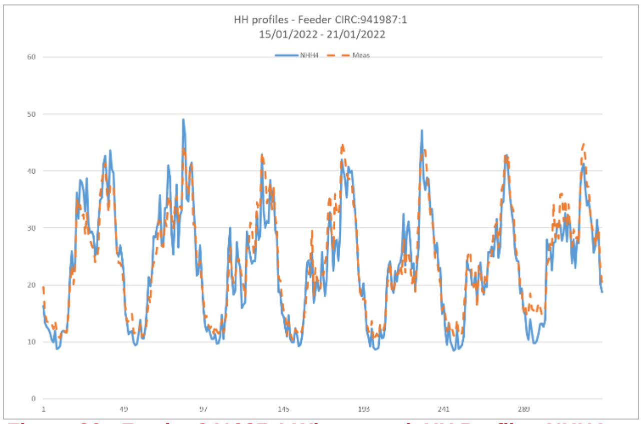


Figure 36 - Feeder 941987:1 Winter week HH Profile - NHH4

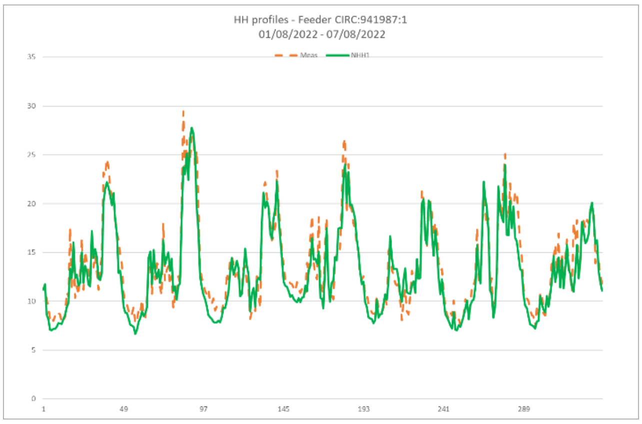


Figure 37 - Feeder 941987:1Summer week HH Profile - NHH1

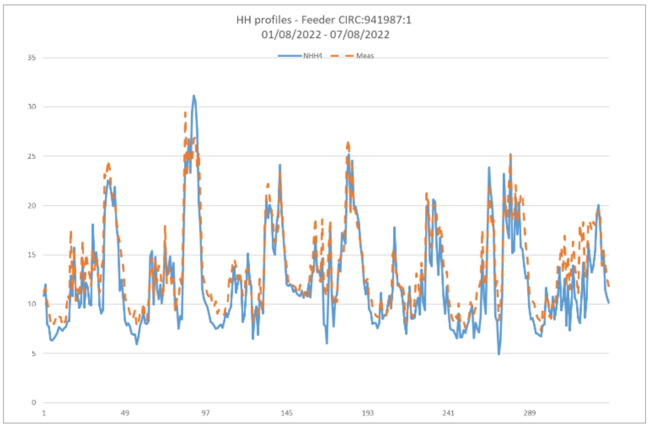


Figure 38 - Feeder 941987:1 Summer week HH Profile - NHH4

4.5.4.2.2 Feeder 942878:3– Daily error 5%

The calculated average annual HH profile error for Feeder 942878:3 is 2.7% (NHH1), 3.0% (NHH2), 3.1% (NHH3) and 3.0% (NHH4)

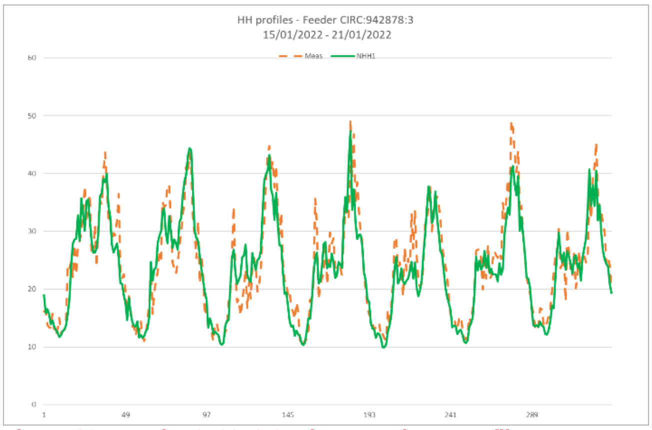


Figure 39 - Feeder 942878:3 Winter week HH Profile - NHH1

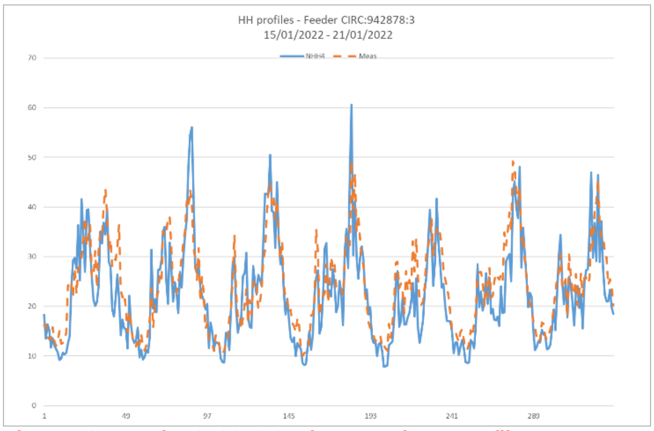


Figure 40 - Feeder 942878:3 Winter week HH Profile - NHH4

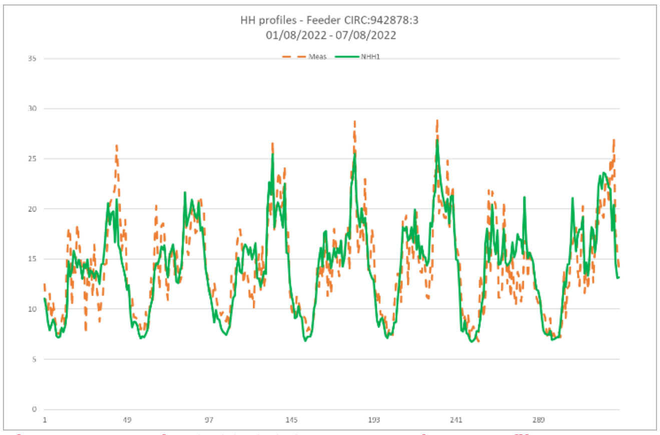


Figure 41 - Feeder 942878:3 Summer week HH Profile - NHH1

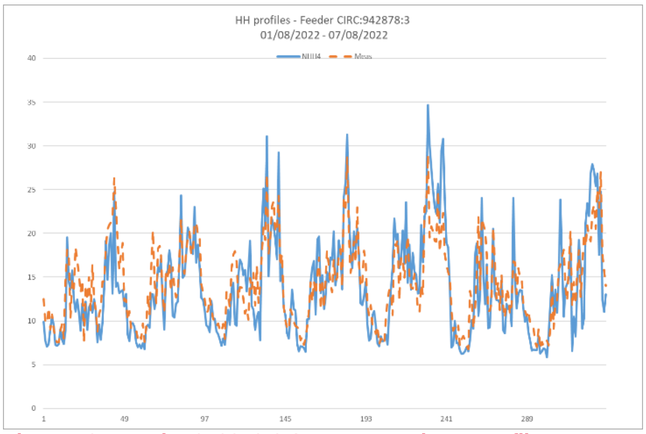


Figure 42 - Feeder 942878:3 Summer week HH Profile - NHH4

4.5.4.2.3 Feeder 942842:1– Daily error 10%

The calculated average annual HH profile error for Feeder 941842:1 is 3.1% (NHH1), 3.4% (NHH2), 3.8% (NHH3) and 4.8% (NHH4)

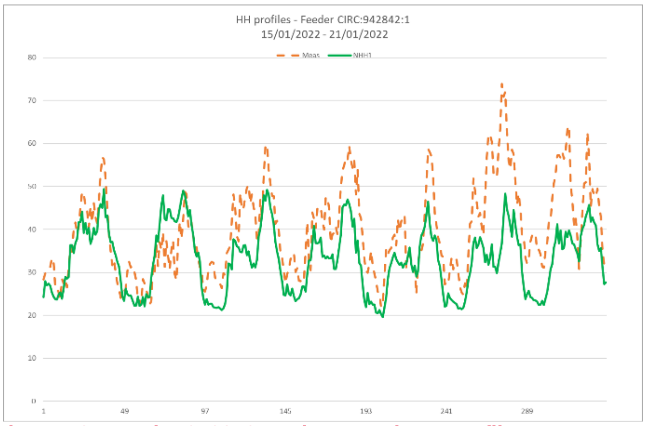


Figure 43 - Feeder 942842:1 Winter week HH Profile - NHH1

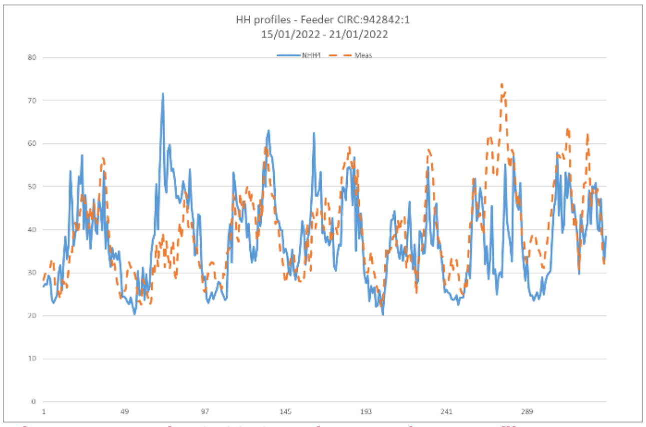


Figure 44 - Feeder 942842:1 Winter week HH Profile - NHH4

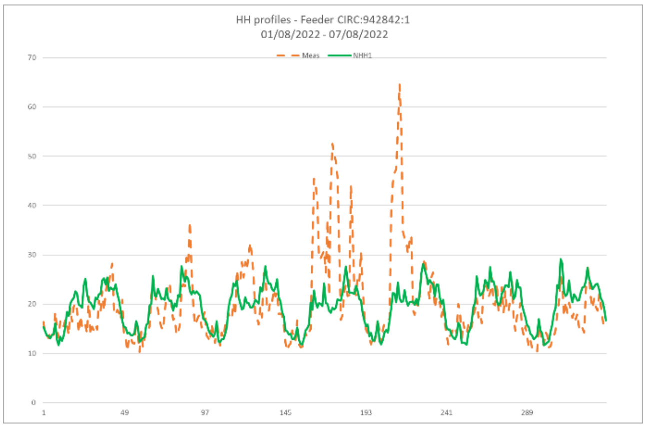


Figure 45 - Feeder 942842:1 Summer week HH Profile - NHH1

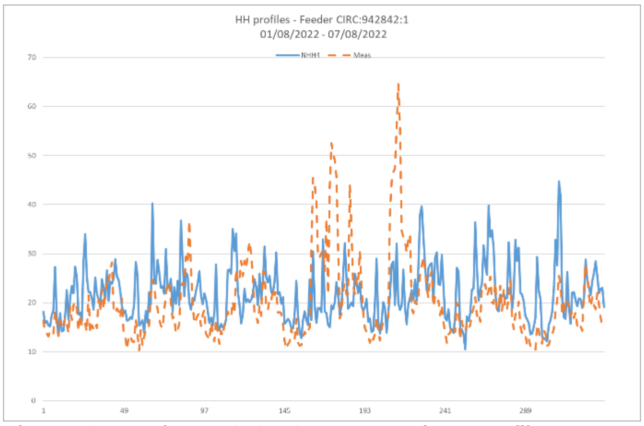


Figure 46 - Feeder 942842:1 Summer week HH Profile - NHH4

4.5.4.2.4 Feeder 942368:2– Daily error 15%

The calculated average annual HH profile error for Feeder 942368:2 is 2.8% (NHH1), 2.7% (NHH2), 3.8% (NHH3) and 3.8% (NHH4)

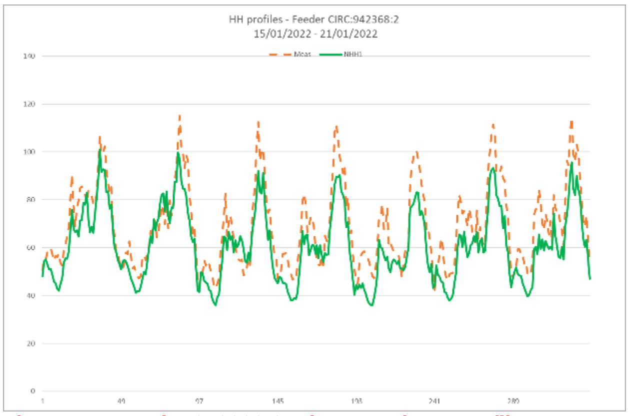


Figure 47 - Feeder 942368:2 Winter week HH Profile - NHH1

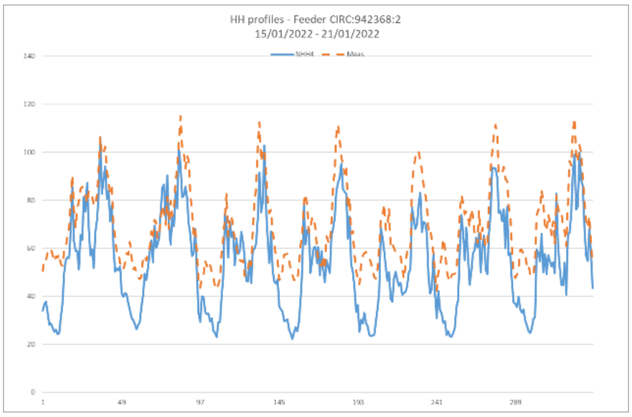


Figure 48 - Feeder 942368:2 Winter week HH Profile - NHH4

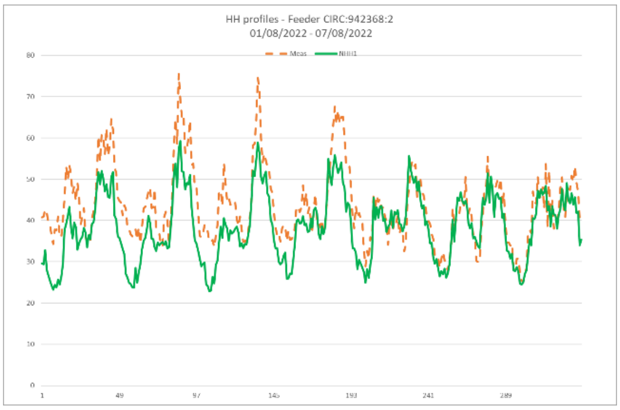


Figure 49 - Feeder 942368:2 Summer week HH Profile - NHH1

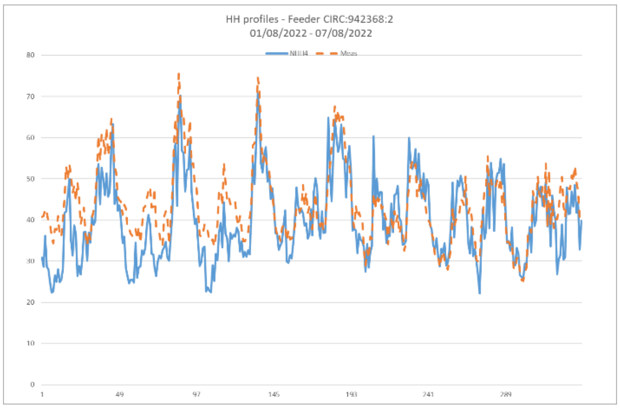


Figure 50 - Feeder 942368:2 Summer week HH Profile - NHH4

4.6 Results – Day of Week

Analysis as performed to determine if some weekdays are better estimated than others. The table below shows the results for the NHH1 algorithm for the different days of the week using the RMS values.

4.6.1 Substation Daily Peaks – Day of Week

The number of substations in each error band for each day of the week is shown in the table below.

Category 1 - Number of substations with RMS Daily peak error in each error band for each weekday for NHH1							
Band	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
<5.0%	2	3	2	3	3	3	2
<7.5%	20	15	14	12	13	13	15
<10.0%	25	22	21	23	20	19	25
<12.5%	29	29	26	27	27	28	30
<15.0%	34	32	33	32	33	32	33
All	34	34	34	34	34	34	34

Table 25 - Substation Daily Peaks - Day of Week for NHH1

A graphical form of this table is shown below.

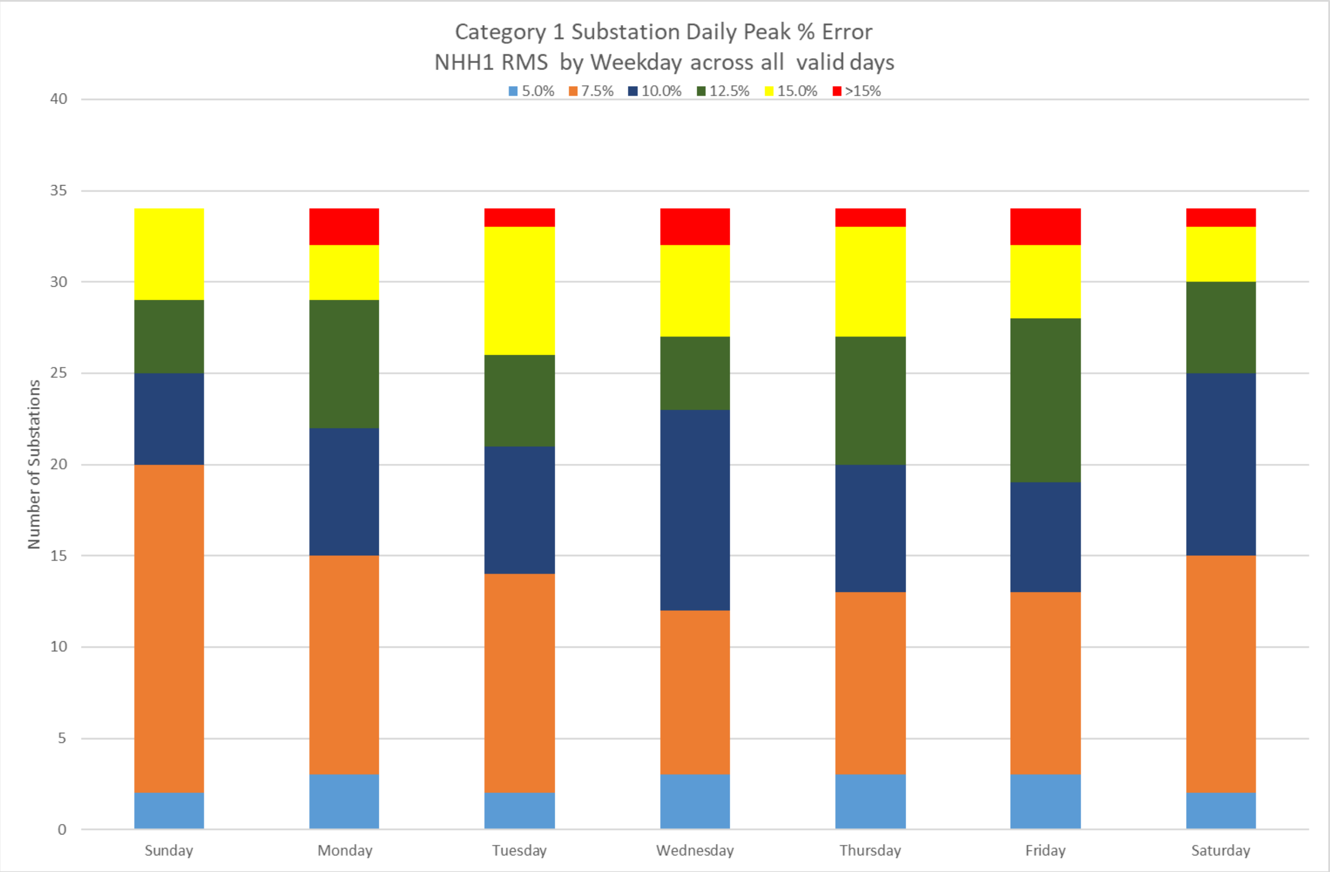


Figure 51 - Substation Daily Peaks - Day of Week Error bands for NHH1

Another view of the data is to look at a graph of the error for each substation for each day sorted into best to worst substations.

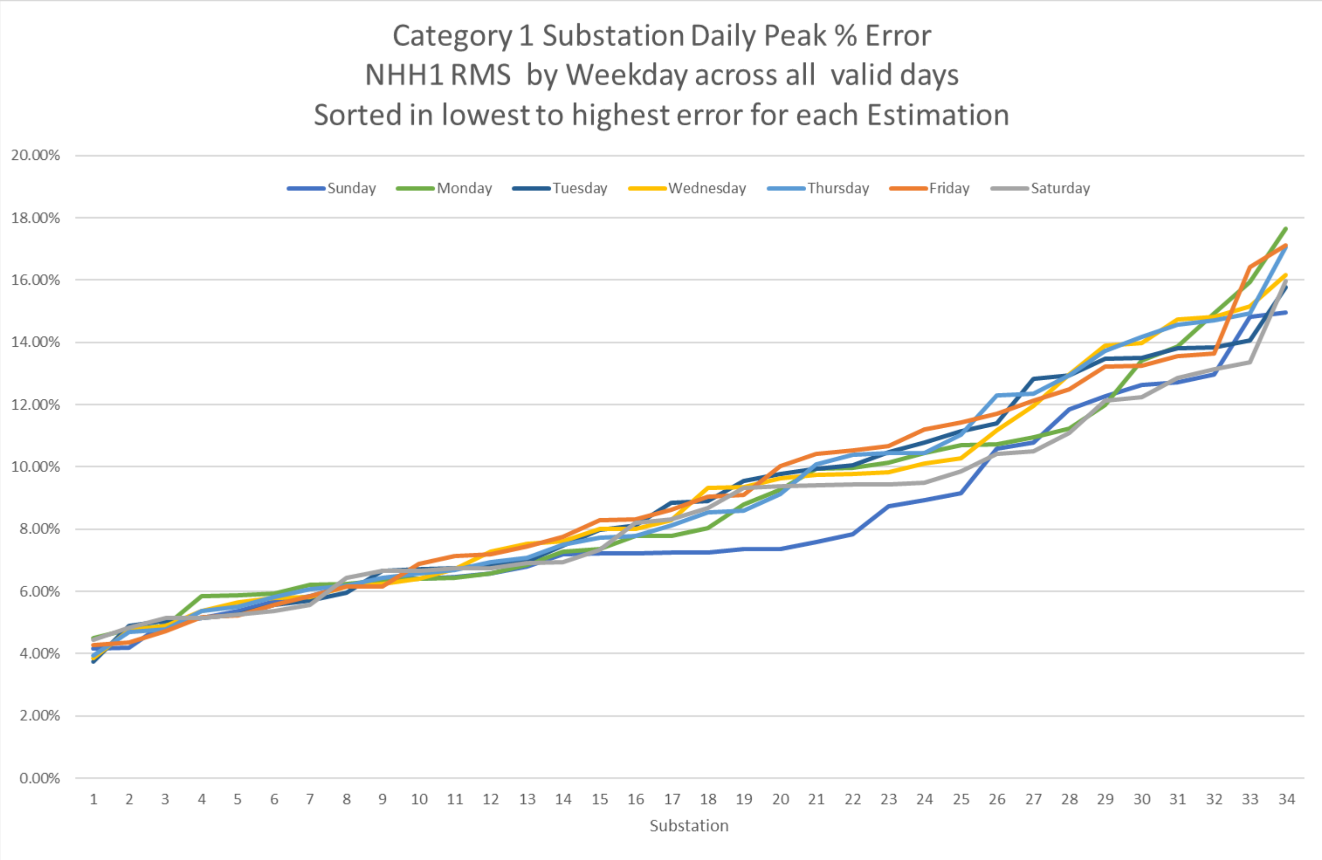


Figure 52 - Substation Daily Peaks - Day of Week for NHH1

The data is also summarised across all substations to provide an RMS, average and the standard deviation value for each day of the week.

Category 1 Daily Peak % error across all substations for NHH1							
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
RMS	8.8%	9.6%	9.7%	9.8%	9.8%	9.9%	9.1%
Average	8.3%	9.0%	9.1%	9.2%	9.2%	9.3%	8.6%
Standard Deviation	3.0%	3.3%	3.3%	3.4%	3.5%	3.4%	2.9%

Table 26 - Substation Daily Peaks - Day of Week Summary for NHH1

4.6.2 Substation Half Hour profile – Day of Week

The number of substations in each error band for each day of the week is shown in the table below. The RMS value for each day has been used and then the RMS value across all days.

Category 1 - Number of substations with RMS HH error in each error band for each weekday for NHH1							
Band	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
<5.0%	0	0	0	0	0	0	0
<7.5%	1	0	0	0	0	0	0
<10.0%	8	6	6	7	7	5	8
<12.5%	16	12	11	11	12	12	16
<15.0%	25	22	22	20	20	22	24
All	34	34	34	34	34	34	34

Table 27 - Substation Half Hour profile – Day of Week for NHH1

A graphical form of this table is shown below.

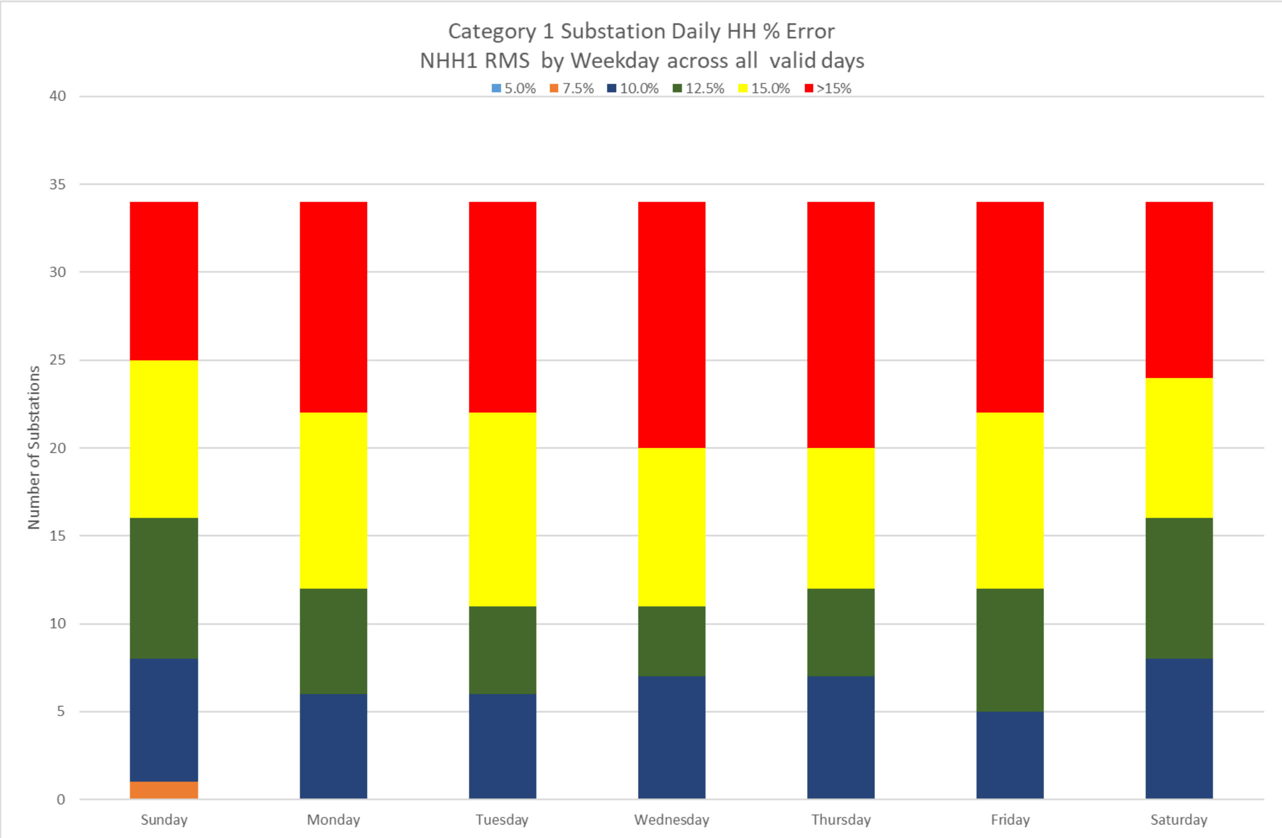


Figure 53- Substation Half Hour profile – Day of Week for NHH1

Another view of the data is to look at a graph of the error for each substation for each day sorted into best to worst substations.

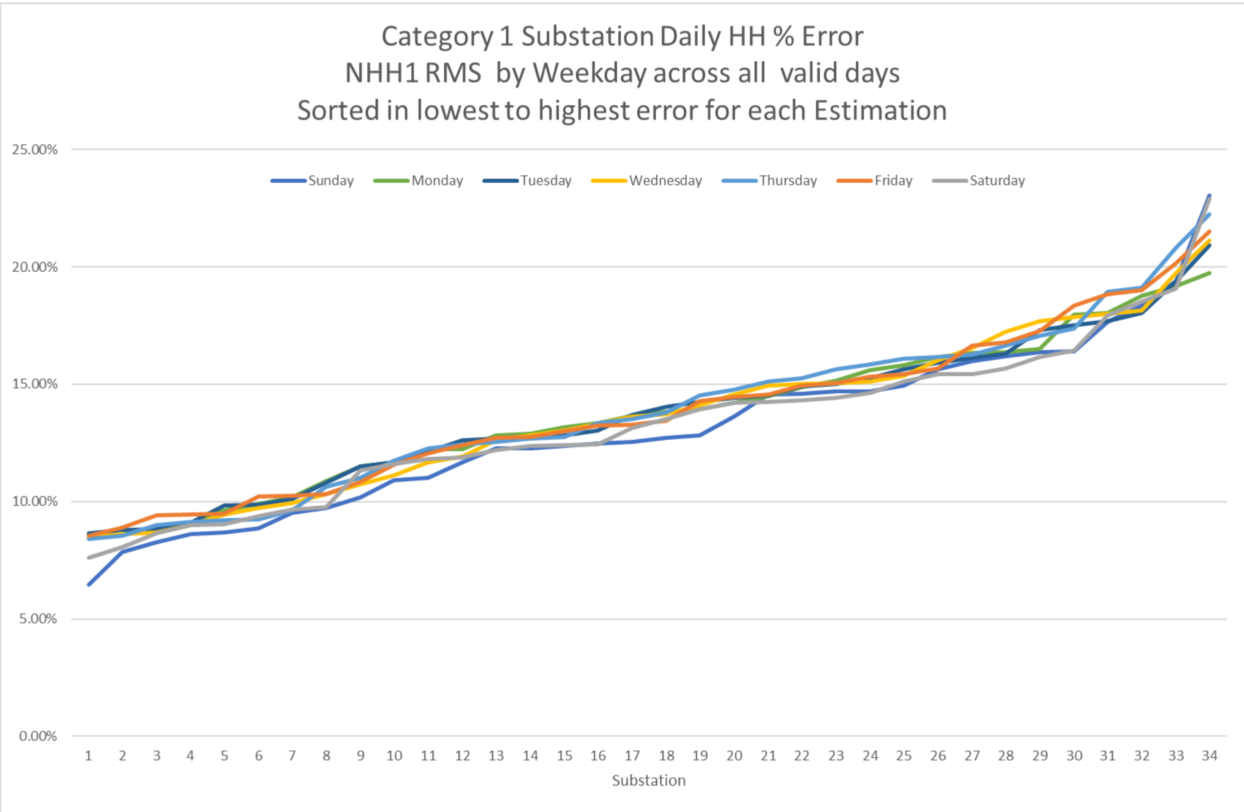


Figure 54 - Substation Half Hour profile – Day of Week for NHH1

The error is generally the same for all days of the week. Saturdays and Sundays for both Daily Peaks and HH error seem to be slightly better than weekdays.

4.7 Results – Monthly

Analysis as performed to determine if some months are better estimated than others. The table below shows the results for the NHH1 algorithm for the different months using the RMS values.

4.7.1 Substation Daily Peaks – Month

The number of substations in each error band for each month is shown in the table below.

Category 1 - Number of substations with RMS Daily peak error in each error band for each Month for NHH1									
Band	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
<5.0%	5	7	10	3	2	3	6	3	5
<7.5%	16	16	16	19	13	16	12	16	17
<10.0%	22	22	20	22	23	22	22	21	26
<12.5%	25	25	26	29	29	30	29	26	29
<15.0%	30	30	32	32	34	32	31	33	32
All	34	34	34	34	34	34	34	34	34

Table 28 - Substation Daily Peaks by Month for NHH1

A graphical form of this table is shown below.

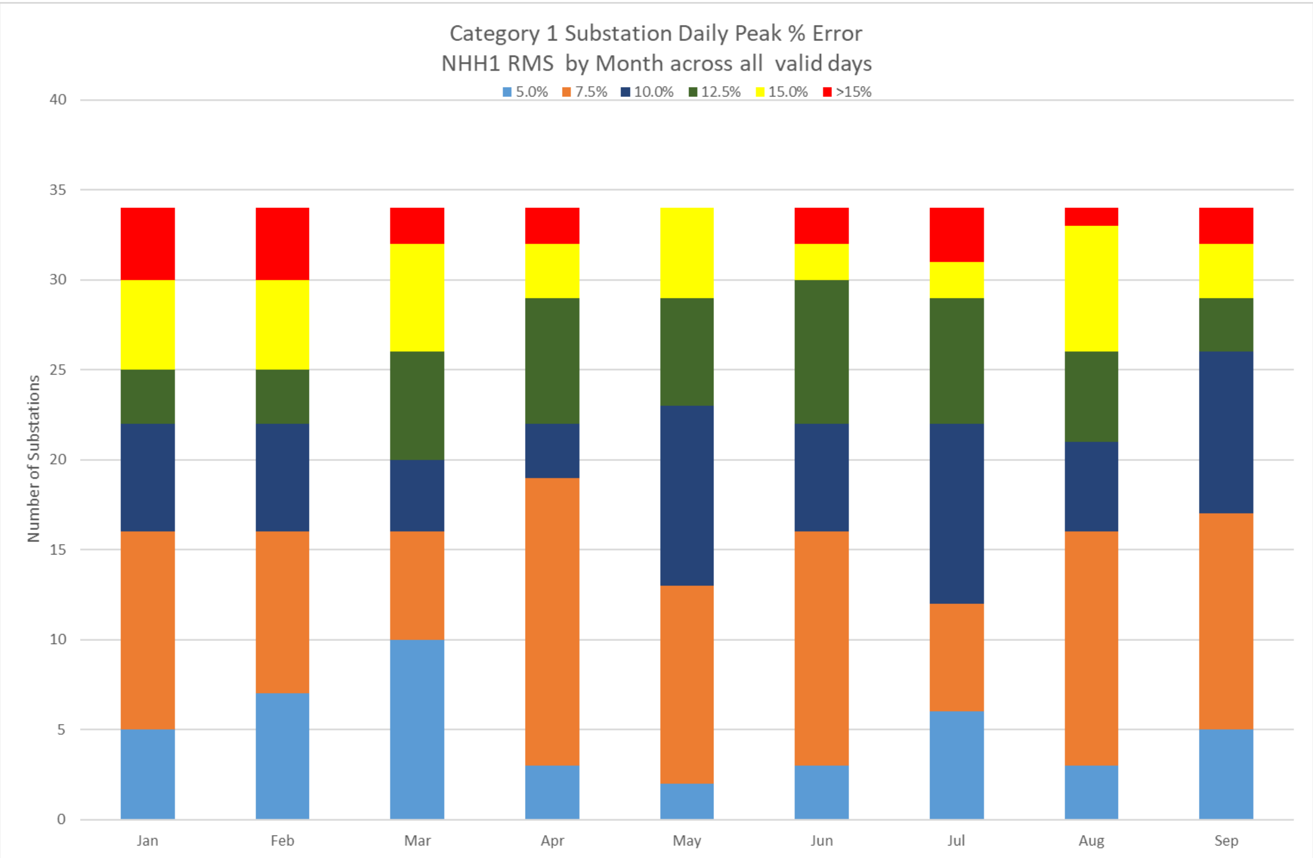


Figure 55 - Substation Daily Peaks by Month for NHH1

Another view of the data is to look at a graph of the error for each substation for each day sorted into best to worst substations.

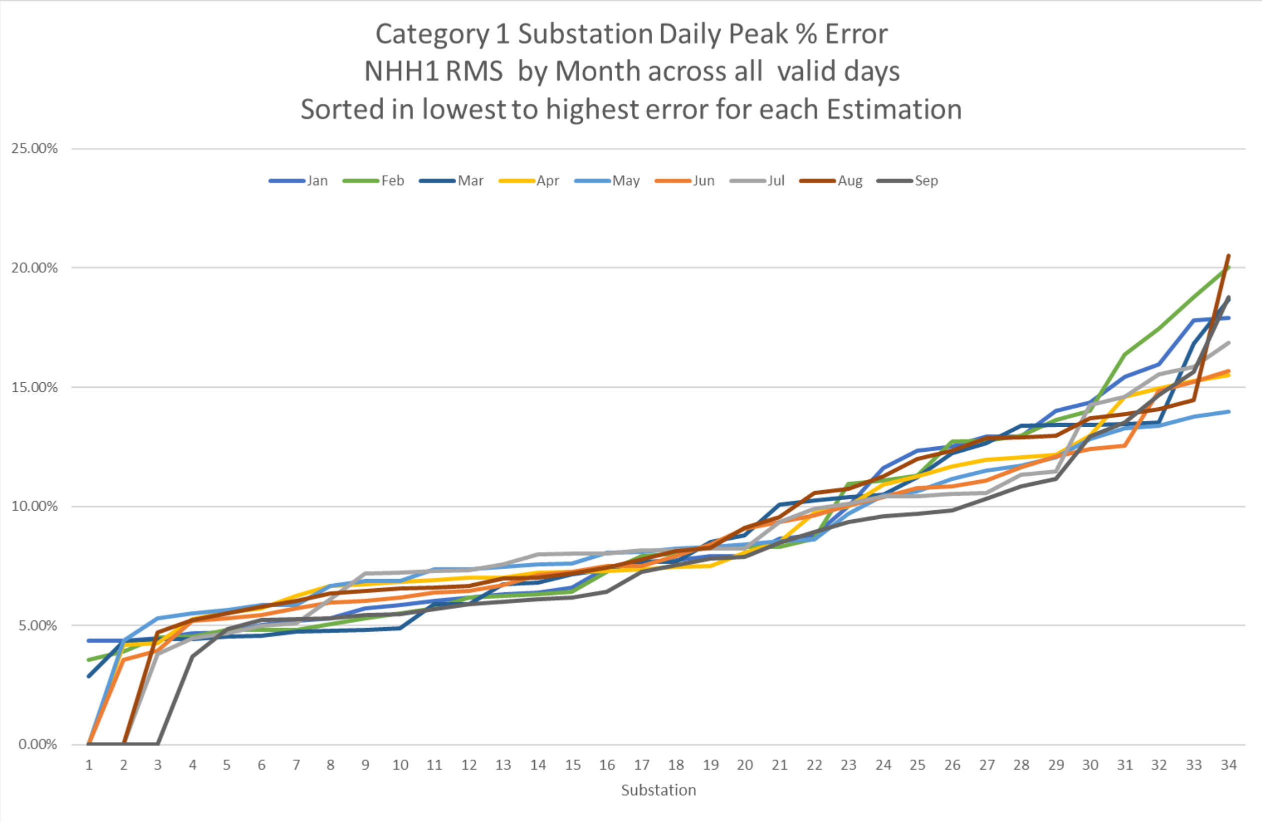


Figure 56 - Substation Daily Peaks by Month for NHH1

The data is also summarised across all substations to provide an RMS, average and the standard deviation value for each month.

Category 1 Daily Peak % error across all substations									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
RMS	9.9%	10.1%	9.6%	9.4%	9.1%	9.2%	9.5%	9.8%	8.9%
Average	9.0%	9.0%	8.7%	8.7%	8.6%	8.5%	8.6%	8.9%	7.8%
Standard Deviation	4.2%	4.6%	4.0%	3.6%	3.1%	3.5%	4.0%	4.2%	4.2%

Table 29- Substation Daily Peaks by Month Summary for NHH1

Note one substation (942856) had no valid data for 6 months, one substation (940337) had no valid data for 3 months and one substation (942651) had no valid data for 1 month. This explains the zeroes on the graph.

There are no obvious good or bad months.

4.8 Smart Meter Population

The estimated errors for each substation were compared against the smart meter population. The percentage of smart meters against all non-half hourly meters using a count of meters and an average of the kW contribution to the estimate was used.

The estimate error value used for a substation is the minimum daily average as used in section 4.4.1.

The table is shown below together with two scatter graphs based the smart meter count percentage and smart meter average kW percentage.

Note the “Daily Min kW error %” is the minimum of the average daily kW error across all estimation techniques.

Substation	Daily Min kW Error %	Cat	% SM Count	% SM kW
941916	2%	1	51%	46%
942369	2%	1	55%	50%
942681	2%	1	55%	47%
942756	3%	1	43%	41%
942037	3%	1	54%	50%
942687	3%	1	54%	50%
940337	3%	1	46%	48%
942368	3%	1	47%	47%
945113	4%	1	63%	63%
942647	4%	1	66%	49%
941988	4%	1	43%	40%
942978	4%	1	52%	46%
940458	4%	1	50%	44%
942683	4%	1	44%	43%
942651	4%	1	45%	40%
942757	5%	1	39%	26%
944922	5%	1	54%	51%
942086	5%	1	56%	54%
942661	5%	1	54%	50%
942649	5%	1	59%	46%
942840	5%	1	43%	34%
941987	5%	1	58%	58%
940717	5%	1	56%	36%
942695	5%	1	56%	61%
942856	5%	1	42%	34%
942774	5%	1	45%	37%
942878	6%	1	53%	55%
942084	7%	1	53%	48%
942855	7%	1	48%	26%
942071	7%	1	50%	47%
942839	7%	1	56%	53%
945237	8%	1	49%	36%
942755	9%	1	49%	43%
942842	10%	1	35%	32%
942680	11%	2	30%	26%
941985	12%	2	48%	37%
942979	12%	2	24%	19%
942950	12%	2	40%	40%

942693	13%	2	50%	48%
942814	13%	2	60%	32%
942843	13%	2	44%	31%
942877	13%	2	26%	19%
945487	21%	3	55%	55%
942876	22%	3	58%	53%
942367	25%	3	51%	43%

Table 30 - Substation Smart Meter Population

The data for the Category 1 substations are displayed in a graphical form below and include a linear trend line. The linear trend line shows an average increase in accuracy of from 6% to 4% for an increase of smart meter proportion from 35% to 65%. The variations of accuracy for specific substations are much greater than this improvement.

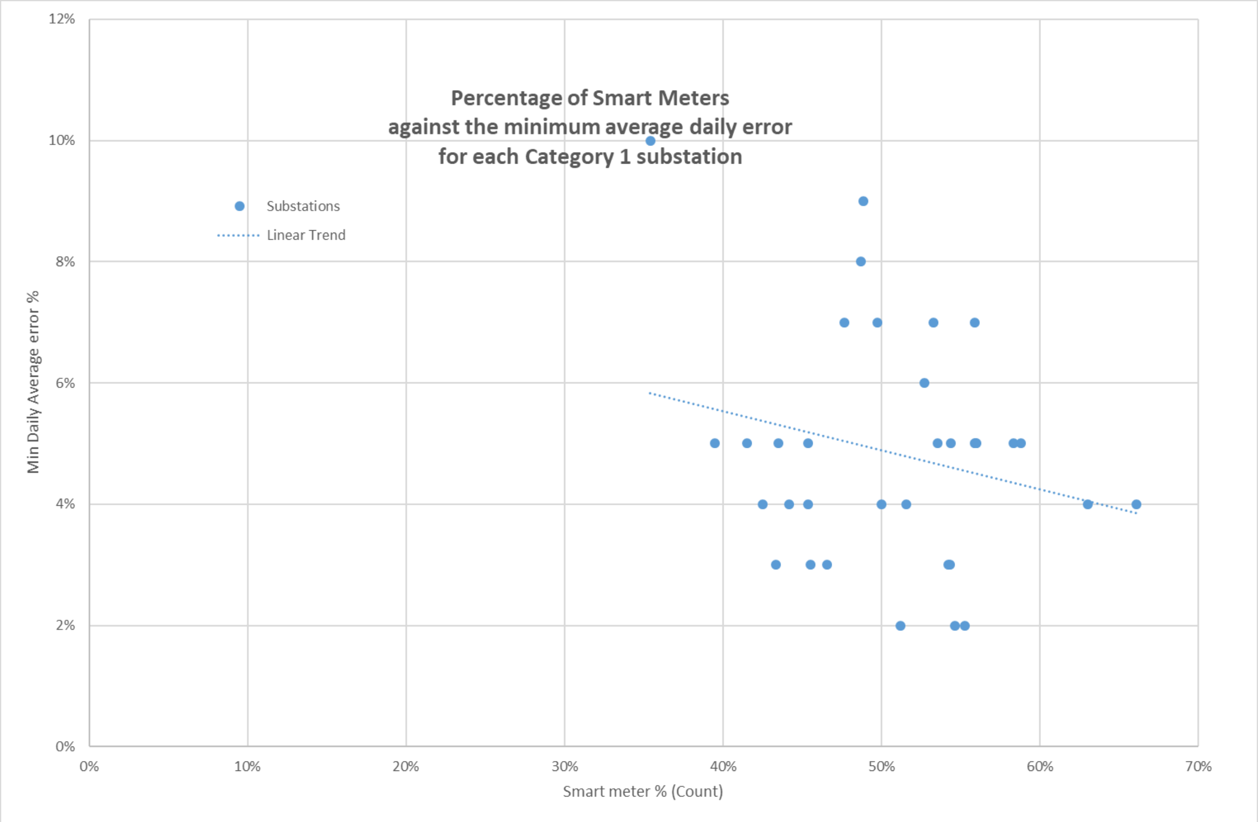


Figure 57 - Smart Meter Population against estimation error

5 Time Reference for each Dataset

Data	Time Reference
Profile Coefficients	BST
Durabill	BST
SM Alerts (Voltage/power)	BST
GridKey	UTC
TSDS	UTC
Visnet	UTC
SM other than alerts (Voltage, power, current)	UTC

Figure 58 - Time Reference for each dataset used.