Enhanced Understanding of Network Losses

Network Modelling and Initial Results

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Executive summary

This document builds the foundation, which will enable the investigation of distribution network losses under different scenarios and conditions. This is realised by modelling a real distribution network in MATPOWER (a steady-state power system simulation tool) and performing a number of simulations, which examine losses estimation accuracy, load growth, as well as the impact of customer flexibility, using data provided by Northern Powergrid. Having built this foundation, we will be able to carry out more investigation for any additional data or scenarios, when they become available.

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1 Network Modelling

A network model has been constructed for *Haxby Road T2 T3 Primary* substation, using MATPOWER [1], which is a package of MATLAB files for solving power system simulation (e.g. power flow analysis) and optimization problems. This will allow the investigation of various scenarios and conditions to be carried out very quickly, as only slight modifications to input data will be needed.

The network has 7 primary feeders and 56 load points, and it is illustrated in Figure 1. The two primary low voltage busbars are coupled to each other through two normally closed circuit breakers (A corresponds to primary transformer T3, and B to primary transformer T2).

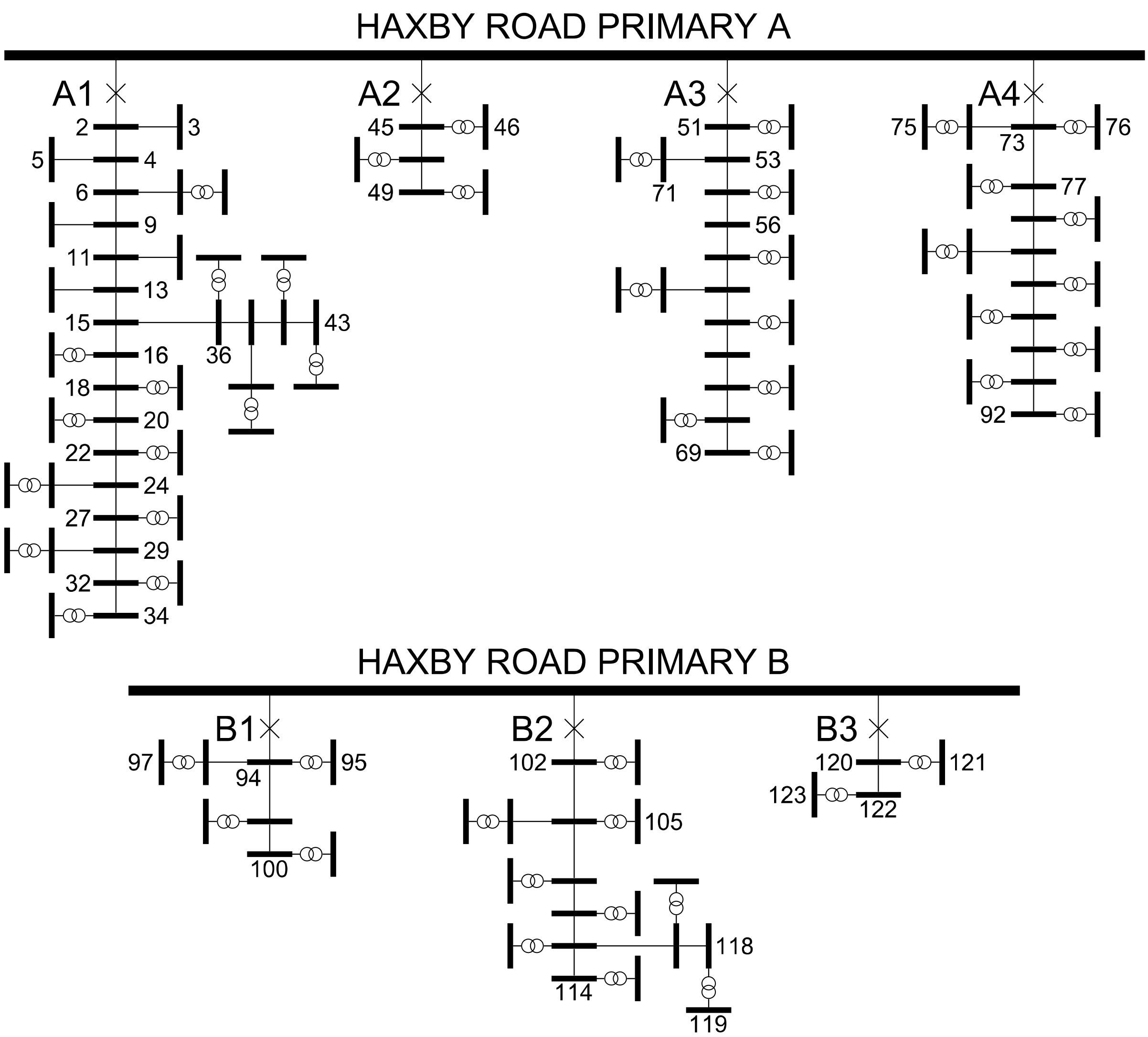

Figure 1: Network Diagram.

Table 1 shows the number of load points and the peak demand of each feeder; the peak load of each feeder is also illustrated in Figure 2.

Table 1: Feeder Data

Primary Feeder	Number of Load Points	Feeder Peak Demand (MW)
Bumper Castle	19	2.2958
Haxby Road Hospital	3	0.508
Bowling Green Court	9	1.8363
New Earswick	10	2.022
Kirkham Avenue	4	0.6959
Hambleton Terrace	9	3.4062
Fossway	2	0.8057
Total	56	11.57

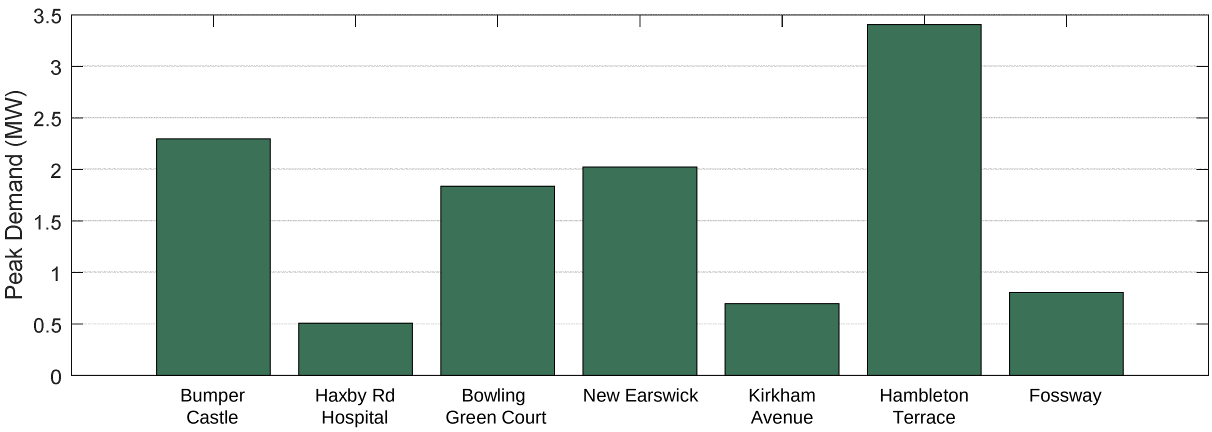

Figure 2: Peak Loading for each Feeder of the Network.

Haxby Rd 2 Deg Peak Demand Grs 2017/18 data were used for the peak demand, and *Haxby Rd 2 Deg Dec 2017 Day* data were used in order to calculate the average demand of each load point. Reactive power was calculated using a power factor of 0.98. Load point data are shown in Table A.1.

Regarding the feeder sections, the lengths shown in the network diagrams were used; in the case of missing data, 350 m sections were assumed. A Prysmian 11 kV single core Al XLPE 185 mm (IPSA2 Database – Line ID = 1020) has been used for all network branches.

Regarding distribution transformers, their rating was assumed to be the kVA demand at peak load, using a power factor of 0.8 (as a worst case – only for the transformer rating calculation). For example, for Wigginton Riding distribution transformer, peak demand was 0.0521 MW; therefore S = P/cosφ = 65 kVA. Branch data are presented in Table A.2.

If all data become available (feeder section lengths, conductor types, distribution transformer data), then the new ones will be used for the simulations.

2 Simulations

2.1 Base Case (Peak Demand 2017/18 – Constant Load)

Using the peak demand data for 2017/2018 (constant load model) presented in Table A.1, a power flow analysis was performed, which yielded the following results.

Table 2: Power Flow Results for Peak Demand (Constant Load)

Feeder Losses	0.125 MW	43.1%
Distribution Transformer Losses	0.165 MW	56.9%
Total	0.29 MW	100%

2.2 Base Case (December 2017 Load Profiles)

Haxby Rd 2 Deg Dec 2017 Day data were used for this simulation. In this case, a load profile was used for each load point; *Haxby* (bus 44) demand profile is shown in Figure 3, as an illustrative example.

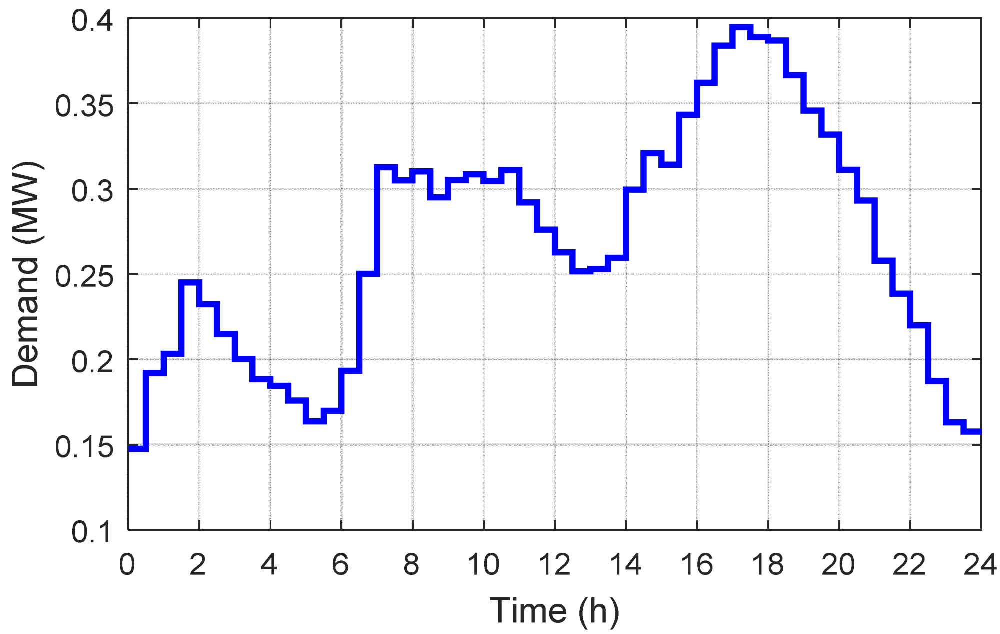

Figure 3: Haxby Load Point Demand Profile (illustrative example).

Power losses were calculated for each time step, using the half-hourly *Haxby Rd 2 Deg Dec 2017 Day* data for each load point; the results are illustrated in Figure 4.

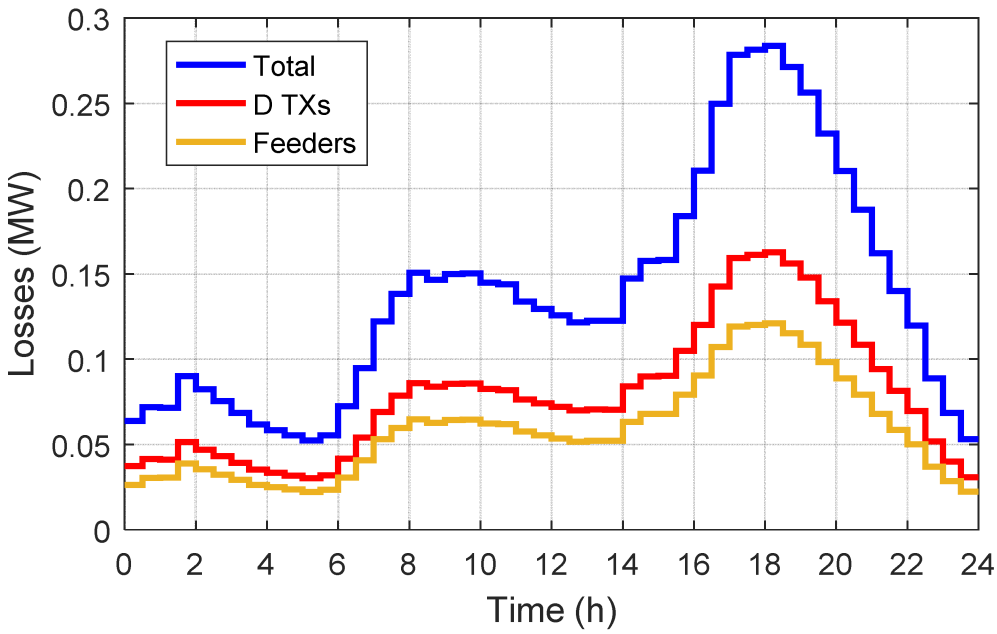

Figure 4: Hourly Variation of Losses.

Table 3 presents the corresponding overall energy losses.

Table 3: Overall Energy Losses

Feeder Losses	1.41 MWh	42.6%
Distribution Transformer Losses	1.90 MWh	57.4%
Total	3.31 MWh	100%

It is clear that distribution transformer losses account for a significant percentage of total network losses; low loss transformers can be a viable option for loss reduction of the network.

2.2.1 Losses Estimation Accuracy

So far, energy losses have been calculated using actual half-hourly demand data; this value will be compared to energy losses computed using a loss load factor (without using the load profiles). The loss load factor (LLF) is defined as:

$$LLF = k \cdot LF + (1-k) \cdot LF^2 \qquad (1)$$

where LF is the load factor, and k is a constant coefficient.

A value of 0.3 for *k* is recommended by *Buller* and *Woodrow* [2], whereas a value of 0.08 is suggested by *Gustafson et al.* [3]. Both of these will be used to compare the energy losses for a day with the value derived using the half-hourly demand data (power flow and loss calculation for each half-hourly period). Using the loss load factor method, the energy losses are calculated as follows:

$$E_{\mathrm{L}} = P_{\mathrm{L}} \cdot N_{\mathrm{hours}} \cdot LLF \tag{2}$$

where E_{L} are the energy losses for a given time period, P_{L} is the power loss calculated at the peak demand for the same period of time, and N_{hours} is the number of hours of the given time interval.

A value of 0.68 was used for the Load Factor (LF), which was calculated as the weighted mean of the individual load point LFs using their corresponding demands as weights (either average or peak) from Table A.1; N_{hours} was equal to 24, as the energy losses were calculated for a day; and P_{L} was 0.29 MW (see Table 2). The results of the comparison are presented in Table 4. Both LLF methods overestimated energy losses; however the second LLF method (k = 0.08) produced an estimate, which is very close to the value derived using the half-hourly demand data.

Table 4: Comparison of Energy Losses Calculation Methods

Losses Calculation Method	Energy Losses (MWh)	Error (%)
Half-hourly Demand Data	3.3072	0
LLF method (k = 0.3)	3.6727	11.05
LLF method (k = 0.08)	3.3395	0.98

2.3 Load Growth

Haxby Rd 2 Deg Peak Demand Grs 2017-2050 data were used in this section. The load profiles for each load point were not available; only peak demand was available in the given dataset. Therefore, the 2017 load profiles were scaled in proportion with the peak demand increase for each load point. Figure 5 shows the demand profile for *Haxby* load point in 2017 and 2050, as an illustrative example; the 2017 load profile (all half-hourly values) was multiplied by 2.076 in order to yield the 2050 load profile, as this was the peak demand increase between those years (0.8804/0.4241). The energy losses for each year between 2017 and 2050 are shown in Figure 6.

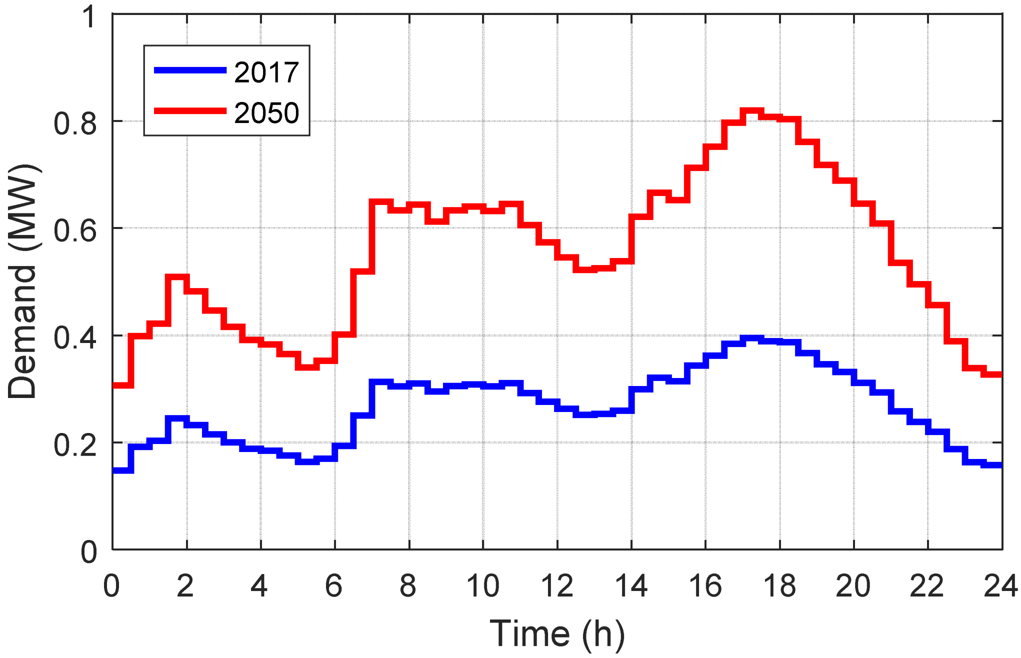

Figure 5: Haxby Load Point Demand Profile in 2017 and 2050.

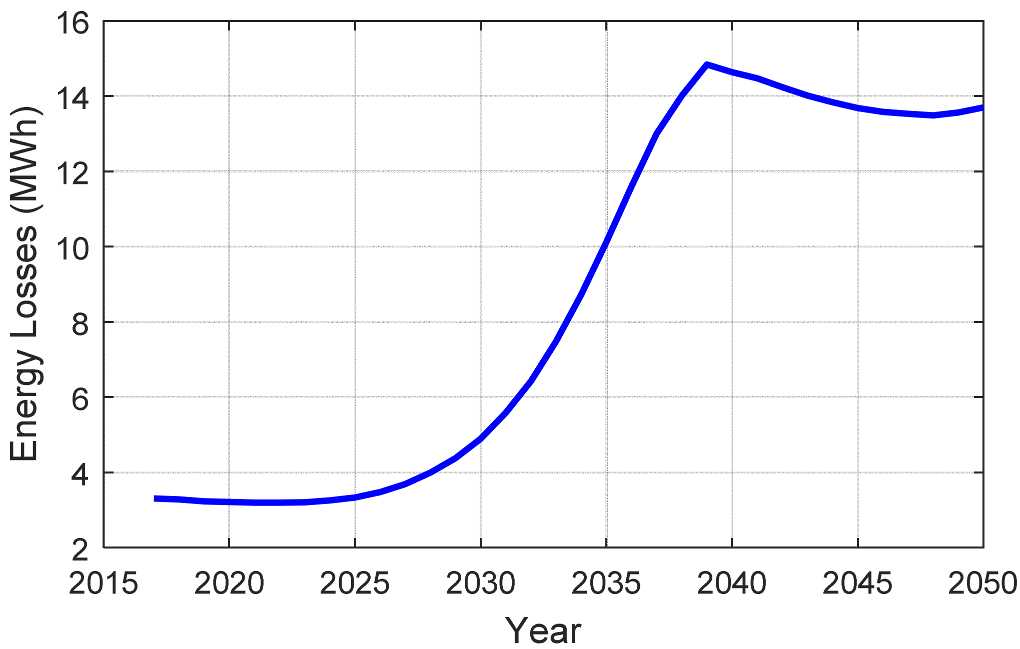

Figure 6: Energy Losses from 2017-2050.

2.4 Customer Flexibility

Haxby Rd 2 Deg Peak Dem Grs CF+ 2017-2050 were used in this section. The load profiles with customer flexibility (CF) were not available. Hence, only power losses at peak demand were calculated for each year and compared with the corresponding values without customer flexibility.

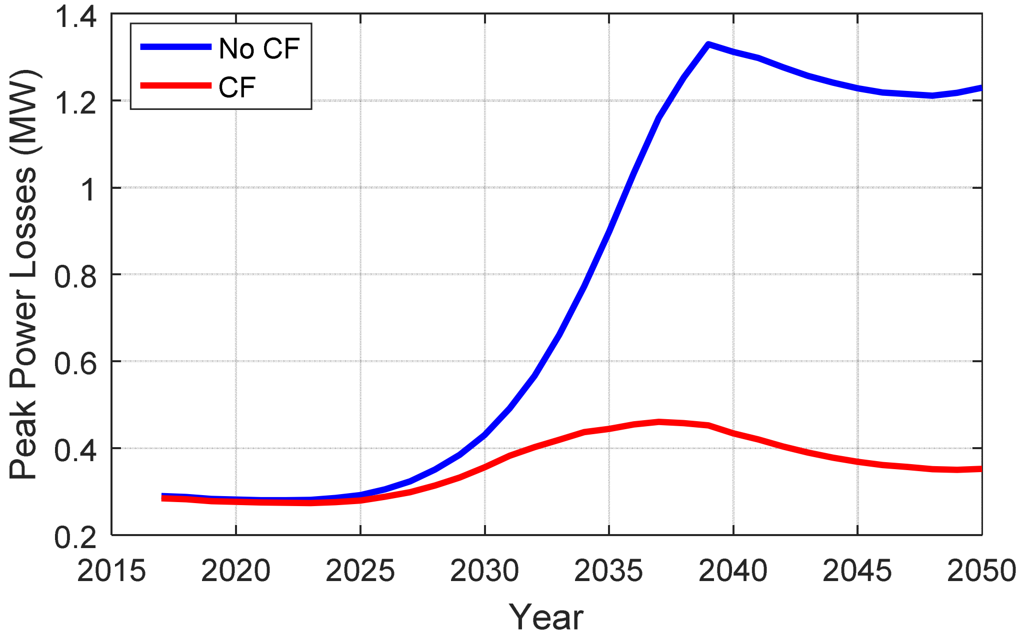

Figure 7: Power Losses Calculated at Peak Demand With and Without Customer Flexibility for each year between 2017 and 2050.

An attempt was made to produce load profiles accounting for CF. The load profiles with and without CF should have the same average value, as the energy consumption must be the same. However, the average demand for *Haxby* load point in 2050 is equal to 0.5568 (according to the scaling method used in Section 2.3), which is greater than the peak demand considering CF in 2050 (0.4562 MW). Consequently, it was not possible to create load profiles considering CF using the aforementioned scaling method.

Another scaling method [4] (to create load profiles in 2050) was also used in order to examine the possibility of deriving demand profiles accounting for CF. According to this method, the output load profile can have minimum and maximum values defined by the user. The maximum value was assumed to be equal to the peak demand value in 2050 (for *Haxby* load point), i.e. 0.8804 MW; the minimum value was considered to be equal to the minimum value of the corresponding load profile in 2017, i.e. 0.1475 MW. The latter value was chosen as an extreme case, in which the minimum demand value for the specific load point remained the same. This load profile (adjusted with the second scaling method) is shown in Figure 8; the load profile according to the first scaling method, as well as the original profile in 2017 are also shown for comparison.

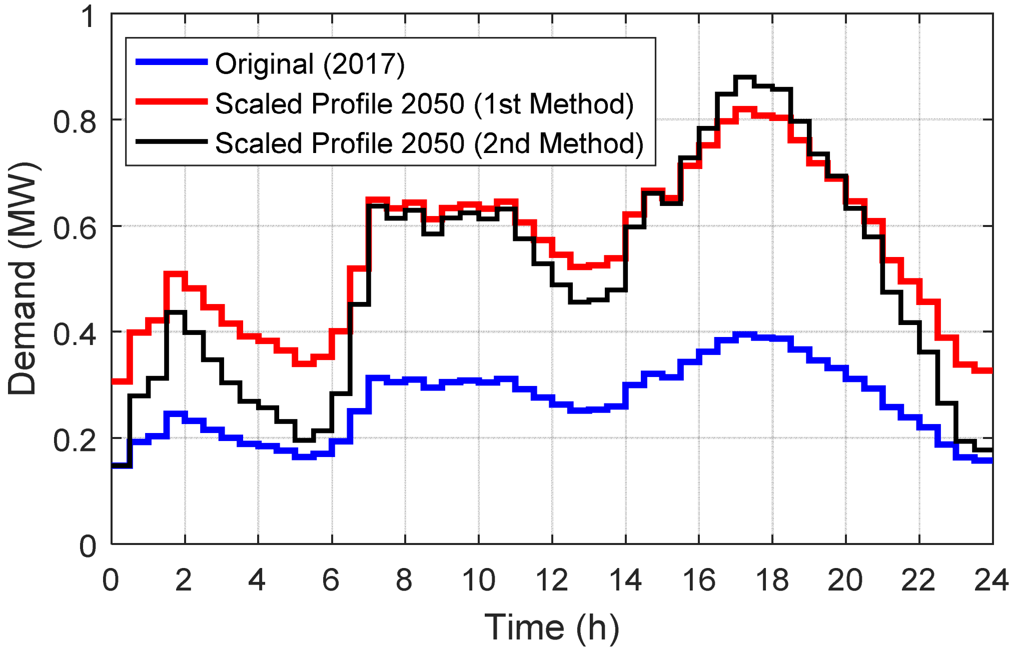

Figure 8: Comparison of Scaling Methods in order to derive Future Load Profiles.

As can be seen in Figure 8, the first scaling method multiplies all values of the original load profile by a given constant (2.076 as mentioned earlier), whereas the second one adjusts the scaling factor according to the minimum and maximum values defined by the user. In the latter case, the minimum value was the same and the maximum value was 2.23 times higher. This means that all profile values between the minimum and the maximum value are adjusted accordingly; a value closer to the minimum is scaled according to a smaller factor, and a value closer to the maximum is scaled to a greater factor, with the limits being 1 and 2.23.

The second method produced a demand profile with a lower average value than the first method, as it was expected; the mean value was 0.5052 MW and the load factor was 0.5739. However, this average value for the load profile in 2050 is still higher than the given peak demand with CF in 2050. Therefore, we were not able to produce load profiles considering CF; this fact indicates that peak demand data with CF might need to be revisited.

3 References

[1] R. D. Zimmerman and C. E. Murillo-Sánchez. (2018). *MATPOWER Website*. Available: http://www.pserc.cornell.edu/matpower/

[2] F. H. Buller and C. A. Woodrow, "Load factor–Equivalent hour values compared," *Electrical World*, pp. 59-60, 1928.

[3] M. W. Gustafson, J. S. Baylor, and S. S. Mulnix, "The equivalent hours loss factor revisited," *IEEE Trans. Power Syst.*, vol. 3, pp. 1502-1508, 1988.

[4] A. Kembhavi. (2007). *Data Scaling*. Available: https://uk.mathworks.com/matlabcentral/fileexchange/15561-data-scaling?focused=5092233&tab=function

Appendix: Network Data

Table A.1: Load Point Data

Load Point	Bus	Average Demand (MW)	Peak Demand (MW)	Load Factor
Substation Bus	1	–	–	
Bumper Castle	3	0.0144	0.0238	0.60
Kettlestring	5	0.0046	0.0077	0.60
Wigginton Riding	8	0.0309	0.0521	0.59
Wigginton Brecks	10	0.0005	0.0007	0.71
Wigginton Nurseries	12	0.0041	0.0071	0.58
Wigginton Villa	14	0.0248	0.0423	0.59
Wigginton South	17	0.0404	0.06	0.67
Wigginton Windsor	19	0.0757	0.1094	0.69
Wigginton Westfield	21	0.1154	0.1691	0.68
Wigginton Mill	23	0.0668	0.0962	0.69
Wigginton Pumps	26	0.0658	0.0969	0.68
Wigginton East	28	0.0715	0.1061	0.67
Wigginton Church	31	0.0853	0.1228	0.69
Wigginton Village	33	0.0214	0.031	0.69
Wigginton	35	0.0485	0.0713	0.68
Wigginton Greendyke	37	0.1065	0.1581	0.67
Haxby West	40	0.2767	0.4175	0.66
Haxby Headlands	42	0.2023	0.2996	0.68
Haxby	44	0.2682	0.4241	0.63
Haxby Road Hospital	46	0.0165	0.0257	0.64
Briggs Street	48	0.1038	0.1515	0.69
Feversham Crescent	50	0.2333	0.3308	0.71
Bowling Green Court	52	0.0631	0.0902	0.70
Haxby Wheatfield	55	0.2145	0.3162	0.68
Haxby Orchard	58	0.2523	0.3644	0.69
Haxby Calf	61	0.1368	0.197	0.69
Haxby South	63	0.1723	0.2678	0.64
Haxby Coppice	66	0.2121	0.3123	0.68
Haxby North	68	0.0987	0.1458	0.68
Haxby Usher	70	0.0917	0.1355	0.68
St John Sports	72	0.0042	0.0071	0.59

New Earswick West	75	0.1984	0.2862	0.69
New Earswick	76	0.1612	0.2459	0.66
New Earswick Central	78	0.2046	0.3126	0.65
New Earswick North	80	0.1907	0.2771	0.69
New Earswick Pumps	83	0.0823	0.1191	0.69
New Earswick School	85	0.0878	0.125	0.70
Joseph Rowntree School	87	0.0042	0.0071	0.59
Haxby Gates	89	0.1290	0.186	0.69
Haxby Hilbra	91	0.0950	0.1397	0.68
Haxby Eastfield	93	0.2247	0.3233	0.69
Kirkham Avenue	95	0.1222	0.1758	0.70
Byland Avenue	97	0.0996	0.1479	0.67
Bell Farm Avenue	99	0.1244	0.1835	0.68
Huntington Sessions	101	0.1294	0.1887	0.69
Hambleton Terrace	103	0.3151	0.4462	0.71
Lucas Avenue	105	0.1150	0.1686	0.68
Link Avenue	107	0.0499	0.0734	0.68
Burton Stone Lane	109	0.4673	0.672	0.70
Pembroke Street	111	0.2387	0.3434	0.70
Clifton Green	113	0.3108	0.4808	0.65
The Avenue	115	0.1653	0.2363	0.70
Grosvenor Road	117	0.5671	0.8636	0.66
Queen Annes	119	0.0865	0.1219	0.71
Fossway (YOR)	121	0.4650	0.6765	0.69
Abbotsway	123	0.0885	0.1292	0.69

Table A.2: Branch Data

Branch No.	*From* Bus	*To* Bus	Length (km)	R (pu)	X (pu)
Bumper Castle Feeder					
1	1	2	1.972	0.3439	0.1695
2	2	3	0.35	0.0610	0.0301
3	2	4	0.35	0.0610	0.0301
4	4	5	0.35	0.0610	0.0301
5	4	6	0.35	0.0610	0.0301
6	6	7	0.7	0.1221	0.0602

7	7	8	TX	26.5310	74.0631
8	6	9	0.35	0.0610	0.0301
9	9	10	0.35	0.0610	0.0301
10	9	11	0.35	0.0610	0.0301
11	11	12	0.35	0.0610	0.0301
12	11	13	0.35	0.0610	0.0301
13	13	14	0.35	0.0610	0.0301
14	13	15	0.35	0.0610	0.0301
15	15	16	0.433	0.0755	0.0372
16	16	17	TX	23.0378	64.3114
17	16	18	0.525	0.0916	0.0451
18	18	19	TX	12.6350	35.2714
19	18	20	0.256	0.0446	0.0220
20	20	21	TX	8.1743	22.8190
21	20	22	0.302	0.0527	0.0260
22	22	23	TX	14.3687	40.1111
23	22	24	0.175	0.0305	0.0150
24	24	25	0.38	0.0663	0.0327
25	25	26	TX	14.2649	39.8213
26	24	27	0.175	0.0305	0.0150
27	27	28	TX	13.0280	36.3684
28	27	29	0.175	0.0305	0.0150
29	29	30	0.38	0.0663	0.0327
30	30	31	TX	11.2562	31.4225
31	29	32	0.175	0.0305	0.0150
32	32	33	TX	44.5893	124.4738
33	32	34	0.35	0.0610	0.0301
34	34	35	TX	19.3866	54.1190
35	15	36	0.7	0.1221	0.0602
36	36	37	TX	8.7430	24.4066
37	36	38	2.369	0.4131	0.2036
38	38	39	0.175	0.0305	0.0150
39	39	40	TX	3.3108	9.2424
40	38	41	0.175	0.0305	0.0150
41	41	42	TX	4.6137	12.8795
42	41	43	0.35	0.0610	0.0301
43	43	44	TX	3.2593	9.0985

Haxby Road Hospital Feeder					
44	1	45	0.7	0.1221	0.0602
45	45	46	TX	53.7847	150.1434
46	45	47	0.322	0.0562	0.0277
47	47	48	TX	9.1239	25.4699
48	47	49	0.35	0.0610	0.0301
49	49	50	TX	4.1786	11.6647
Bowling Green Court Feeder					
50	1	51	0.35	0.0610	0.0301
51	51	52	TX	15.3245	42.7792
52	51	53	0.35	0.0610	0.0301
53	53	54	0.7	0.1221	0.0602
54	54	55	TX	4.3715	12.2033
55	54	56	0.175	0.0305	0.0150
56	56	57	0.35	0.0610	0.0301
57	57	58	TX	3.7933	10.5892
58	57	59	0.1615	0.0282	0.0139
59	59	60	0.47	0.0820	0.0404
60	60	61	TX	7.0166	19.5872
61	59	62	0.1615	0.0282	0.0139
62	62	63	TX	5.1616	14.4088
63	62	64	0.349	0.0609	0.0300
64	64	65	0.647	0.1128	0.0556
65	65	66	TX	4.4261	12.3557
66	65	67	0.668	0.1165	0.0574
67	67	68	TX	9.4806	26.4656
68	67	69	0.492	0.0858	0.0423
69	69	70	TX	10.2012	28.4774
70	53	71	0.35	0.0610	0.0301
71	71	72	TX	194.6855	543.4769
New Earswick Feeder					
72	1	73	1.884	0.3285	0.1619
73	73	74	0.89	0.1552	0.0765
74	74	75	TX	4.8297	13.4825
75	73	76	TX	5.6213	15.6921
76	73	77	0.582	0.1015	0.0500
77	77	78	TX	4.4218	12.3438

78	77	79	0.414	0.0722	0.0356
79	79	80	TX	4.9883	13.9252
80	79	81	0.395	0.0689	0.0340
81	81	82	0.35	0.0610	0.0301
82	82	83	TX	11.6059	32.3987
83	81	84	0.303	0.0528	0.0260
84	84	85	TX	11.0581	30.8695
85	84	86	0.34	0.0593	0.0292
86	86	87	TX	194.6855	543.4769
87	86	88	1.477	0.2576	0.1270
88	88	89	TX	7.4315	20.7456
89	88	90	0.496	0.0865	0.0426
90	90	91	TX	9.8945	27.6212
91	90	92	0.623	0.1086	0.0536
92	92	93	TX	4.2755	11.9353
Kirkham Avenue Feeder					
93	1	94	0.722	0.1259	0.0621
94	94	95	TX	7.8627	21.9493
95	94	96	0.323	0.0563	0.0278
96	96	97	TX	9.3460	26.0898
97	94	98	0.277	0.0483	0.0238
98	98	99	TX	7.5328	21.0283
99	98	100	0.35	0.0610	0.0301
100	100	101	TX	7.3252	20.4488
Hambleton Terrace Feeder					
101	1	102	0.469	0.0818	0.0403
102	102	103	TX	3.0979	8.6479
103	102	104	0.771	0.1345	0.0663
104	104	105	TX	8.1985	22.8866
105	104	106	0.143	0.0249	0.0123
106	106	107	TX	18.8320	52.5707
107	104	108	0.403	0.0703	0.0346
108	108	109	TX	2.0569	5.7421
109	108	110	0.389	0.0678	0.0334
110	110	111	TX	4.0252	11.2367
111	110	112	0.551	0.0961	0.0474
112	112	113	TX	2.8749	8.0256

113	112	114	0.382	0.0666	0.0328
114	114	115	TX	5.8496	16.3296
115	112	116	1.112	0.1939	0.0956
116	116	117	TX	1.6006	4.4681
117	116	118	1.11	0.1936	0.0954
118	118	119	TX	11.3394	31.6545
Fossway Feeder					
119	1	120	0.564	0.0984	0.0485
120	120	121	TX	2.0433	5.7039
121	120	122	0.728	0.1270	0.0626
122	122	123	TX	10.6987	29.8660