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energy

Marshfield Village

OpenLV Data Analysis

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OpenLV
Your local
electricity data

Contents

1. Background

The OpenLV Project trialled an open software platform in electricity substations that can monitor substation performance and electricity demand. The platform, called LV-CAP™ and developed by EA Technology, can host multiple applications in order to provide a variety of services to network operators, communities and the wider industry.

The software has been installed in 80 Low Voltage (LV) distribution substations located in Western Power Distribution’s (WPD’s) licence areas – the Midlands, the South West and South Wales. As part of the project, the Centre for Sustainable Energy (CSE) worked with seven community organisations, including Marshfield Energy Group, in order to test whether substation data could be accessed via a web app, and how it could be used to achieve local benefit. More information about the OpenLV project is available at www.openlv.net.

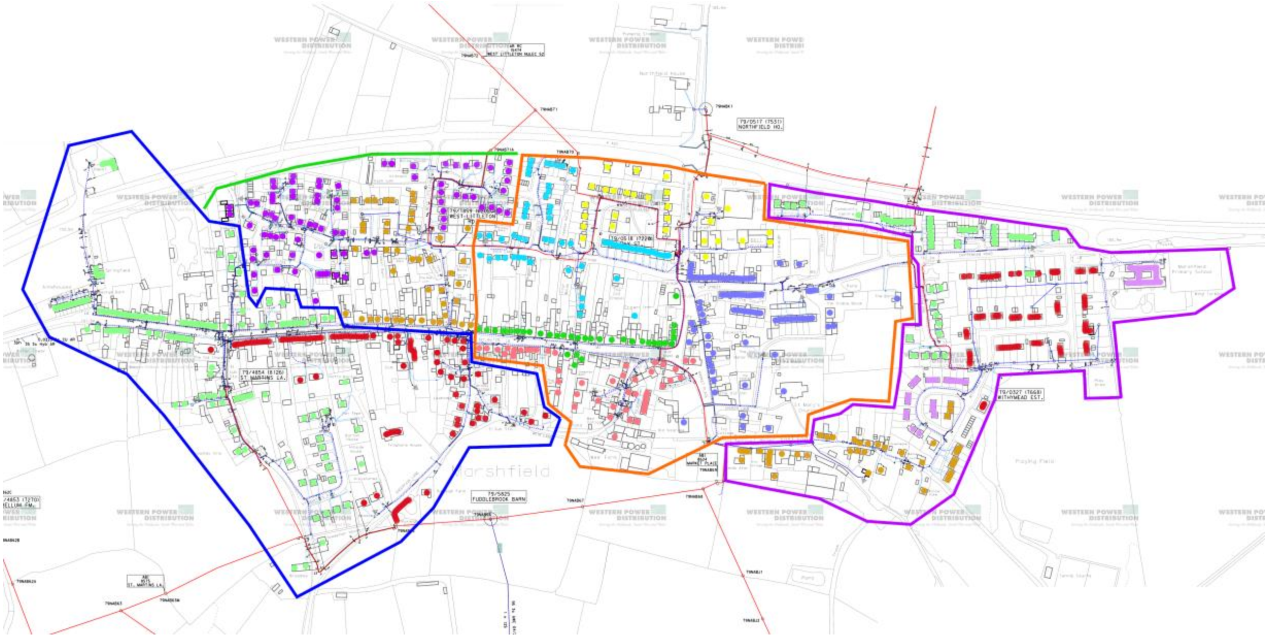
This report provides some analysis of the OpenLV electricity data collected from the four Marshfield substations since September 2018, together with some background information, in order to support the development of strategies and actions to improve the village’s sustainability.

2. Marshfield village substations and feeders

Marshfield village is served by four substations, each of which was monitored through the OpenLV project through the installation of an LV-CAP™ unit. The unit numbers referred to in this report correspond with the following substations in the village:

Unit 043: WITHYMEAD ESTATE
Unit 044: HAY STREET
Unit 069: WEST LITTLETON ROAD
Unit 070: ST MARTINS LANE

The units monitor the phases, feeders and busbars within the substation. The map below shows how buildings are connected to the substations via feeders. It is reproduced with kind permission from Western Power Distribution as part of the OpenLV project.



Marshfield Village Substation and Feeder Map

3. Potential for New Renewable Generation

Electricity: Solar PV, Wind

Using generated electricity locally, i.e. in the dwellings connected to the *same phase* as the generation, will minimise energy losses. Electricity generated and fed to one feeder on a particular phase can be used by a house connected to the same phase but on a different feeder. This is because the feeders are connected via the busbar.

Excess generation, i.e. when more electricity is generated than is used by the dwellings connected to the same phase as the generation, is seen when the OpenLV current reading *for a phase* is a negative value.

Excess generation can be used locally if there are loads which can be activated when it is detected. For example, it could be used to charge EVs, charge battery storage, to heat domestic hot water or cool freezers to a lower temperature than usual so that they run less when there is not excess generation and carbon intensity is higher.

When energy is exported, the substation transformer is designed to work most efficiently when the current across the phases is balanced. This applies to energy use as well as generation.

Minimum Currents by Phase

The table below shows the smallest average currents seen on each phase for the period Oct 2018 to Oct 2019. Spikes above 310A and below -310A have been excluded.

UNIT	PHASE	CURRENT MIN
43	1	11.83
43	2	25.16
43	3	30.99
44	1	47.45
44	2	42.63
44	3	62.48
69	1	18.0
69	2	21.13
69	3	22.49
70	1	2.22
70	2	17.16
70	3	24.6

Table 1: Minimum average currents by phase (summed across all feeders)[1]

As all these values are positive, this means that all local generation is being used within the LV network of each substation.

Minimum Currents by Feeder and Phase

The table below shows the minimum current per phase for the period Oct 2018 to Oct 2019. Spikes above 310A and below -100A have been excluded. Where these values are negative, it means that energy is being exported from a local feeder phase to either the same phase on another local feeder (or out via the transformer, however this is not the case due to the previous results).

UNIT	FEEDER	PHASE	NAME	CURRENTMIN
43	1	1	Withymead, Withymead Cres + School (L1)	-22.0
43	1	2	Withymead, Withymead Cres + School (L2)	-13.375
43	1	3	Withymead, Withymead Cres + School (L3)	-18.5
43	2	1	Withymead, Little End + Bungalows (L1)	10.375

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[1] The average current values were divided into active and reactive components using the phase angle values. These components were summed by phase across the feeders then combined again into a total current. The minimum total current values were then found and reported.

UNIT	FEEDER	PHASE	NAME	CURRENTMIN
43	2	2	Withymead, Little End + Bungalows (L2)	4.25
43	2	3	Withymead, Little End + Bungalows (L3)	-23.875
43	3	1	Withymead, Withymead + Chippenham Rd S (L1)	3.0
43	3	2	Withymead, Withymead + Chippenham Rd S (L2)	10.375
43	3	3	Withymead, Withymead + Chippenham Rd S (L3)	10.0
43	4	1	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L1)	-43.5
43	4	2	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L2)	5.25
43	4	3	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L3)	-9.125
44	1	1	Hay St, High St S + Weir Lane + Old School (L1)	4.875
44	1	2	Hay St, High St S + Weir Lane + Old School (L2)	7.25
44	1	3	Hay St, High St S + Weir Lane + Old School (L3)	3.875
44	2	1	Hay St, Hitchen + Back Lane (L1)	18.125
44	2	2	Hay St, Hitchen + Back Lane (L2)	8.875
44	2	3	Hay St, Hitchen + Back Lane (L3)	9.75
44	3	1	Hay St, Hay St + Market Pl + Church (L1)	-14.5
44	3	2	Hay St, Hay St + Market Pl + Church (L2)	-37.0
44	3	3	Hay St, Hay St + Market Pl + Church (L3)	-43.75
44	4	1	Hay St, High St N (L1)	-4.875
44	4	2	Hay St, High St N (L2)	8.125
44	4	3	Hay St, High St N (L3)	8.625
44	5	1	Hay St, Bell Sq + Fairfield (L1)	3.5
44	5	2	Hay St, Bell Sq + Fairfield (L2)	-18.5
44	5	3	Hay St, Bell Sq + Fairfield (L3)	-23.5
69	1	1	W Littleton Rd, Tanners + Hibbs (L1)	11.375
69	1	2	W Littleton Rd, Tanners + Hibbs (L2)	-21.75
69	1	3	W Littleton Rd, Tanners + Hibbs (L3)	-35.875
69	2	1	W Littleton Rd, High St N + Robbins (L1)	-23.125
69	2	2	W Littleton Rd, High St N + Robbins (L2)	12.875
69	2	3	W Littleton Rd, High St N + Robbins (L3)	16.5
70	1	1	St Martins Lane, High St + Almshouses + St Martins (L1)	-18.5

UNIT	FEEDER	PHASE	NAME	CURRENTMIN
70	1	2	St Martins Lane, High St + Almshouses + St Martins (L2)	10.125
70	1	3	St Martins Lane, High St + Almshouses + St Martins (L3)	10.25
70	2	1	St Martins Lane, High St S + Sheepfair (L1)	-41.375
70	2	2	St Martins Lane, High St S + Sheepfair (L2)	6.75
70	2	3	St Martins Lane, High St S + Sheepfair (L3)	-13.875

Table 2: Minimum currents by feeder and phase

None of the above values are near to -310A, so generation is not causing overload of the feeder cabling at the point of export from the feeder (i.e. the fuse carrier in the substation where the OpenLV measurements are taken). Electricity that is generated and used within the feeder phase is not included in these values and is not being measured.

Transformer Load

The table below shows the maximum current seen between October 2018 and October 2019 at each of the substations. Spikes above 310A and below -310A have been excluded.

UNIT	CURRENT MAX SEEN	CAPACITY	REMAINING CAPACITY
43	756.16	1.25kA	494
44	1209	3.33kA	2123
69	744.22	1.31kA	566
70	824.19	2.1kA	1276

Table 3: Maximum transformer current and remaining capacity[2]

These values show that there is available capacity for further generation. The maximum current from a 5kWp PV array will be just under 20A. In the worst case, if all this energy were exported via the transformer and not used locally, there is capacity for perhaps 200 further 5kWp PV arrays. These would need to be spread across the substations, feeders and phases.

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[2] As for Table 1, the total current per unit, phase and time period was calculated. The absolute values of these currents (as both positive and negative currents load the transformer) were used. These values were then summed to give a total current per unit and time period. Finally, the maximum of these currents per unit are reported above.

4. Sites for New Renewable Generation

Feeder Cabling Considerations

For single-phase installations, sites for new renewable installations must have capacity in the feeder phase they are connected to for the additional current. However this only becomes an issue when generation exceeds consumption and electricity is exported from the feeder to other feeders or the transformer. Looking at this a different way, assuming the consumption on a feeder phase remains as it was before the renewable installation, without the new renewables this consumption demand is met from the transformer, with the renewables, some of this same demand shifts from being met by the transformer to being met by the renewables. So the load on the feeder phase cabling remains the same. When renewable supply exceeds the demand on the feeder phase, this excess is exported from the feeder phase to the same phase on other feeders, or out via the transformer. This excess must be less than the maximum current the feeder can support, 310A.

If all renewable generation were exported from a feeder (i.e. the worst case of no consumption on feeder phase), as a 5kWp PV array will at most produce about 20A current, about 15 5kWp PV arrays could be connected. It would seem this number could be increased due to the consumption on the feeder, but in fact because this would mean exceeding the 310A cabling capacity, it is not the case. Also, as the demand is variable, it could theoretically go to zero, so the above estimated limit of 15 arrays should be used. This includes existing PV on a feeder phase.

For 3-phase installations, the generation will be split evenly across all 3 phases, so the above can be applied by taking the output and dividing by 3 to give a per-phase value, then using this for each phase in turn.

Substation Considerations

In Table 1, ‘Minimum average currents by phase (summed across all feeders)’, it is seen that currently there is no export via the transformers (when averaged over the ½ hour data collection intervals). However, some of the minimum currents are near to zero, so it is likely that only a small amount of extra generation will change this.

The table below shows the average current per transformer seen between October 2018 and October 2019 by each of the substations. Spikes above 310A and below -310A have been excluded.

UNIT	CURRENT AVG
43	306.34
44	537.31
69	277.91
70	320.88

Table 4: Average Transformer Current

As there is no export currently, this table shows the average demand. If renewable generation was added to the feeders supplied by each of these transformers with capacity equal to these average values, i.e. 15 5kWp PV arrays on substation 43, 27 PV arrays on substation 44 etc., it is possible that the generation could balance the demand.

However, this would mean the potential for no current flow and/or export current flow through the transformers and no current and/or negative flow on the high voltage side of the electricity network. Acceptance of this would need to be obtained from the network operator.

The next table (below) shows the minimum current per transformer seen between October 2018 and October 2019 by each of the substations. Spikes above 310A and below -310A have been excluded.

UNIT	CURRENT MIN
43	113.96
44	214.98
69	112.76
70	100.39

Table 5: Minimum Transformer Current

As there is no export currently, this table shows the minimum demand. If acceptable to the network operator, the transformers could be used to export generation, balanced across the phases, up to their capacity. In addition, the above minimum demands could be met from renewables. Table 19, 'Transformer Maximum Current Ratings' below gives the transformer capacities. So, for substation 43, 1250A + 114A gives a possible generation current of 1364A. Allowing 10% overhead, this is reduced to 1230A, allowing around 50 5kWp panels.

Note that exporting electricity through the substation means energy is lost due the efficiency of the transformer, and also the second transformer receiving the energy elsewhere. This is likely to be more than the energy lost due to heating of the feeder supply cables when energy is used locally. So it is always more efficient to use generated energy locally from the phase the generation is connected to. See also battery storage below.

5. Potential for Electric Vehicle (EV) charging

The table below shows the maximum current seen per feeder phase for the period Oct 2018 to Oct 2019. Spikes above 310A have been excluded.

UNIT	FEEDER	PHASE	NAME	CURRENT MAX	HEAD-ROOM	NO. 32A CHARGE POINTS
43	1	1	Withymead, Withymead Cres + School (L1)	124.125	185.875	5
43	1	2	Withymead, Withymead Cres + School (L2)	126.25	183.75	5
43	1	3	Withymead, Withymead Cres + School (L3)	118.75	191.25	5
43	2	1	Withymead, Little End + Bungalows (L1)	190.25	119.75	3
43	2	2	Withymead, Little End + Bungalows (L2)	153.75	156.25	4
43	2	3	Withymead, Little End + Bungalows (L3)	123.75	186.25	5
43	3	1	Withymead, Withymead + Chippenham Rd S (L1)	129.25	180.75	5
43	3	2	Withymead, Withymead + Chippenham Rd S (L2)	172.125	137.875	3
43	3	3	Withymead, Withymead + Chippenham Rd S (L3)	178.125	131.875	3
43	4	1	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L1)	164.0	146.0	4
43	4	2	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L2)	223.5	86.5	2
43	4	3	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre (L3)	174.625	135.375	3
44	1	1	Hay St, High St S + Weir Lane + Old School (L1)	140.25	169.75	4
44	1	2	Hay St, High St S + Weir Lane + Old School (L2)	164.0	146.0	4
44	1	3	Hay St, High St S + Weir Lane + Old School (L3)	214.0	96.0	2
44	2	1	Hay St, Hitchen + Back Lane (L1)	218.25	91.75	2
44	2	2	Hay St, Hitchen + Back Lane (L2)	227.375	82.625	2
44	2	3	Hay St, Hitchen + Back Lane (L3)	210.125	99.875	2

44	3	1	Hay St, Hay St + Market Pl + Church (L1)	157.625	152.375	4
44	3	2	Hay St, Hay St + Market Pl + Church (L2)	141.875	168.125	4
44	3	3	Hay St, Hay St + Market Pl + Church (L3)	201.625	108.375	3
44	4	1	Hay St, High St N (L1)	232.625	77.375	2
44	4	2	Hay St, High St N (L2)	229.125	80.875	2
44	4	3	Hay St, High St N (L3)	203.75	106.25	2
44	5	1	Hay St, Bell Sq + Fairfield (L1)	94.875	215.125	6
44	5	2	Hay St, Bell Sq + Fairfield (L2)	144.875	165.125	4
44	5	3	Hay St, Bell Sq + Fairfield (L3)	131.75	178.25	5
69	1	1	W Littleton Rd, Tanners + Hibbs (L1)	194.625	115.375	3
69	1	2	W Littleton Rd, Tanners + Hibbs (L2)	204.125	105.875	2
69	1	3	W Littleton Rd, Tanners + Hibbs (L3)	233.125	76.875	2
69	2	1	W Littleton Rd, High St N + Robbins (L1)	158.625	151.375	4
69	2	2	W Littleton Rd, High St N + Robbins (L2)	194.125	115.875	3
69	2	3	W Littleton Rd, High St N + Robbins (L3)	206.25	103.75	2
70	1	1	St Martins Lane, High St + Almshouses + St Martins (L1)	308.75	1.25	0
70	1	2	St Martins Lane, High St + Almshouses + St Martins (L2)	233.5	76.5	2
70	1	3	St Martins Lane, High St + Almshouses + St Martins (L3)	282.125	27.875	0
70	2	1	St Martins Lane, High St S + Sheepfair (L1)	131.625	178.375	5
70	2	2	St Martins Lane, High St S + Sheepfair (L2)	179.5	130.5	3
70	2	3	St Martins Lane, High St S + Sheepfair (L3)	217.25	92.75	2

Table 6: Maximum current and headroom by feeder and phase

The headroom column in the table above contains 310A minus the maximum current. This is the capacity available for single phase charge points (i.e. the medium speed chargers rated up to 32A).

The table below shows the maximum load seen per feeder for the period Oct 2018 to Oct 2019. This is recorded as the highest phase current x3. Spikes above 310A have been excluded.

UNIT	FEEDER	FEEDER NAME	CURRENT MAX BAL	HEADROOM BAL	NO. 32A CHARGE POINTS
43	1	Withymead, Withymead Cres + School	378.75	551.25	15
43	2	Withymead, Little End + Bungalows	570.75	359.25	10
43	3	Withymead, Withymead + Chippenham Rd S	534.375	395.625	11
43	4	Withymead, Withymead W + Chippenham Rd N + Barn End + Com Centre	670.5	259.5	7
44	1	Hay St, High St S + Weir Lane + Old School	642.0	288.0	8
44	2	Hay St, Hitchen + Back Lane	682.125	247.875	6
44	3	Hay St, Hay St + Market Pl + Church	604.875	325.125	9
44	4	Hay St, High St N	697.875	232.125	6
44	5	Hay St, Bell Sq + Fairfield	434.625	495.375	13
69	1	W Littleton Rd, Tanners + Hibbs	699.375	230.625	6
69	2	W Littleton Rd, High St N + Robbins	618.75	311.25	8
70	1	St Martins Lane, High St + Almshouses + St Martins	926.25	3.75	0
70	2	St Martins Lane, High St S + Sheepfair	651.75	278.25	7

Table 7: Maximum current and headroom by feeder

The headroom column is 310A x 3 minus the maximum load per feeder for each feeder. These values should be used when considering fast charger installations, which are 3-phase devices.

The above limits are for charge points where the user expects charging to occur on demand when they plug in. If the times when plugged-in EVs charge were controlled, these times could be linked to when other EVs have finished charging, when renewable energy is being generated and when substation load is low. This has the potential of substantially increasing the possible number of chargepoints.

6. Potential for Battery Storage

Battery storage needs to be considered carefully. There are various reasons for using battery storage, for example:

1) Reducing Carbon

2) Reducing Cost

3) Providing Grid Balancing Services

Reducing Carbon

While the renewable energy production is carbon neutral, if some of this energy is lost before it can be used these losses need to be made up from the grid, which is not carbon neutral.

When renewable generation is used locally, i.e. by demand connected to the same phase (but not necessary the same feeder) from a substation, efficiency losses are through heating of the feeder cabling etc. When renewable energy is exported through the transformer and imported again elsewhere, there are greater efficiency losses in transforming the electricity to higher voltage and back to low voltage. When electrical energy is converted to chemical energy in a battery storage system, there are also greater energy losses.

Taking these points into account, from a carbon perspective it is therefore best to use generation to directly service demand connected to the same phase. If this is not possible, the efficiency of the distribution network transformers and cabling needs to be compared to the efficiency of local battery storage. Note also that battery storage will become less efficient with age and real world efficiency could be worse than optimum performance values quoted in literature.

Reducing Cost

Battery storage could be charged from cheap overnight electricity and/or from (local) Solar PV during the day and then used to reduce electricity demand from the grid when costs are higher. For the cheap overnight electricity case, again, the efficiency of the battery storage needs to be considered. Will the electricity from battery storage charged overnight from cheap rate electricity be less expensive per kWh than the high rate electricity?

Providing Grid Balancing Services

At times there is more generation than demand, at other times there are peaks in demand that need to be met by running extra power stations. The intensity of these peaks and troughs can be reduced via battery storage where the charging and discharging is controlled via wider electricity demand. This can be done via a time of use tariff (e.g. Agile Octopus) such that when costs are low the battery charges and when they are high it discharges. This will also reduce electricity costs.

Where can battery storage be connected in Marshfield?

Battery storage can be thought of as a combination of the previous two sections: When it is charging it is like a EV connected to the supply, when it is discharging it is like a generation source connected to the supply.

Battery storage input and output current values should therefore be included in the totals for EV charge points and renewable generation respectively and considered in conjunction with these.

7. Tariff Selection

The table below gives the average kWh per feeder phase and the total MWh across all the feeder phases for each ½ hour of the day over the year Oct 2018 to Oct 2019. Spikes above or below 37.2kWh have been excluded.

Time of day	Avg (kWh)	Total (MWh)
00:00	2.96	40.87
00:30	2.77	38.28
01:00	2.92	40.39
01:30	2.79	38.58
02:00	2.71	37.45
02:30	2.75	37.96
03:00	2.71	37.44
03:30	2.62	36.23
04:00	2.57	35.62
04:30	2.66	36.71
05:00	2.72	37.67
05:30	2.96	40.88
06:00	3.25	44.97
06:30	3.70	51.18
07:00	4.09	56.55
07:30	4.47	61.82
08:00	4.51	62.46
08:30	4.58	63.33
09:00	4.55	62.96
09:30	4.46	61.75

Time of day	Avg (kWh)	Total (MWh)
10:00	4.39	60.68
10:30	4.38	60.50
11:00	4.34	59.96
11:30	4.39	60.57
12:00	4.37	60.28
12:30	4.41	60.92
13:00	4.31	59.53
13:30	4.21	58.20
14:00	4.14	57.33
14:30	4.09	56.63
15:00	4.15	57.48
15:30	4.35	60.10
16:00	4.63	63.96
16:30	5.10	70.53
17:00	5.64	78.05
17:30	6.19	85.66
18:00	6.48	89.67
18:30	6.63	91.67
19:00	6.59	91.22
19:30	6.44	89.12
20:00	6.19	85.66
20:30	5.92	81.88
21:00	5.57	77.05
21:30	5.22	72.26
22:00	4.71	65.08
22:30	4.18	57.88
23:00	3.68	50.91
23:30	3.26	45.07

Table 8: Active energy use

Standard, Economy-7 and Time-of-use tariff comparison

In the table below, the Standard and Economy-7 tariffs are taken from government "Standard Assessment Procedure" for houses[3]. The time of use example rates are for the Agile Octopus tariff for 8th Nov 2019. The number of houses in Marshfield value used is 741, taken from the 2011 census[4].

Time of day	Total (MWh)	Standard	rate	Economy	7 rate	Time of use	example rate
		£/kWh	Total cost	£/kWh	Total cost	£/kWh	Total cost
00:00	40.87	£0.1319	£5,390.38	£0.0550	£2,247.69	£0.0861	£3,518.66
00:30	38.28	£0.1319	£5,048.84	£0.0550	£2,105.28	£0.0903	£3,456.49
01:00	40.39	£0.1319	£5,326.97	£0.0550	£2,221.25	£0.0798	£3,222.84
01:30	38.58	£0.1319	£5,088.60	£0.0550	£2,121.86	£0.0735	£2,835.57
02:00	37.45	£0.1319	£4,939.86	£0.0550	£2,059.84	£0.0731	£2,737.71
02:30	37.96	£0.1319	£5,007.46	£0.0550	£2,088.02	£0.0693	£2,630.91
03:00	37.44	£0.1319	£4,937.95	£0.0550	£2,059.04	£0.0672	£2,515.77
03:30	36.23	£0.1319	£4,778.15	£0.0550	£1,992.40	£0.0504	£1,825.77
04:00	35.62	£0.1319	£4,697.81	£0.0550	£1,958.91	£0.0693	£2,468.22
04:30	36.71	£0.1319	£4,841.87	£0.0550	£2,018.98	£0.0586	£2,151.13
05:00	37.67	£0.1319	£4,968.35	£0.0550	£2,071.71	£0.0756	£2,847.67
05:30	40.88	£0.1319	£5,391.57	£0.0550	£2,248.19	£0.0743	£3,037.10
06:00	44.97	£0.1319	£5,931.11	£0.0550	£2,473.17	£0.0874	£3,930.09
06:30	51.18	£0.1319	£6,750.96	£0.0550	£2,815.03	£0.0798	£4,084.35
07:00	56.55	£0.1319	£7,459.13	£0.1529	£8,646.71	£0.0903	£5,106.59
07:30	61.82	£0.1319	£8,153.68	£0.1529	£9,451.84	£0.1071	£6,620.62
08:00	62.46	£0.1319	£8,239.08	£0.1529	£9,550.84	£0.0966	£6,034.08
08:30	63.33	£0.1319	£8,352.59	£0.1529	£9,682.42	£0.0903	£5,718.26
09:00	62.96	£0.1319	£8,304.11	£0.1529	£9,626.21	£0.0899	£5,659.89
09:30	61.75	£0.1319	£8,144.32	£0.1529	£9,440.99	£0.0840	£5,186.68
10:00	60.68	£0.1319	£8,003.62	£0.1529	£9,277.88	£0.0878	£5,327.65
10:30	60.50	£0.1319	£7,980.32	£0.1529	£9,250.88	£0.0832	£5,033.83
11:00	59.96	£0.1319	£7,908.25	£0.1529	£9,167.34	£0.0792	£4,748.55
11:30	60.57	£0.1319	£7,988.62	£0.1529	£9,260.50	£0.0792	£4,796.80
12:00	60.28	£0.1319	£7,950.58	£0.1529	£9,216.40	£0.0817	£4,924.66
12:30	60.92	£0.1319	£8,035.61	£0.1529	£9,314.98	£0.0792	£4,825.02

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[3] https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf (see p225)

[4] https://hosted.southglos.gov.uk/census/parishes/Parishes-E04001061.pdf

Time of day	Total (MWh)	Standard	rate	Economy	7 rate	Time of use	example rate
		£/kWh	Total cost	£/kWh	Total cost	£/kWh	Total cost
13:00	59.53	£0.1319	£7,852.06	£0.1529	£9,102.19	£0.0813	£4,839.82
13:30	58.20	£0.1319	£7,676.91	£0.1529	£8,899.16	£0.0813	£4,731.86
14:00	57.33	£0.1319	£7,562.21	£0.1529	£8,766.20	£0.0861	£4,936.36
14:30	56.63	£0.1319	£7,469.78	£0.1529	£8,659.05	£0.0857	£4,853.37
15:00	57.48	£0.1319	£7,581.03	£0.1529	£8,788.02	£0.0817	£4,695.75
15:30	60.10	£0.1319	£7,927.53	£0.1529	£9,189.69	£0.1006	£6,046.32
16:00	63.96	£0.1319	£8,435.67	£0.1529	£9,778.73	£0.2140	£13,686.38
16:30	70.53	£0.1319	£9,302.55	£0.1529	£10,783.62	£0.2392	£16,870.12
17:00	78.05	£0.1319	£10,294.97	£0.1529	£11,934.05	£0.2426	£18,935.26
17:30	85.66	£0.1319	£11,298.97	£0.1529	£13,097.90	£0.2455	£21,030.31
18:00	89.67	£0.1319	£11,827.20	£0.1529	£13,710.23	£0.2426	£21,753.44
18:30	91.67	£0.1319	£12,091.19	£0.1529	£14,016.24	£0.2308	£21,157.29
19:00	91.22	£0.1319	£12,032.24	£0.1529	£13,947.92	£0.0930	£8,483.69
19:30	89.12	£0.1319	£11,754.78	£0.1529	£13,626.27	£0.0899	£8,011.78
20:00	85.66	£0.1319	£11,298.76	£0.1529	£13,097.65	£0.0966	£8,274.90
20:30	81.88	£0.1319	£10,800.62	£0.1529	£12,520.20	£0.0861	£7,050.29
21:00	77.05	£0.1319	£10,163.30	£0.1529	£11,781.42	£0.0981	£7,558.91
21:30	72.26	£0.1319	£9,530.81	£0.1529	£11,048.23	£0.0861	£6,221.40
22:00	65.08	£0.1319	£8,584.07	£0.1529	£9,950.75	£0.0863	£5,616.41
22:30	57.88	£0.1319	£7,634.88	£0.1529	£8,850.44	£0.0729	£4,219.73
23:00	50.91	£0.1319	£6,714.41	£0.1529	£7,783.42	£0.0819	£4,169.15
23:30	45.07	£0.1319	£5,944.51	£0.1529	£6,890.94	£0.0714	£3,217.88
Total electricity cost			£373,398.22		£378,590.67		£311,605.35
Per house			£503.91		£510.92		£420.52
Standing charge per house			£54.00		£78.00		£73.00
Total per house			**£557.91**		**£588.92**		**£493.52**

Table 9: Tariff Comparison

The above table shows the (average) cost per house for three tariffs based on the average profile of energy use across Marshfield.

The Economy 7 and time of use tariffs could be decreased if electricity consumption were moved from high cost to low cost times of day. This could be done manually or automatically via smart appliance controls.

8. Substation Health Warnings

Temperature

The table below contains the minimum, average and maximum transformer temperatures for each of the substations over the year Oct 2018 to Oct 2019.

UNIT	TEMPMIN	TEMPAVG	TEMPMAX
43	-3.0	20.5	38.9
44	1.7	18.1	44.7
69	-5.0	21.2	38.5
70	3.9	16.4	36.8

Table 10: Transformer temperatures

The “hot-spot” temperature within these transformers can generally be taken as being 20 degrees above the oil or casing temperatures above. Hot spot temperatures 90 degrees or above are cause for concern. The highest hot spot temperature for the above substations is 64.7 degrees, indicating that there is no cause for concern for these transformers based on temperature.

Max Current

From Table 3 Maximum transformer current and remaining capacity it can be seen that the maximum transformer loads are well within their capacities. So there is also no cause for concern for these transformers based on load.

9. A Scenario To Reduce Marshfield's Electricity Generation CO_2 Emissions

This scenario demonstrates how PV installation could be maximised, then determines how much EV charging demand could be met, within the existing electricity infrastructure.

Part 1: Additional PV Installations

An initial idea of the number of additional solar PV installations that could be connected can be calculated by first looking at the transformer capacities. Referring to Table 5 and Table 19, allowing a 10% overhead, and assuming 5kWp PV installations, the capacity per substation is:

UNIT	**CURRENT MIN**	**Transformer Max Current**	**Available current**	**Less 10% overhead**	**Number 5kWp (typically 20 panel) PV installations (max 20A per installation)**
43	113.96	1.25kA	1363	1227	61
44	214.98	3.33kA	3545	3190	159
69	112.76	1.31kA	1423	1281	64
70	100.39	2.1kA	2200	1980	99

Table 11: Capacity for further PV per Substation

Splitting this out per feeder and phase gives the following installations per feeder phase:

UNIT	***Number of feeders***	***Number of feeder phases***	***5kWp Installations per feeder phase***
43	*4*	*12*	*5*
44	*5*	*15*	*10*
69	*2*	*6*	*10*
70	*2*	*6*	*16*

Table 12: Capacity for further PV per feeder phase based on substation capacity

Next the maximum current per feeder phase needs to be considered. The feeder phases are fused at (at least) 310A, so, using a 10% overhead, the max renewable generation would be 280A. (This would need to be agreed with the network operator). Existing renewable installations also need to be considered.

Below the "remaining capacity" limits the current through the fuse to the rated maximum (-10%) but also limits the current flowing in the feeder cables to this same amount.

UNIT	***Feeder***	***Existing Renewables (kWp)***	***(Peak) Current (A) - Existing Renewables***	***Remaining capacity (A)***	***Number of further 5kWp Installations per feeder phase***
43	*1*	*12 (turbine)*	*50*	*230*	*3*
	2	*4*	*17*	*263*	*4*
	3	*0*	*0*	*280*	*4*
	4	*11.5*	*48*	*232*	*3*
44	*1*	*0*	*0*	*280*	*4*
	2	*0*	*0*	*280*	*4*
	3	*24*	*100*	*180*	*3*
	4	*0*	*0*	*280*	*4*
	5	*9.5*	*40*	*240*	*4*
69	*1*	*19*	*79*	*201*	*3*
	2	*3*	*13*	*267*	*4*
70	*1*	*14.25*	*59*	*221*	*3*
	2	*15.5*	*65*	*215*	*3*

Table 13: Capacity for further PV per feeder phase based on feeder phase capacity

Important note: The above assumes the existing PV is spread evenly across the phases. If this is not the case, the above approach should be re-done per feeder phase as the available capacity for new PV will not be split evenly between the feeder phases.

Finally the number of installations per feeder phase limits set by the transformer and by the feeder need to be compared and the smallest number taken for each feeder. In this case, the values in Table 13 are all less than Table 12, so the values in Table 13 apply.

The data shows it is possible to install a further 138 5kWp PV installations.

Part 2: EV Charging Possibilities

In Marshfield 741 houses were recorded in the 2011 census[5]. If these houses have on average 2 cars each and drive on average 10,000 miles per year per car, there are:

741 x 2 x 10000 = 14.82 million miles travelled in cars by residents of Marshfield per year.

From the UK Government car fuel economy site[6], the 2018 Nissan Leaf has an efficiency of 3.0 miles/kWh. Therefore, to power 14.82 million miles,

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[5] https://hosted.southglos.gov.uk/census/parishes/Parishes-E04001061.pdf

[6] https://carfueldata.vehicle-certification-agency.gov.uk/search-new-or-used-cars.aspx

14.82 x 10^6 / 3.0 = 4.94 GWh / year

which means an additional demand from Marshfield of 564kW on average over the whole year.

564kW = 2.35kA at 240v, or approx. 30% of the total capacity of the existing substations.

This doesn't allow for fast-charging and assumes the charging load can be automatically managed so that it is spread evenly throughout the day.

Automatically managed demand means that the number of charge points installed matches the number of EVs, but that load on the network is controlled by limiting the number of charge points actively charging at a given time or by limiting their charge rate. In general this means that a vehicle needs to be plugged in for longer for it to be charged. Acceptance of this could be encouraged through a graded charging scheme, e.g. from very expensive for fast charge, to expensive for standard charge, though to mid-priced for a 12 hour charge time to low-priced for a 24 hour charge time.

To see if there is capacity to charge this number of vehicles with automatically managed demand, the feeder headroom tables, Table 6 and Table 7 are used. The extra load per substation is then confirmed to be within capacity.

If the charge points can be allocated per feeder and phase, Table 6 and Table 4 can be used.

UNIT	TOTAL FEEDER HEADROOM	TRANSFORMER CURRENT AVG	TRANSFORMER HEADROOM	HEADROOM
43	1841.5	306.34	1.25	943.66
44	1937.875	537.31	3.33	1937.875
69	669.125	277.91	1.31	669.125
70	507.25	320.88	2.1	507.25
			TOTAL:	4057.91

Table 14: Combined Feeder and Transformer Headroom (per-feeder phase case)

The total of the "headroom" column is 4.1kA. This means that, if the charge points were spread across the feeders and phases as per Table 6, the miles travelled per year by Marshfield residents could be in EVs charged from the Marshfield electricity supply *and* leave capacity for approx 87 fast-chargers (again, spread carefully across the feeders).

If the charge points can only be spread evenly across the phases, Table 7 and Table 4 should be used.

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[7] Allowing 200A per fast charger.

UNIT	TOTAL FEEDER HEADROOM	TRANSFORMER CURRENT AVG	TRANSFORMER HEADROOM	HEADROOM
43	1565.625	306.34	943.66	943.66
44	1588.5	537.31	2792.69	1588.5
69	541.875	277.91	1032.09	541.875
70	282	320.88	1779.12	282
			TOTAL:	3356.035

Table 15: Combined Feeder and Transformer Headroom (per-feeder case)

This allows for an extra 3.3 kA of consumption, which is still more than the average requirement, so, some fast chargers would still be possible. The above two tables also show that the available transformer capacity for substations 44, 69 and 70 is higher than the feeder available capacity. *Therefore it is possible to add a further feeder to these substations specifically to supply EV charge points.*

Without automatically managed demand, the number of charge points is limited by the network capacity. The tables below show this, again based on tables Table 6 and Table 7.

UNIT	FEEDER	PHASE	HEADROOM	HEADROOM LESS 10%	NO. FAST CHARGERS	NO. STD. CHARGERS
43	1	1	185.875	167.2875		3
43	1	2	183.75	165.375		3
43	1	3	191.25	172.125		3
43	2	1	119.75	107.775		1
43	2	2	156.25	140.625		2
43	2	3	186.25	167.625		3
43	3	1	180.75	162.675		2
43	3	2	137.875	124.0875		1
43	3	3	131.875	118.6875		1
43	4	1	146	131.4		4
43	4	2	86.5	77.85		2
43	4	3	135.375	121.8375		3
44	1	1	169.75	152.775		4
44	1	2	146	131.4		4
44	1	3	96	86.4		2
44	2	1	91.75	82.575		2
44	2	2	82.625	74.3625		2
44	2	3	99.875	89.8875		2

UNIT	FEEDER	PHASE	HEADROOM	HEADROOM LESS 10%	NO. FAST CHARGERS	NO. STD. CHARGERS
44	3	1	152.375	137.1375		4
44	3	2	168.125	151.3125		4
44	3	3	108.375	97.5375		3
44	4	1	77.375	69.6375		2
44	4	2	80.875	72.7875		2
44	4	3	106.25	95.625		2
44	5	1	215.125	193.6125	1	3
44	5	2	165.125	148.6125		2
44	5	3	178.25	160.425		2
69	1	1	115.375	103.8375		3
69	1	2	105.875	95.2875		2
69	1	3	76.875	69.1875		2
69	2	1	151.375	136.2375		4
69	2	2	115.875	104.2875		3
69	2	3	103.75	93.375		2
70	1	1	1.25	1.125		0
70	1	2	76.5	68.85		2
70	1	3	27.875	25.0875		0
70	2	1	178.375	160.5375		5
70	2	2	130.5	117.45		3
70	2	3	92.75	83.475		2
				TOTALS:	1	96

Table 16: Fast and Standard Chargers Per Feeder Phase (no automated demand management)[8]

UNIT	FEEDER	HEADROOM BAL	HEADROOM LESS 10%	NO. FAST CHARGERS	NO. STD. CHARGERS
43	1	551.25	496.125		9
43	2	359.25	323.325		3
43	3	395.625	356.0625		4

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[8] Fast charger demand used is 67A per phase; Standard charger demand used is 32A single phase. Fast chargers added where phase with lowest headroom is more than 100A except for substation 43 as there is no transformer capacity. For substation 43 the headroom for the first 3 feeders is reduced by 200A each to limit substation load.

UNIT	FEEDER	HEADROOM BAL	HEADROOM LESS 10%	NO. FAST CHARGERS	NO. STD. CHARGERS
43	4	259.5	233.55		7
44	1	288	259.2		8
44	2	247.875	223.0875		6
44	3	325.125	292.6125		9
44	4	232.125	208.9125		6
44	5	495.375	445.8375	1	7
69	1	230.625	207.5625		6
69	2	311.25	280.125		8
70	1	3.75	3.375		0
70	2	278.25	250.425		7
			TOTALS:	1	80

Table 17: Fast and Standard Chargers Per Feeder (no automated demand management)[9]

From these tables it is clear that without managing demand to be within capacity, the number of charge points possible will limit the possibilities for EV use.

Potential for Zero Carbon Driving

If all the Solar PV from “Part 1: Additional PV Installations” (above) were installed, then, combined with the existing Solar PV there would be approx. 790kWp of solar PV in the village. Using a typical average southern England output of of 1050kWh/kWp10, this could yield 830MWh per year. On average, this is around 95kW, 395A at 240v or about 16% of the EV charging demand.

Potential for Zero Carbon E-Bike Cycling

Reviewing a small number of e-bikes where an energy use specification is given, this is in the range 20 to 40 Wh/mile. This is equivalent to 25 to 50 miles/kWh, so, compared to a car, an e-bike is around 12 times more efficient. Therefore, the proposed Solar PV installations would, taken over the full year, be capable of completely powering e-bikes used instead of EVs.

The web based ‘Propensity for cycling tool[11]’ suggests that there is a fair potential for cycling in Marshfield, based on the census data about who commutes to where.

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[9] Fast charger demand used is 200A 3-phase; Standard charger demand used is 32A single phase. Fast chargers added where feeder with headroom is more than 300A except for substation 43 as there is no transformer capacity. For substation 43 the headroom for the first 3 feeders is reduced by 200A each to limit substation load.

[10] From https://www.energysavingtrust.org.uk/renewable-energy/electricity/solar-panels – a 4kWp installation in southern England yields around 4,200 kWh / year.

[11] https://pct.bike/

10. Foundation Data and Assumptions

These estimations are based on the following information and assumptions:

1) Substation transformer ratings:

Substation Name	**Transformer Rating**
Withymead Estate	300 kVA
Hay Street	800 kVA
West Littleton Road	315 kVA
St Martins Lane	500 kVA

Table 18: Transformer Ratings

2) Nominal voltage, phase to neutral, of 240V

3) From the above, the maximum currents per transformer are:

Substation Name	**Transformer Max Current**
Withymead Estate (43)	1.25kA
Hay Street (44)	3.33kA
West Littleton Road (69)	1.31kA
St Martins Lane (70)	2.1kA

Table 19: Transformer Maximum Current Ratings

4) Feeder per-phase maximum capacities of 310A (the size of the smallest typical fuse)

Each feeder consists of 3 phases each with a capacity of 310A, so the total feeder capacity is 930A split evenly across the phases.

It is possible for the load on a feeder to be split unevenly across the phases. This could mean that one phase has capacity to supply, for example, EV or battery storage charging but another does not. Therefore the analysis was by feeder and phase. However, it is difficult to find out which phase a particular property is connected to, so, either this needs to be determined (see below) or the most heavily loaded phase used when deciding if there is capacity.

Also, the total of the feeder phase maximum current values will always be higher than the substation maximum current value. This is because it is not expected that all feeders will be fully loaded at the same time.

11. Connection of Renewable Generation

Renewable generation can be connected to the grid in various ways.

1) Small (typically house) scale generation. For example, solar PV on a house roof with a size typically up to 5 kWp. This is usually connected to the single phase of a feeder that supplies the house with electricity. Balancing between phases is simply due to the randomness of which houses have solar PV and which phase they are connected to.

2) Larger scale generation. For example, solar PV on the roof of a supermarket, or a wind turbine. This could be connected to a 3 phase supply thereby balancing the energy fed to each phase and allowing larger capacity generation without compromising phase balancing.

3) Large scale generation. For example a solar PV farm. This would not be connected to the LV network. It would be connected at a higher voltage level within the network, probably 11kV. Therefore, issues around the capacity of LV substations do not apply.

12. Which phase am I on?

To use the above suggestions effectively the phase a house is connected to often needs to be determined. As it is unlikely the grid operator will be happy to trace the underground cables or switch off each phase in turn so that the houses that loose power can be seen, an alternative method is needed.

Where houses are supplied via overhead cables on poles it is often clear which houses are connected to the same phase. There are (usually) 4 cables on the overhead poles which correspond to the 3 phases and neutral. Each house should be connected to neutral and one phase. This will allow finding out which houses are on the same phase, but not which phase those houses are on.

Where houses are supplied by underground cable the situation is more difficult. The grid operator always wants to balance demand across the 3 phases so, often, houses will be connected sequentially to each phase in turn. This could be along each side of a street, or both sides. Alternatively, where there are 3 streets of similar size, each could be on a different phase. Investigation using the method below is needed to determine how houses have been connected.

To find which phase a house is on the OpenLV current data can be used. The background current on each feeder is reasonably stable between midnight and 4am and between 9am and 3pm (see Figure 1 below). If a load which draws more than, say, 20% of this background current is connected for the full time during of one of the ½ hour OpenLV measurement periods this will be seen in the data. For example, if the background load on each phase is around 40A, running an electric shower or connecting an electric convector heater (and making sure it is producing heat, i.e. the thermostat turned to max) for a full ½ hour between either on the hour and half past or half past and on the hour, will be seen in the OpenLV current data. Plotting a per-phase current graph for the feeder the house is connected to covering the time the shower was running or heater was connected will show an increase in current on just the phase supplying that house.

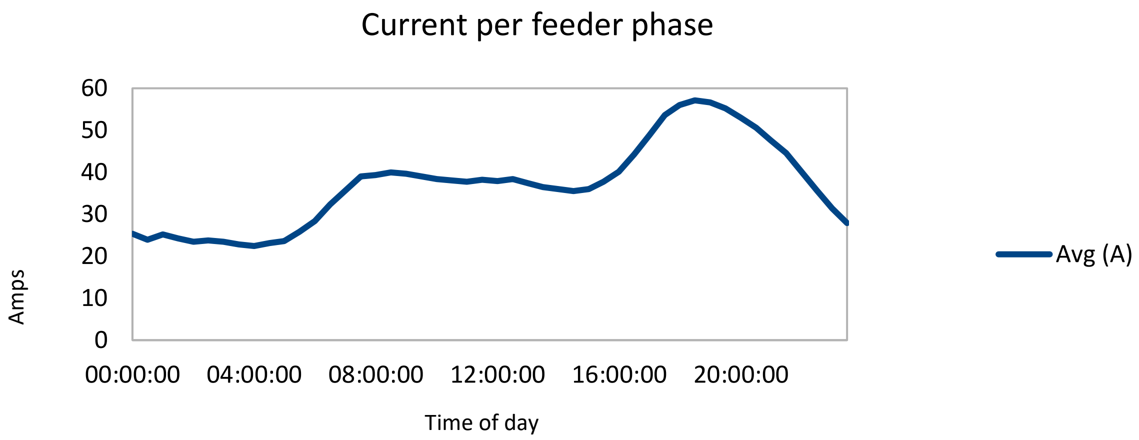

Figure 1: Current per feeder phase

13. Case studies

Renewable energy

- A range of resources and case studies can be seen in the 'Renewable Energy' section of CSE's local energy advice website: www.cse.org.uk/local-energy/resources
- Lockleaze Energy Partnership are developing a community solar model that enables the local community to own and operate a 1 megawatt cluster of solar panels on 300 roofs in Bristol to create a new business model for post-subsidy rooftop solar. http://lowcarbongordano.co.uk/

Electric vehicles

- Electric Corby have been working for several years on expanding charging infrastructure as a community scale demonstrator location for future low carbon living. www.electriccorby.co.uk/projects/electric-vehicle-charging-infrastructure
- Electric nation explores a range of issues and opportunities brought by the growth in EV ownership. www.electricnation.org.uk
- Nadder Community Energy (Wiltshire) are setting up a community electric car club in a rural community. www.nadderce.org.uk
- Brighton Energy are exploring opportunities for using locally generated solar power could supply electric community transport and public EV charge points. www.brightonenergy.org.uk
- Riding sunbeams are developing technical solutions to make it possible to use solar PV to power rail travel www.ridingsunbeams.org

Battery storage

- Bath and West Community Energy's Solar Streets project includes the installation and monitoring of solar PV and battery storage in 16 houses as part of a community based initiative. https://www.bwce.coop/solar-streets
- Meadows Ozone Energy Services have trialled installation of community batteries as part of the SENSIBLE project (Storage Enabled Sustainable Energy for Buildings and Communities) http://www.mozes.co.uk/current_projects_sensible.html
- Energise Barnsley's battery storage project looked at potential for battery storage, with and without solar PV at household level, to mitigate the need for network reinforcement. http://www.energisebarnsley.co.uk/battery-storage

Time of use tariffs

- Agile Octopus (tariff data also available via the OpenLV community web app) https://octopus.energy/agile/
- Energy Local https://energylocal.org.uk
- Low Carbon Hub have a pilot project trialling meter aggregation and local balancing of electricity at street level which, combined with smart metering, will enable time of use as well as local generation tariffs, and visualisations of energy demand. www.lowcarbonhub.org/news/2019/40m-project-leo-launches

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