UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

Transport Research Group

Volume 3: Results Analysis for

Sequence Sets 3, 4 and 5

version 1.1 including corrections

for the EngD Thesis:

Modelling and Managing

The Charging of Massed Electric Vehicles on

Constrained Residential Power Networks

(UK / EU style LV systems)

by

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Vol 3 Chapter 1: Introduction

This document presents and analyses data from the author's FPB EV on UK LV Network simulator, described in his EngD Thesis. The reader is advised to have the Thesis to hand. Note that the EVs modelled are "mid-Century types" and in general impose less load then today's EVs, for a variety of reasons set out in the Thesis (see Thesis Appendix A: FPB Design Assumptions).

Results are précised. Key outputs (images, spreadsheets) are available in the repository.

V3-1.1 Overview of Result Volumes and Sequences

Sequences are grouped into Sets, which share a theme in common.

Volume 1	~	Main Thesis
Volume 2	Seq Set 0	plain residential loads, no EVs
	Seq Set 1	all Dumb EVs on networks (no control)
	Seq Set 2	Dumb EVs controlled by clamps (charge point disconnectors) *inc. DRFFR, Static Batteries, Aggregator Control*
Volume 3	Seq Set 3	Dumb EVs with clamps plus local V2G support *inc. V2G and Aggregator Control*
	Seq Set 4	Dumb EVs with Aggregator control (Time of Use services)
	Seq Set 5	MCS controlling mixes of Smart EVs, no clamps *inc. amended Residential Loads, DRFFR, V2G, Static Batteries*
Volume 4	Seq Set 6	MCS controlling mixes of Smart EVs, with clamps *inc. DRFFR, V2G, Static Batteries*

Data for Sequence Set 7 is available, but not written up.

Each Set consist of 1 or more Sequences. A Sequence is a matrix of simulations which sample outcomes on a common sub-theme. Each Sequence has output from 16,000 simulated weeks, organised in a matrix of 32 plies each of 500 simulations. Each ply has a set "miles per day" (mpd) and Number of EVs (N EV) per 100 houses. 1 EV per house is termed "parity". Note that some UK regions average 1.32 cars per house.

The 4 mpd ranges are: 19, 27, 38 and 49, with 8 N EV ranges of 10, 20, 40, 60, 80, 100, 120, 140 EVs per 100 houses; see Figure 1-1 below. Each ply cell has the same mpd and N EV, with (repeatable) randomised trip timings for the trips driven within the cell.

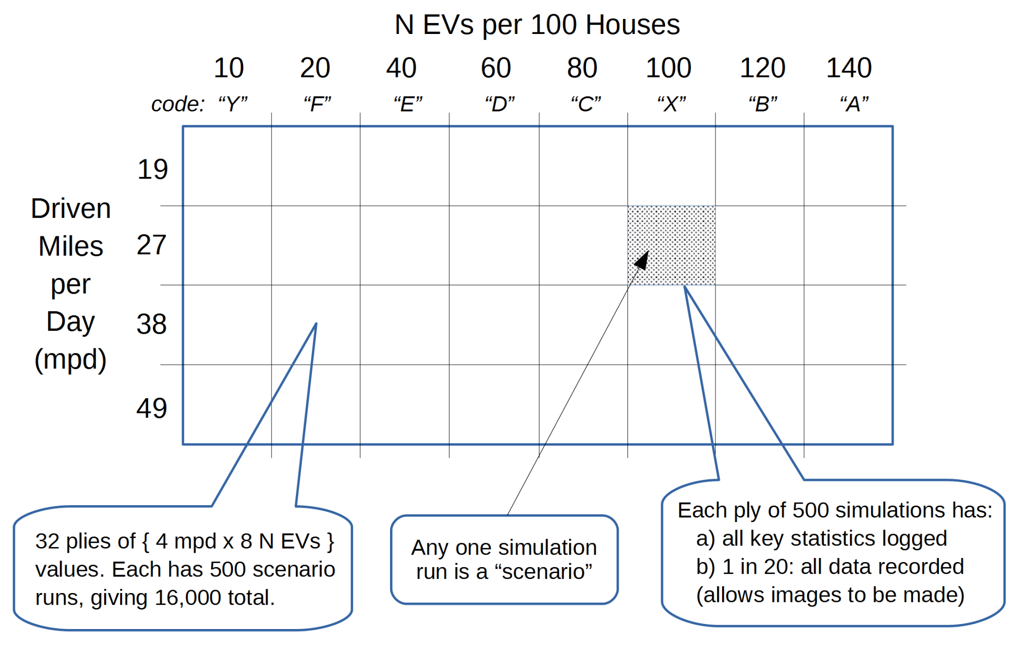

Figure 1-1: Allocation of 16,000 simulations in a Sequence

Simulations execute in batches of N EV value i.e. **columns** e.g. for 80 EVs: 500 simulated weeks at 19 mpd, repeated for 27 mpd, 38 mpd and 47 mpd. Each column takes c. 8 hours to execute but can be parallelised; the whole Sequence taking c. 1 day to run.

This method is adopted over "projection for year X" as:

- EV uptake is unknown
- EV uptake may not be linear
- EV uptake will likely occur in affluent areas first i.e. be patchy, and
- driven miles effects duration of charging, lifting probability of co-incident charging.

Simulation tools used include:

- the standard FPB suite
- the intermediate post processing suite
- a range of spreadsheets such as the Meta spreadsheets and
- any other analysis tools or plots of interest, as deemed fit and
- Excel and LibreOffice (an office suite like MS Office) are also used.

In this simulator, EVs always depart no matter what; a rule to enforce trip timing fidelity. Without this, simulations cannot be compared as trips will diverge over time.

On parking at home, the EV asks the driver “When do you need to depart, and about how far will you drive tomorrow?” The answer is assumed to include to the end of next day. This is converted to a SOC level plus margin, giving a charging target for departure time.

V3-1.2 The Data Repository Files

The Data Repository holds sample results and post-processed data, structured as follows:

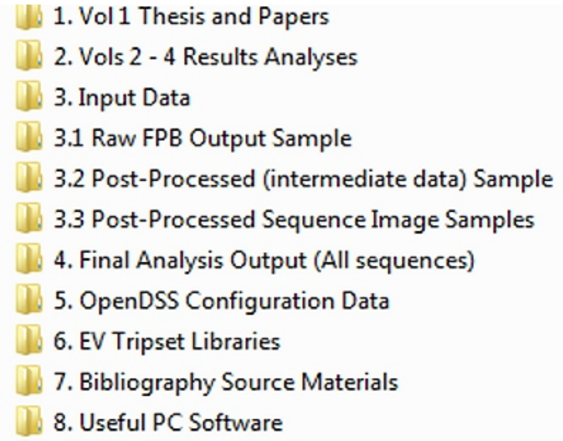

Figure 1-2: Results Data Repository Structure

As data sizes are large, samples only are included for most files e.g. Folder 3.3 contains folders of images for each Sequence’s group 8 only. However Folder 4 contains a complete set of final results spreadsheets, in Meta_Seq zip files (e.g. Meta_Set_1.1.3.zip), each containing:

- contact sheets for end of week result summaries: Home charge kWh, AFH kWh, Dispatch (V2G) kWh, EV mpd, EV N plugins, EV SOC
- MetaChart spreadsheet version 2.3 for <sequence code, mpd> e.g. MetaChart2.3_Seq_1.1.3_19mpd.ods: plots EV and network characteristics by N EV, for that mpd driven
- **MetaMeta2.3_Seq_N.N.N.n e.g. MetaMeta2.3_Seq_1.1.3.xlsx** (final results)
- Meta_mpd.xlsx e.g. Meta_49.xlsx. summarises N EV results for driven mpd
- a README file with contents and Errata.

The key output is the final results MetaMeta file, shown above in bold.

V3-1.3 Common Terms

Table 1: Common Terms

Parameter	***Example***	***Units***	***Definition***
98%tile	34.0	kW	kW at 98% position for a ranked list of per-period max kW (per ph). As there are 10 of these per hour, then 2% of the week has higher kW loads i.e. 3.36 hours exceed this value.
AEVA 2018			Autonomous and Electric Vehicles Act 2018, by the UK Parliament
AFH			Away from Home; usually refers to EV charging e.g. “17 kWh AFH”
clamp, clamped			Operation of a DNO controlled switch inside each EVSE (implied by AEVA 2018 Section 15 to be present) so to disconnect the EV from supply.
DR / FFR or DRFFR or DSR			Demand Reduction / Fast Frequency Response
dumb EV	EV which does not communicate with a local controller (although might with a remote Aggregator)		
kWh^{b}	“battery view” of energy, not the same as network due to EV losses		
loss %	0.6	%	proportion of supplied energy dissipated as Joule heating of network elements. This ignores any harmonics. Real-world values may be higher
Max_kW	45.1	kW	the highest seen phase kW (all phases)
Mean Headroom	86.8	kW	the mean of { maximum further load the feeder cable might supply, across all phases }. Value is 3 x average of (cable ph. headroom - per period peak kW) for a week, averaged over n simulations
Mean OOB	0.193	#	a measure of Out of Balance (feeder phase balance). Lower is better. The value is the average of, per period: (peak ph kW - instantaneous average kW) / instantaneous average kW

Net Losses	53	kWh	lost energy as heat from transformer and cabling
SV1G EV	Smart EV; dialogues with a local controller and will accept charging control instructions. Cannot dispatch power to grid		
Total kWh Delivered	8,178.5	kWh	energy delivered to customers in a week (including EVs connected at home)
Unutilised kWh	12,452	kWh	integral over week of: (hi_limit kW - per period peak load kW), summed over phases
V2G EV	A SV1G EV which can dispatch power to grid		

V3-1.4 Power Ratings (kW, kVA)

There are several kW ratings. These are:

- hi_limit: the deemed phase supply limit (in kW) from the substation to LV loads (the value is set as 1.25 * transformer rating / 3 -2kW)
- cable limit: the continuous rating of the feeder cable (also has emergency maximum) - often higher than the transformer rating. In industry rated as Amps per phase, but converted to kW for this work
- transformer rating in kVA: the 24hr continuous duty capability of the transformer. Transformers can exceed this for brief periods but will suffer (ageing accelerates).

In the UK, the following is usual: Transformer continuous rating < hi_limit < cable limit.

Traditionally, fuses are rated in the hi_limit to cable limit band. Fuses have non-linear operation curves and in practice will blow in milliseconds at x 10.0 of rating, but may need hours to blow at x 1.1. Electronic fuses have characteristics set by program.

FPB assumes EV inverters exhibit:

- 200 W leading reactive plus nominal kW load, and
- are constant kW loads (i.e. vary current draw inversely with local volts changes).

The reactive component of residential load is found using pf = 0.95. Harmonics are another serious issue but ignored as out of scope (see Thesis).

V3-1.5 Energy and Losses (kWh, kWh^b)

Energy units are qualified by context. When referring to energy,

- kWh refers to the LV energy transfer (sometimes called the “socket view”) and
- kWh**b** is the “battery view” i.e. the kWh energy experience of the EV battery, as
  - EV charging incurs c. 16% loss i.e. battery kWh**b** is c. 0.84 of socket kWh, and
  - V2G dispatch has similar losses, so socket received kWh is about 0.84 of kWh**b**;
- losses are modelled and applied within the FPB (adjustable for each EV marque).

The default view for EVs is the battery (kWh**b**) view. If an EV log is asked about energy, it relates the battery view not the socket view (as might a car report re fuel tank levels).

The losses used in FPB are soft-set and are “slightly better” than measured in **(Shirazi, 2017)**. This is judged reasonable given that, over the next several decades, some small improvements may be expected. Conversely, the EVs are given slightly degraded consumption rates on the grounds that, as EVs become normalised, manufacturers will cease to compete on range and add luxury i.e. “bells and whistles” which act to impair consumption; these toys consume energy.

V3-1.6 Broaching and Blowing Fuses

It has been difficult to get a clear answer as to when substations are damaged or their fuses blow. What is known is that stress ages assets faster; if raised ageing is acceptable the substation is given stronger fuses. However a consistent method needed to be found. This has been termed “broaching” i.e. an assessment of when assets (transformer and cables) exceed rating sufficiently as to cause damage. This relates to a nominal installation, not a specific built set.

Fuses blow immediately on high current peaks, or over an extended period of sustained modest overload. Thus the broached assessor code has two rules:

- to flag “broached” instantaneously if the load peaks above a trigger value, being 1.4 x the feeder cable rating, and
- to tolerate no more than two sequential periods of modest overload.

A “modest” overload is defined as load between 1.5 x transformer continuous rating and the cable rating trigger value. Two sequential overloads are allowed; a third broaches and corresponds to at least 18 minutes of continuous x 1.5 overload. If this overload persists, asset damage / accelerated ageing will be caused. These rules form a repeatable method to detect a need to protect assets.

Note It is industry standard to run substation transformers in “distribution rating”, being 1.25 x continuous rating, which assumes any peaks are brief. The high-limit line is:

$$hi\,limit = minimum\left(1.25\,x\,transformer\ rating/3,\ cable\ kW\ rating\ per\ phase\right) - 2\,kW \qquad (1)$$

An example from a successful Seq_1.1.1 19mpd, 20 EV run, from group 14 (.pdfs may be zoomed; the underlying images are at 400 dpi):

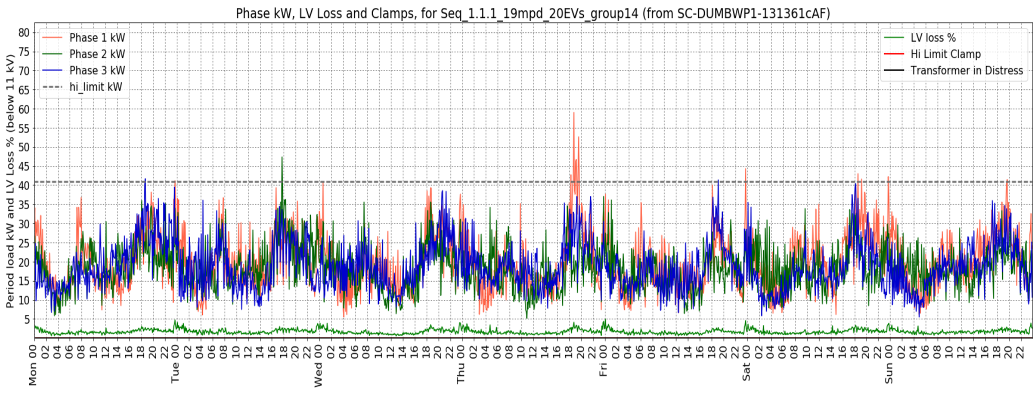

Figure 1-3: Seq_1.1.1 19mpd 20 EVs - passed, no broaches found

To the eye this is near identical to the baseline feeder load. Next is a “fail” plot:

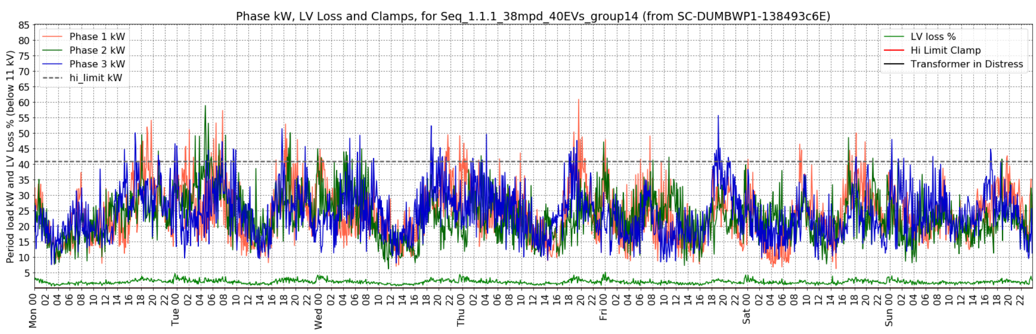

Figure 1-4: Seq_1.1.1 38mpd 40 EVs - failed with broaches

Why does Figure 1-3 not blow, given the peaks exceed the hi_limit line? Peaks were insufficient to trigger a cable fuse and infrequent enough to not exceed 2 periods at x1.5 transformer rating. Figure 1-4 failed with too many modest overloads.

The End of Week charts are described in the Thesis Appendix-D.

V3-1.7 Sequence Coding

Sequence codes e.g. Seq_1.1.2.2 (as Seq_N1.N2.N3.n4) consist of:

N1	Sequence Set number for a theme e.g. Seq_0: Residential Loads (no EVs)
N2	Scenario code (arbitrary, often ascending)
N3	Network ADMD Strength (1: Weak 1.2 kW, 2: Typical 1.5 kW, 3: Strong 2 kW, 4: NPG 3.7 kW, 5: Strong Plus 2.5 kW, 6: Strong Xtra Plus 3 kW)
n4	optional variant on an existing scenario; numbers are arbitrary

thus Seq_2.1.2.8 means: Set 2, scenario 1, network type 2, variant code 8.

V3-1.8 Common Methodology

From each of the 4 mpd x 8 N EV group of 500 simulations, data for 1 in 20 are plotted (called groups 1 .. 25, each having plots for Feeder, EV CICD and EV Arrive/Depart). Across simulation Sequences, EVs of a shared group number travel the same trips.

V3-1.9 Plots of Simulation Results

.pdf images are high resolution so may be zoomed. The plots shown in a triple-set are:

- **Figure 1-5**: Feeder kW load plot. This shows:
  - three phase feeder load (as seen at the feeder connection to busbars), with
  - **losses line** (green) and distress and clamping flags (black, red) by the axis
  - this plot modulates the MCS hi_limit kW setpoint for both DR and FFR
- **Figure 1-6**: a CICD plot (Charging-Idle-Clamped-Disconnected), which shows a count of activity of at-home EVs, as:
  - **green**: charging,
  - **red**: clamped (EVSE disconnected),
  - **cream**: waiting to charge,
  - **grey**: finished charging waiting to depart,
  - **blue**: V2G dispatch,
  - **clear**: parked at home not connected
  - **black** number at home (clear gap below black implies: not connected), plus
  - **wandering green line**, showing the 25th percentile EV's SOC;
- **Figure 1-7**: an Arrive / Depart hourly EV movements plot:

- **pink bars**: count of **departures** in the hour (red tip: count of number undercharged i.e. left before target charging SOC met)
- **blue bars**: count of **arrivals** in the hour (green tip: count of number charged Away from Home AFH i.e. at a destination charging point).

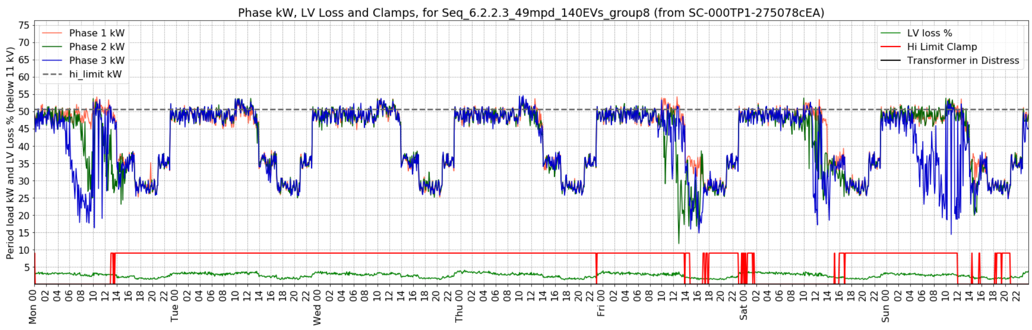

Figure 1-5: Sample of a Feeder plot

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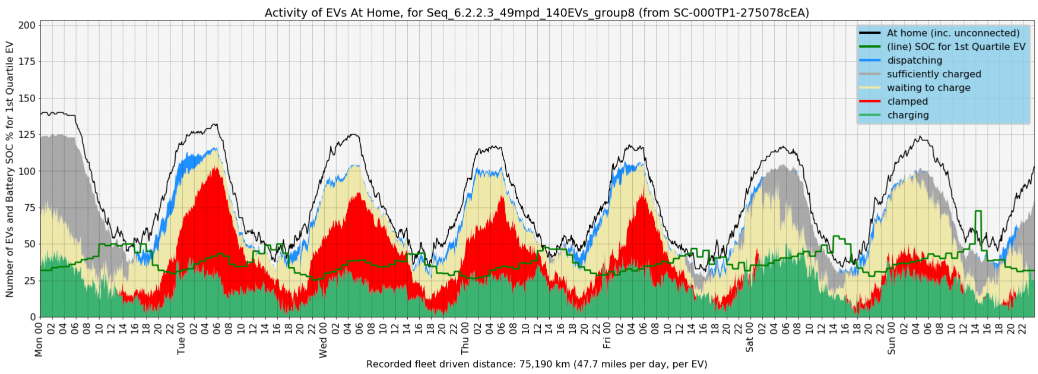

Figure 1-6: Sample of a CICD plot

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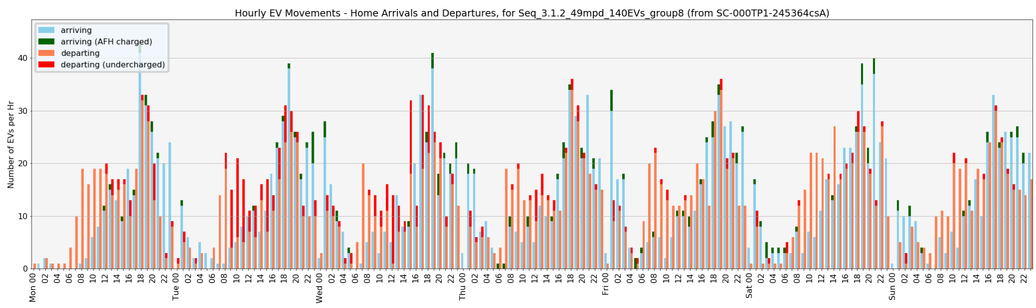

Figure 1-7: Sample of an Arrive / Depart plot

Images are taken group 8 result plots; this assists allowing comparisons to be made as all simulation group 8 will use the same trips.

Note that the figures have a common timeline so relate vertically.

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Vol 3 Chapter 2: Sequence Set 3

This section overviews Sequences in Set 3. These use clamps with V2G support, the method reported by WPD intended for use by the Electric Nation project.

V3-2.1 Description of Sequence Set 3

Purpose: To investigate whether V2G can support clamps in such a manner that EVs benefit, in terms of:

- reduction in clamp counts
- reduction in severe undercharging.

The primary comparisons will be vs. Set 2 (clamps only) results.

V3-2.2 Simulations in Sequence Set 3

Table 2: Simulations in Sequence Set 3

Sequence	**Simulation ID**	**Description**
Seq_3.1.2	(S_AA)	Variation vs. Seq_2.1.2.9: 1 in 4 EVs are V2G; pre-burn_V2G ON
Seq_3.2.2	(S_A4)	Variation vs. Seq_2.1.2.9: 1 in 4 EVs are V2G; pre-burn_V2G ON and V2G are forced to dispatch twice an hour, for 6 minutes per dispatch every 30 minutes
Baselines	***Description***	
Seq_2.1.2.9	*Winter, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, normal plugin regime*	

To show the progression of a policy as EV number rise, the plots are for:

- “partway penetration”: 40 EVs per 100 houses, driving the UK average 27pmd,
- “parity penetration” (1 EV per home): 27mpd 100 EVs and
- “high impact”: 48mpd 140 EVs per 100 houses.

Raw data is available online at a University of Southampton data repository, with summary logs for all runs. Zipped, each sequence set is about 7.3 Gbytes.

V3-2.3 Broaching: None

No broaches occurred In either sequence 3.1.2 or 3.2.2.

V3-2.4 Summary of Set 3 Findings

Table 7 indicates that V2G reduces severe undercharging in 3 plies, vs. Seq_2.1.2.9, so aids the situation. However the greater V2G effort (implying greater costs) utilised to achieve this in Seq_3.2.2 implies that a "blind fire" approach (from a remote Aggregator who is unaware of local LV situations) does not offer any advantages over 3.1.2 to justify the increased c. 700 kWh V2G spend at parity. The author concludes from this that V2G spend needs to be directed, rather than repetitive or random.

This opinion is however based on the local view; there might have been a goal at the high-level achieved, to which an LV view is unaware. For that to be the case, the V2G effort would need to "escape" the LV network i.e. contribute to reduced loading. This seems to have occurred during times the network is not "EV saturated" (i.e. managed to be at or below the hi_limit). But in times when it is saturated, such as in Figure 2-6, the V2G effort is consumed locally. V2G energy supplies whatever local EV is looking to charge and is not seen by the greater network. The recipient EV is though charged earlier.

The author concludes that V2G should be locally directed, as:

- this minimises needed V2G spend hence cost, and
- does not offer the "false hope" of benefiting the greater network, for it may be consumed locally.

It would seem simpler to modulate the MCS hi_limit setpoint, a straightforward means to produce the intended outcome. Yet this implies the existence of a single local authority, not multiple (the likely case with EVs commanded by many interspersed retailers).

Note that V2G is a not a zero-sum exercise, for losses mean that 40 - 50% extra energy must be locally charged i.e. for every 1 kWh spent, the greater grid supplied c. 1.7 kWh.

V3-2.5 Sequence 3.1.2

Sequence	Simulation ID	Description
Seq_3.1.2	(S_AA)	Variation vs. Seq_2.1.2.9: 1 in 4 EVs are V2G; pre-burn_V2G ON (i.e. commit to support extra kW load)
Baseline	***Description***	
Seq_2.1.2.9	*Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), hi_limit 51.3 kW, normal plugin regime*	

A quarter of this sequence are V2G capable EVs, able to support the local network. The remainder are dumb. There is however a complication:

- V2G needs direction hence needs the MCS as a local controller;
- in this simulator, MCS also manages non-dumb EV charging i.e. V2G EVs obey charging control commands, even when V2G is not needed.

Regardless of being a real-world case, the above requires some contortions to isolate the root causes of different results - is *delta* due to V2G or MCS charging control?

V3-2.5.1 Seq_3.1.2 in Summary

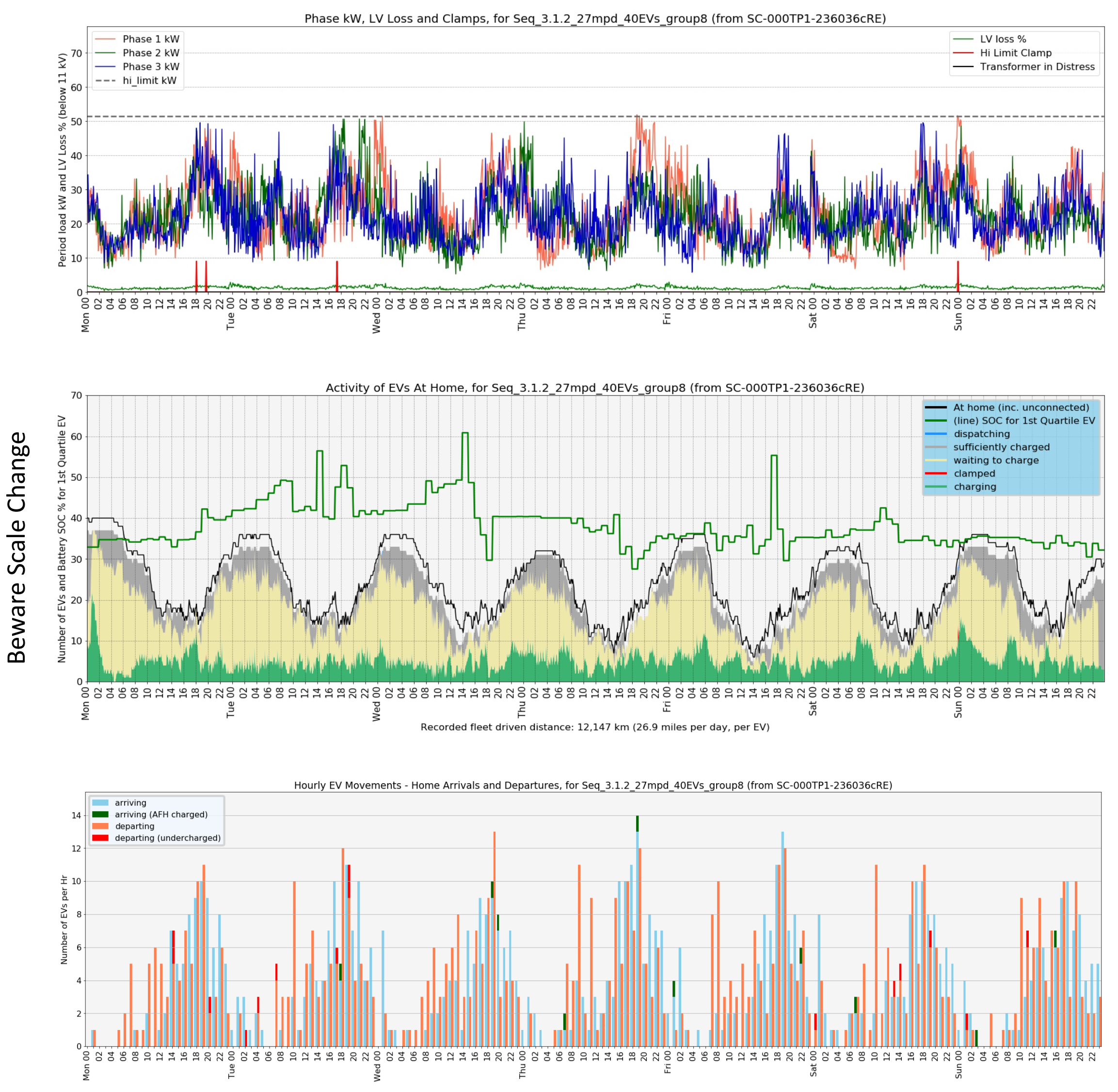
Table 3: 3.1.2 Overall Usable EV Bands

Overall Usable Plies	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								
	49mpd								

This has been a very successful sequence with 29 usable plies; the first in which parity EVs do not encounter a reason to fail. This is primarily due to the MCS system diversifying the V2G EV charge timings, with assistance from V2G dispatch.

V3-2.5.2 Seq_3.1.2: Feeder and EV Plots

V3-2.5.2.1 Seq_3.1.2: 27mpd 40EVs



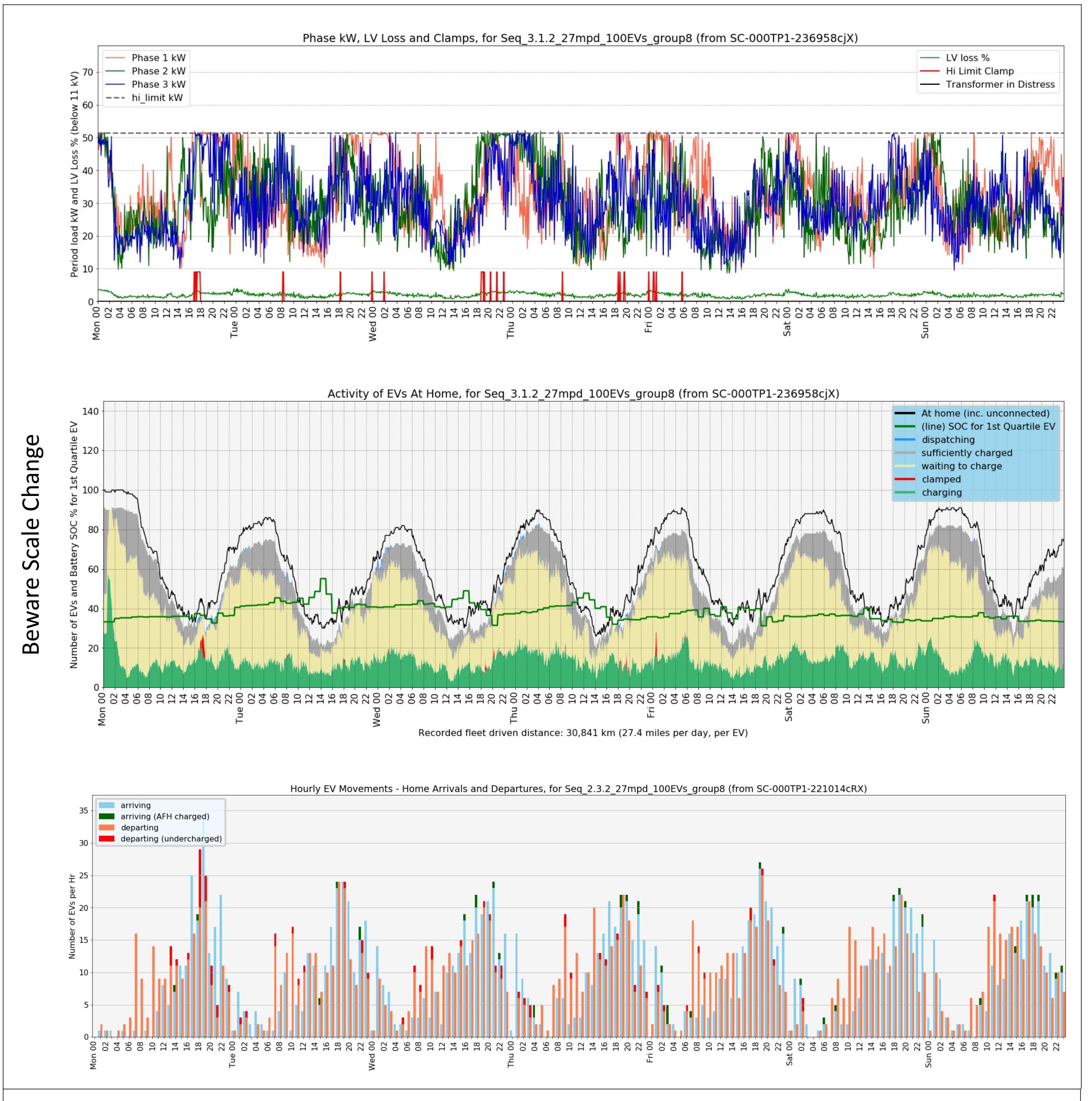
EoW stats: kWh[b] EV total: 2,314 Home: 2,014 AFH: 300 V2G: 0.5

Figure 2-1: Seq_3.1.2 27mpd 40 EVs group 8 plots. Weekly feet km: 12,212

Notes re above plots:

- (Feeder) occasional clamps are seen
- (CICD) EV SOC appears healthy in the 30 - 60% band. Note the occasional clear gap between the colour and the black total-EV count; some people are arriving home and not plugging-in. This indicates confidence they have enough charge.
- (Arrive/Depart) occasional colourised tips show undercharging or use of AFH
- AFH charging supplies c. 13% of EV charge.

V3-2.5.2.2 Seq_3.1.2: 27mpd 100EVs



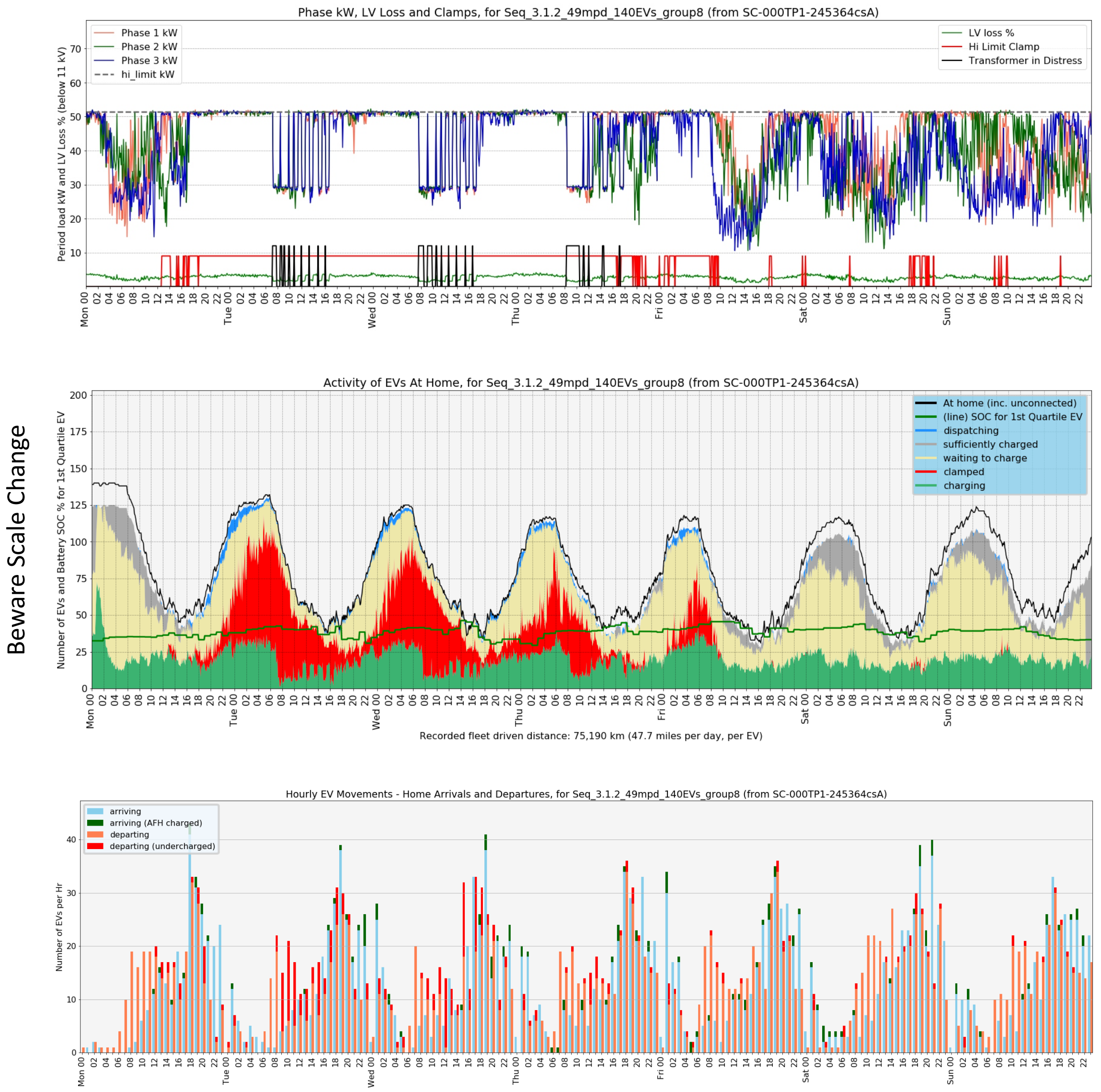
EoW stats: kWh[b] EV total: 5,923 Home: 5,099 AFH: 824 V2G: 55

Figure 2-2: Seq_3.1.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- (Feeder) clamping has slightly increased
- (CICD) EV SOC is down slightly
- (Arrive/Depart) colourised tips show more undercharging and use of AFH
- AFH charging now supplies c. 14% of EV charge.

V3-2.5.2.3 Seq_3.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,221 Home: 9,634 AFH: 4,587 V2G: 681

Figure 2-3: Seq_3.1.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) clamping has greatly increased, plus transformer clamps are seen => the substation transformer is in thermal saturation
- (CICD) EV SOC is down; clamps and V2G (blue) are very visible
- (Arrive/Depart) colour tips are common; undercharging and use of AFH has risen
- AFH charging now supplies c. 1 / 3rd of EV charge.

At this point, the difference between battery and network kWh will be reiterated.

The total charge received (after internal EV losses) by the EV batteries was 14,221 kWh. The amount delivered by the charge-points precede losses, and are c. 14,221 * 1.18 = 16,730 kWh.

On the V2G side, of the 681 kWh lost from batteries, about 681 * 0.82 = 558 kWh was delivered via V2G into the network.

Note that the V2G power delivered might have driven local domestic appliances or charged other EVs; perhaps to recharge a low SOC V2G EV. The EV may be low due to past V2G expenditure - but now it is time to depart, so it needs recover SOC. Such circular trips are possible but are not encouraged as losses compound.

“Ping pong’ing charge” between vehicles makes no sense as losses are 30 - 50% per cycle; another reason to make V2G dispatch a last option (circular trips and wasting kWh are more likely if V2G is a first resort).

The most efficient use of kWh[b] - is to keep it in the battery for driving.

The data below are from MetaMeta spreadsheets (as online) for Seq_2.1.2.9 and Seq_3.1.2. Broaches = 0, N out-of-volt range = 0, Fleet km = match both cases.

The parity case (UK average mpd with 1:1 household EV penetration) is shown in pink.

V3-2.5.3 Data Tables Seq_3.1.2

Table 4: Unused kWh (weekly averages) for 3.1.2 vs. 2.1.2.9

No V2G EVs, No MCS	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,094	16,401	15,017	13,637	12,285	10,938	9,661	8,338
		27mpd	16,983	16,161	14,546	12,931	11,392	9,865	8,380	3,135
		38mpd	16,893	15,986	14,144	12,315	10,579	8,833	1,848	0
		49mpd	16,814	15,836	13,827	11,864	10,022	5,801	14	0
MCS with 1 in 4 EVs are V2G	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,099	16,423	15,093	13,752	12,436	11,115	9,815	8,485
		27mpd	16,988	16,183	14,615	13,030	11,503	9,963	8,397	5,958
		38mpd	16,893	15,999	14,195	12,379	10,635	8,813	4,541	158
		49mpd	16,811	15,844	13,856	11,889	10,012	7,464	103	0
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	4	22	75	115	151	177	154	147
		27mpd	5	22	69	99	111	98	17	2,823
		38mpd	0	13	51	65	55	-20	2,693	158
		49mpd	-3	8	29	25	-9	1,663	89	0

Weekly Average Unused kWh: Baseline 2.1.2.9 (grey), Seq_3.1.2 (yellow).

NB the difference is B - A (Seq_3.1.2 values, less those of Seq_2.1.2.9)

Unused kWh is the spare headroom region between the network rating and instantaneous load, over a week. The three cells in green are highlighted as they are significantly up. Here, the V2G case is drawing less energy then non-V2G. Does this indicate V2G operation, or the way the MCS can guide non-dumb EV charging patterns?

This is found by subtracting the V2G component (converted from kWh[b] to kWh as seen by the LV network, assuming a 16% loss) in Table 5 **D** from the difference **C**, giving **E**:

Table 5: Unused kWh (weekly averages) for 3.1.2 vs. 2.1.2.9 ctd.

V2G: kWh Dispatched	D	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0	0.0	0.2	1.6	6.1	20.2	45.7	92.2
		27mpd	0.0	0.0	0.4	3.3	14.1	46.3	110.8	229.5
		38mpd	0.0	0.0	1.0	7.2	29.8	103.8	244.2	504.3
		49mpd	0.0	0.0	1.2	9.8	46.8	160.9	355.5	571.7
Difference C - D	E	N EV	10	20	40	60	80	100	120	140
		19mpd	4.0	22.0	74.8	113.4	144.9	156.8	108.3	54.8
		27mpd	5.0	22.0	68.6	95.7	96.9	51.7	-93.8	2593.5
		38mpd	0.0	13.0	50.0	57.8	25.2	-123.8	2448.8	-346.3
		49mpd	-3.0	8.0	27.8	15.2	-55.8	1502.1	-266.5	-571.7

Seq_3.1.2 Recorded V2G kWh injection (D, blue) showing extra component (E, strong yellow).

Clearly, V2G assists, but is not the whole contribution seen. The authors interpretations are:

- cells of V2G kWh in blue show kWh injection giving uplift, however
- there is a large discrepancy in yellow, which suggests the difference arises due to managed charging by the MCS.

Note the scaling between these; the MCS action is providing c. x10 the benefit of V2G, given control over 1/4 of EVs.

Also note this forms a "sweet spot" in the load band. For less strenuous duties than the strong yellow (lower mpd, lower N EV), there is no great advantage of MCS + V2G; beyond the strong yellow (i.e. 49mpd 140 EVs) the system has committed as much as it can and has no further V2G kWh to offer.

Table 6: Counts of Undercharging events per EV (weekly averages) for 3.1.2 vs. 2.1.2.9

		N EV	10	20	40	60	80	100	120	140
No V2G EVs, No MCS	2. EV UnChg A	19mpd	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
		27mpd	1.8	1.8	1.9	1.8	1.8	1.8	1.8	1.9
		38mpd	2.3	2.4	2.4	2.4	2.4	2.4	2.5	3.1
		49mpd	2.9	2.9	2.9	2.9	2.9	2.9	3.4	4.7
MCS with 1 in 4 EVs are V2G	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1
		27mpd	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.6
		38mpd	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.4
		49mpd	2.6	2.7	2.7	2.6	2.6	2.6	2.9	4.0
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
		27mpd	-0.4	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
		38mpd	-0.3	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.6
		49mpd	-0.3	-0.2	-0.3	-0.3	-0.3	-0.3	-0.5	-0.6

Weekly Average Undercharged EVs: Baseline 2.1.2.9 (grey), Seq_3.1.2 (yellow)

Positive values indicate 3.1.2 is higher

The green boxes have substantial V2G operation, yet a reduction in undercharging is seen in weeks with less V2G operation (e.g. weeks with N EV < 60). This indicates the MCS alone is reducing undercharging.

A similar exercise for severely undercharged EVs gives the difference table below, showing that their situation is improved at duty extremes. Green cells show V2G contribution with red showing severe undercharging limit fails:

Table 7: ***3.1.2 Difference table for Severely Undercharged EVs. (weekly averages)***

3. Diff Sevr. UnCHg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
	27mpd	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02
	38mpd	0.00	-0.01	-0.03	-0.03	-0.02	-0.06	-0.47	-2.68
	49mpd	0.00	0.00	-0.01	-0.02	-0.02	-0.18	-2.34	-4.34

(limit: < 0.007)

The following table considers clamping counts:

Table 8: 2.1.2 MCS Clamps (weekly averages)

4. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0.2	0.4	1.5	3.9	9.9	22.7	34.1	57.2
	27mpd	0.2	0.6	2.7	8.7	22.6	53.0	84.9	177.5
	38mpd	0.3	0.8	5.1	17.3	43.6	123.9	291.7	1,028.1
	49mpd	0.3	1.2	7.6	27.3	74.4	255.5	863.2	2,092.4

(limit: < 420)

The author interprets this to mean: V2G can assist in a specific extreme situation, but once available V2G resource is consumed then clamps must manage the network.

V3-2.5.4 Seq_3.1.2 Summary

Table 9: 2.1.2.9 Overall Usable EV Bands

5. Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								
	49mpd								

This has been a very successful sequence and is the first in which parity EVs do not encounter a reason to fail. This is due primarily to the MCS management plus V2G.

V3-2.6 Sequence 3.2.2

Sequence	Simulation ID	Description
Seq_3.2.2	(S_A4)	Variation vs. Seq_3.1.2: 1 in 4 EVs are V2G; pre-burn_V2G ON and V2G are forced to dispatch twice an hour, for 6 minutes per dispatch
Baseline	***Description***	
Seq_3.1.2	*Variation vs. Seq_2.1.2.9: 1 in 4 EVs are V2G; pre-burn_V2G ON*	
Seq_2.1.2.9	*Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), hi_limit 51.3 kW, normal plugin regime*	

Sequence 3.2.2 again has a quarter of all EVs as V2G, with the remainder dumb. The difference between this sequence and Seq_3.1.2 is that:

- regardless of the local situation, under aggregator control, the V2G EVs are forced to dispatch twice per hour if they are able, i.e.
  - must be home and plugged in
  - must have sufficient battery SOC available
- this may have more or less utility; local EVs and MCS must work with the issue.

This a possible a real-world case. Today, an aggregator cannot know the instantaneous situation of every network feeder and phase, but may be bound by contract to command V2G action. The pattern used here is an artifice and is:

- 6 minutes of V2G every 30 minutes, being periods 1, 6, 11, 16, 21... etc.

The authors expectations of this are:

- V2G is up hence the need to recharge is up
- V2G incurs extra losses
- hence the strategy will be detrimental, due to V2G loss / expenditure.

A point of interest, when compared to later cases with a similar amount of V2G deployed:

- is V2G intrinsically of use, or
- must it be utilised judiciously?

Implicitly, this V2G regime is proportionate to the count of EVs resident.

V3-2.6.1 Seq_3.2.2 in Summary

Table 10: 3.2.2 Overall Usable EV Bands

Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								
	49mpd								

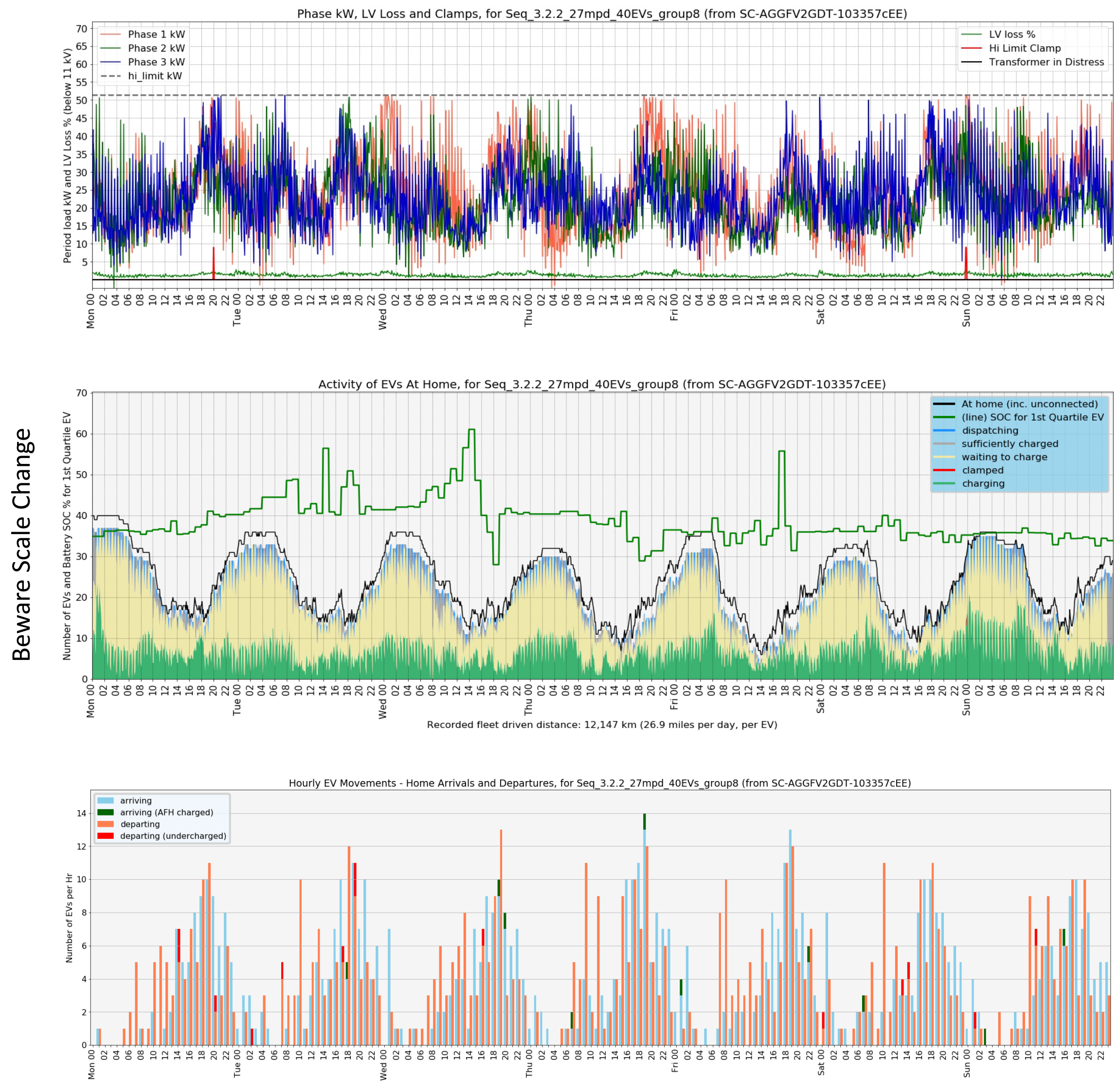
This simulation sequence matches the capabilities of 3.1.2, yet 3.2.2 does not show any advantages to justify the c. 700 kWh V2G spend (in the parity case) vs. c. 50 kWh V2G spend in 3.1.2. The author concludes from this that V2G spend needs to be directed, rather than repetitive or random.

In the extreme case it is clear that although V2G occurs, it is being consumed locally i.e. does not escape to the greater network, for the V2G injection goes to feed other EVs.

This implies that an aggregator, sans local knowledge, cannot meaningfully impact a local situation. However this has been only one sequence; perhaps the simulations need to be repeated for other situations.

V3-2.6.2 Seq_3.2.2: Feeder and EV Plots

V3-2.6.2.1 Seq_3.2.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,514 Home: 2,215 AFH: 299 V2G: 61

Figure 2-4: Seq_3.2.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

The forced V2G can be seen as regular blue striations in the CICD plot.

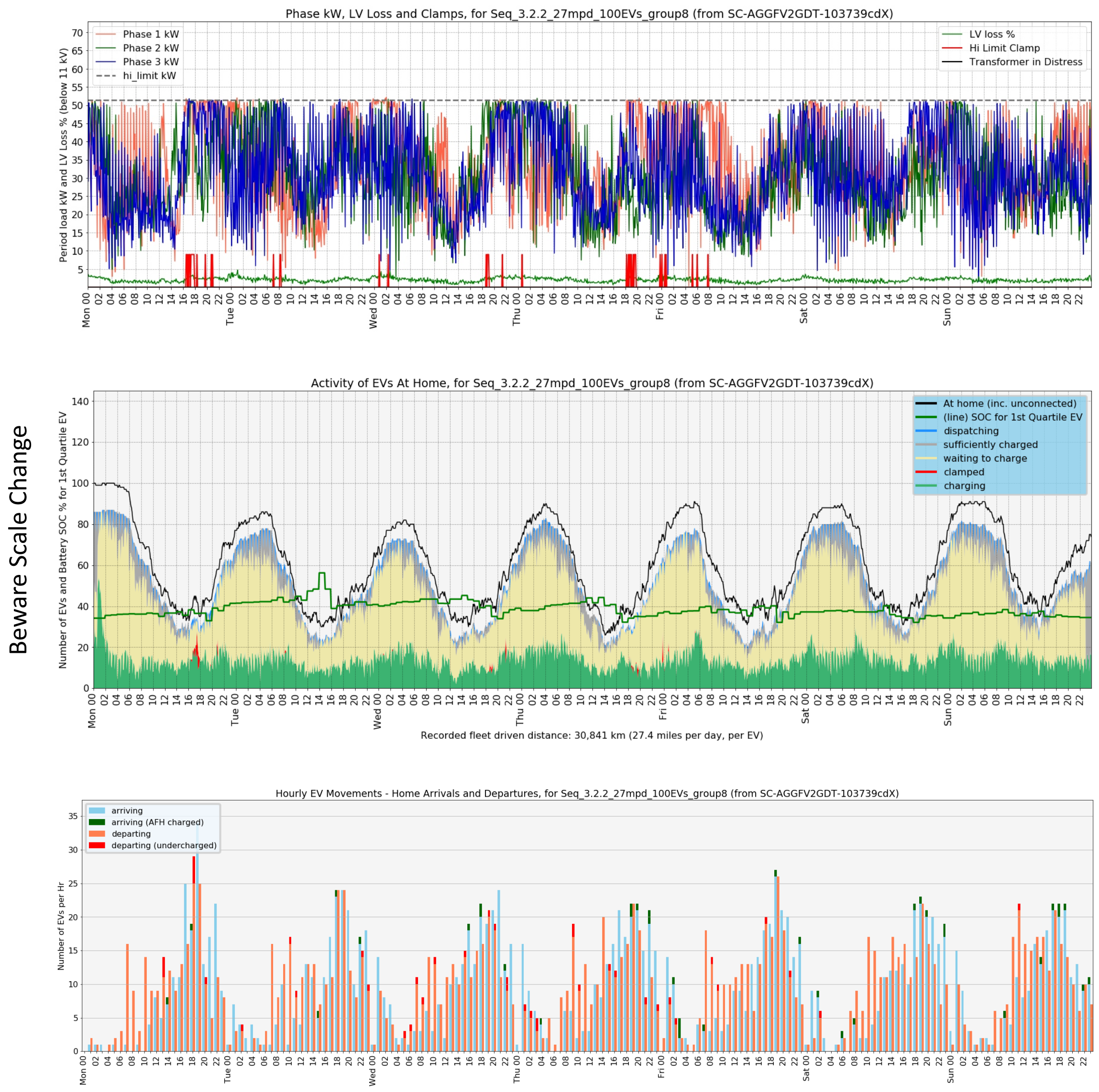
Note that the means for Seq_3.1.2 were:

EoW stats: kWh[b] EV total: 2,314 Home: 2,014 AFH: 300 V2G: 0.54

Notes re above plots:

- (Feeder) there are occasional clamps
- (CICD, Arrive/Depart) other than V2G there are few differences vs. Seq_3.1.2.

V3-2.6.2.2 Seq_3.2.2: 27mpd 100EVs



EoW stats: kWh[b]	EV total: 6,292	Home: 5,473	AFH: 819	V2G: 776

Figure 2-5: Seq_3.2.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

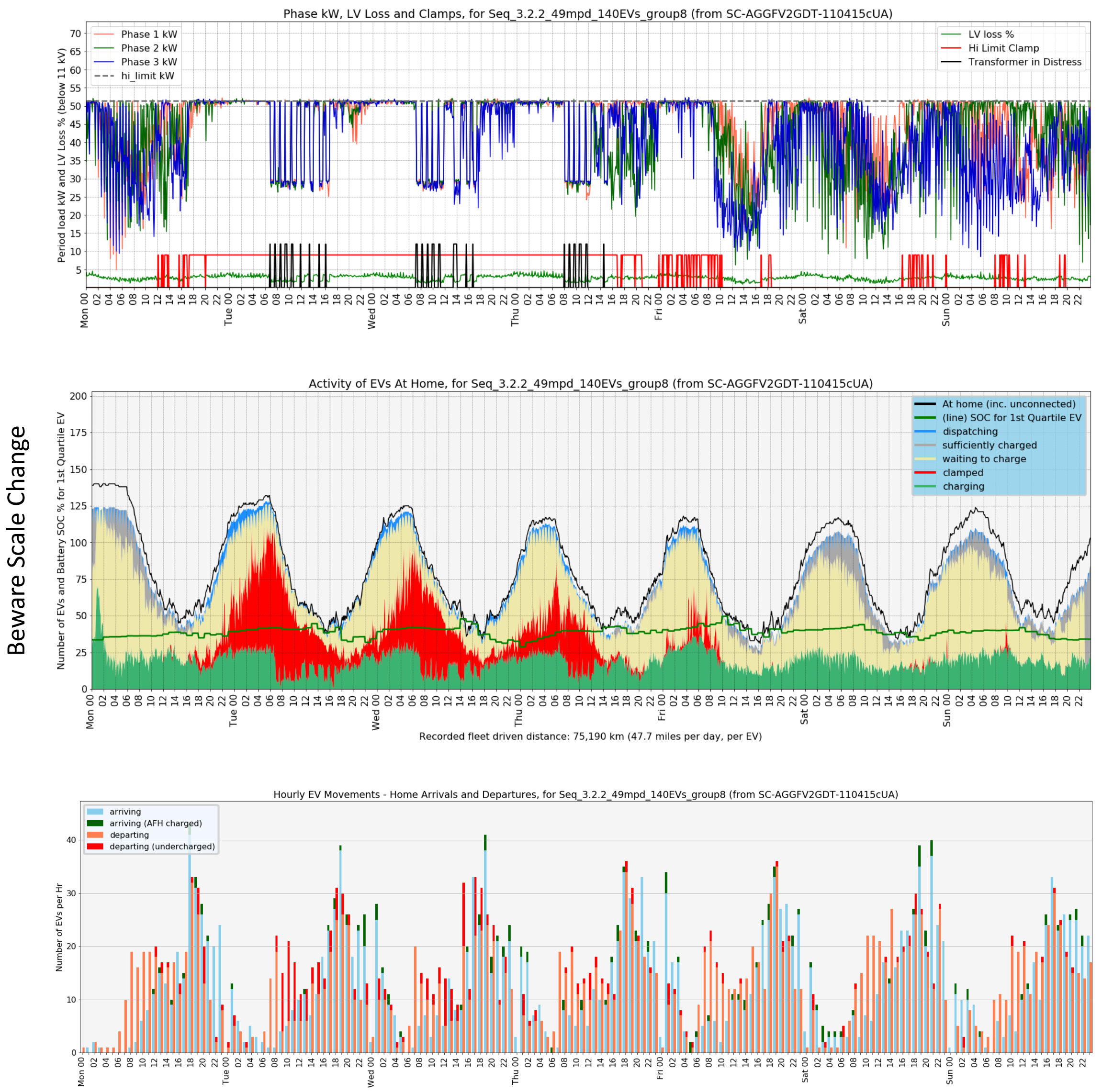
Note that the means for Seq_3.1.2 were:

EoW stats: kWh[b]	EV total: 5,923	Home: 5,099	AFH: 824	V2G: 55

Notes re above plots:

- (Feeder) there are more clamps
- (CICD, Arrive/Depart) again there are few differences vs. Seq_3.1.2.

V3-2.6.2.3 Seq_3.2.2: 49mpd 140EVs



EoW stats: kWh**b** EV total: 14,895 Home: 10,263 AFH: 4,632 V2G: 1,454

Figure 2-6: Seq_3.2.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Note that the means for Seq_3.1.2 were:

EoW stats: kWh**b** EV total: 14,221 Home: 9,634 AFH: 4,587 V2G: 681

Notes re above plots:

- (Feeder) clamping has greatly increased and transformer clamps are seen
- (CICD, Arrive/Depart) again there are few differences vs. Seq_3.1.2.
- All sources of charge now supply more - for the same driven distance.

V3-2.6.3 Data Tables Seq_3.2.2

Data are from MetaMeta spreadsheets for Seq_3.2.2 and Seq_3.1.2. Broaches = 0, N out-of-volt range = 0, Fleet km = match both cases. The parity case (UK average mpd with 1:1 household EV penetration) is yellow; green highlights the 3.1.2 V2G active plies.

Table 11: Unused kWh (weekly averages) for 3.1.2 vs. 3.2.2

MCS with 1 in 4 EVs V2G	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,099	16,423	15,093	13,752	12,436	11,115	9,815	8,485
		27mpd	16,988	16,183	14,615	13,030	11,503	9,963	8,397	5,958
		38mpd	16,893	15,999	14,195	12,379	10,635	8,813	4,541	158
		49mpd	16,811	15,844	13,856	11,889	10,012	7,464	103	0

2x Hourly V2G Duty	B	N EV	10	20	40	60	80	100	120	140
		19mpd	16,887	16,147	14,614	13,205	11,931	10,656	9,402	8,123
		27mpd	16,786	15,915	14,140	12,497	11,016	9,535	8,032	5,845
		38mpd	16,689	15,716	13,704	11,841	10,154	8,393	4,414	117
		49mpd	16,623	15,581	13,399	11,389	9,571	6,921	85	0

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-212	-276	-478	-548	-505	-460	-413	-362
		27mpd	-202	-269	-476	-533	-486	-428	-365	-113
		38mpd	-205	-283	-491	-538	-481	-420	-126	-41
		49mpd	-188	-263	-457	-500	-441	-543	-17	0

Weekly Average Unused kWh: Baseline 3.1.2 (grey), Seq_3.2.2 (yellow).

NB the difference is B - A (Seq_3.2.2 values, less those of Seq_3.1.2)

It appears that the process reduces headroom (spare capacity) vs. not.

However does the EV fleet now receive more useful charge then in 3.1.2? This can be evidenced by comparing undercharging rates:

Table 12: Counts of Undercharging events per EV (weekly averages) for 3.2.2 vs. 3.1.2

No V2G EVs, No MCS	2. EV UnChg A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1
		27mpd	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.6
		38mpd	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.4
		49mpd	2.6	2.7	2.7	2.6	2.6	2.6	2.9	4.0
MCS with 1 in 4 EVs are V2G	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.9	1.1	1.0	1.1	1.1	1.1	1.1	1.1
		27mpd	1.4	1.6	1.6	1.5	1.6	1.6	1.6	1.6
		38mpd	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.5
		49mpd	2.7	2.7	2.7	2.7	2.6	2.7	2.9	4.2
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		27mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		38mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		49mpd	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1

Weekly Average Undercharged EVs: No significant differences

No.

Table 13: Difference in Severe Undercharging per EV (weekly averages) for 3.2.2 vs. 3.1.2

Difference

3. Diff Sevr. UnChg	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
	27mpd	0.0002	-0.0003	0.0003	0.0002	-0.0001	0.0001	0.0000	-0.0001
	38mpd	0.0008	0.0002	0.0012	0.0010	0.0004	0.0002	0.0003	0.0021
	49mpd	0.0014	0.0015	0.0018	0.0016	0.0008	0.0005	0.0035	0.0178

(limit: < 0.007)

Weekly Average Undercharged EVs: No significant differences

The red shows severe undercharging limit fails; positive means the severe undercharging in 3.2.2 is higher. Overall 3.2.2 is higher but by very low amounts.

The following table considers clamping counts. The differences to 3.1.2 are very low, improving by 4.0 in the parity case. In 3.2.2, no further plies are added to those of 3.1.2.

Table 14: 3.2.2 MCS Clamps (weekly averages)

4. MCS Clamps	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd	0.1	0.4	1.3	3.4	8.6	20.5	30.4	50.6
	27mpd	0.1	0.5	2.4	7.7	21.2	49.0	79.2	159.5
	38mpd	0.2	0.7	4.8	17.1	42.6	119.8	270.7	933.3
	49mpd	0.3	1.0	7.5	28.2	78.6	267.8	809.9	1,914.1

(limit: < 420)

V3-2.6.4 Seq_3.2.2 Summary

Table 15: 3.2.2 Overall Usable EV Bands

5. Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								
	49mpd								

This simulation sequence has shown no advantages over 3.1.2 to justify the c. 700 kWh V2G spend. The author concludes that V2G spend needs to be directed, rather than repetitive or random.

However this has been only one sequence; perhaps the simulations need to be repeated for other situations.

V3-2.7 Sequence 3 in Summary

MCS, V2G and clamping work together to aid the local situation, however the Aggregator control (blind to local situations) offers no discernable benefits yet spends considerable amounts of V2G energy, likely driving up costs and losses.

Vol 3 Chapter 3: Sequence Set 4: 4.1.2, 4.2.2, 4.3.2

These sequences model an aggregator operating a control for demand peak reduction DSR / DR, often region-wide, and explores how this impacts LV and EV situations.

The scenario is that an aggregator holds a high-level contract for a DR service and has a fleet of contracted (controlled) EVs. The control signal is sent to EVs at a level above LV (e.g. at national, regional or city) to change or influence whole grid demand. Implicitly, the aggregator cannot tell what is happening at local level. Even if in receipt of “have actioned your command” response, aggregators are assumed not to know in real-time other local demands, so cannot view the local LV impacts of their actions.

Sequence	**Simulation ID**	**Description**
Seq_4.1.2	(S_94)	Winter, NEV, mpd sets, all dumb EVs, no clamps, pre-burn_V2G OFF, hi_limit 51.3 kW, normal plugin regime. There is no DR/FFR signal; there is no MCS operation. All EVs are under aggregator control and the following Time of Use signal, asserting the following control: • from 1pm: idle only (no charging or dispatch) • from 6pm: charging only allowed if SOC < 33% • from 11pm: unrestricted operation. *(Baseline: Seq_1.1.2)*
Seq_4.2.2	(S_97)	Variation vs. Seq_4.1.2: Clamps active, priority mode (2) *(Baseline: Seq_2.1.2.9)*
Seq_4.3.2	(S_96)	Variation vs. Seq_4.1.2: Clamps active, priority mode (2); 1 in 4 EVs are V2G; pre-burn_V2G ON and under MCS control (**NB** Time of Use charging restrictions still apply) *(Baseline: Seq_2.1.2.9)*

Baselines	***Description***
Seq_1.1.2	*Winter, all EVs dumb, no clamps, no MCS, Typical network, hi_limit 51.3 kW, normal plugin regime*
Seq_2.1.2.9	*As Seq_1.1.2 above but with C2CT clamps ON (mode 2)*

V3-3.1 Broaching

Only the unclamped Sequence_4.1.2 experienced broaches:

Table 16: Average Weekly Broaches for 1.1.2 and 4.1.2

Seq_1.1.2	1. A	N EV	10	20	40	60	80	100	120	140
		19mpd	0	0	0	11	60	249	349	333
		27mpd	0	0	2	53	203	383	358	344
		38mpd	0	0	7	125	357	371	352	380
		49mpd	0	0	10	188	383	360	392	439

Seq_4.1.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0	0	3	78	270	447	445	449
		27mpd	0	1	26	230	457	461	460	474
		38mpd	0	3	108	395	462	477	481	497
		49mpd	0	0	118	434	456	475	493	500

New broaches in 4.1.2 are colourised deep red

Broaches Seq_4.1.2 vs. Baseline Seq_1.1.2. Broaches are worse, possibly due to charging constraints resulting in a "group rush to charge" at later times.

This is seen elsewhere and is termed "crowding", being: A timed prohibition of charging causes a build-up for demand. At the next opportunity, i.e. lifting of the DR constraint, EVs (independently, yet simultaneously) decide to charge en mass as the prohibition is lifted. Any evidence for this would be in the timing of Feeder plot kW peaks in this simulation / timing of clamps in later simulations.

The results above show 4.1.2 has lost ability to support the 20 EV population band, degrading the situation for both EV driver and DNO. Thus what is concluded:

i) aggregation control is demonstrated as effecting kW reduction at set times
ii) this does not impede EVs in absolute terms, but
iii) has here an unexpected (to the aggregator) deleterious impact on the LV system i.e. aggregation can operate as to reduce the LV networks ability to support EVs

any real-world EV aggregation method must improve on that shown.

V3-3.2 Set 4 Findings Summary

The Set 4 sequences are a step backward. In Seq_4.1.2, the broached plies have increased. This shows that misused Aggregation commands can effect LV network by:

1) building up a demand, through stopping any charging
2) when the constraint is lifted, many EVs charge simultaneously hence broach network limits.

The clamps used in Seq_4.2.2 cures the network broaching but imposes severe undercharging on EVs. Adding V2G in Seq_4.3.2 gives some improvement re undercharging, however there remain too many undercharges; no ply is free.

V3-3.3 Results for Sequence 4.1.2

Sequence	Simulation ID	Description
Seq_4.1.2	(S_94)	Winter, NEV, mpd sets, all dumb EVs, no clamps, pre-burn_V2G OFF, hi_limit 51.3 kW, normal plugin regime. There is no DR/FFR signal; there is no MCS operation. All EVs are under aggregator control and the following Time of Use signal, to attempt to control peaks: • from 1pm: idle only (no charging) • from 6pm: charging only allowed if SOC < 33% • from 11pm: unrestricted operation.
Baseline	***Description***	
Seq_1.1.2	*Winter, all EVs dumb, no clamps, no MCS, Typical network, hi_limit 51.3 kW, normal plugin regime*	

V3-3.3.1 Seq_4.1.2 in Summary

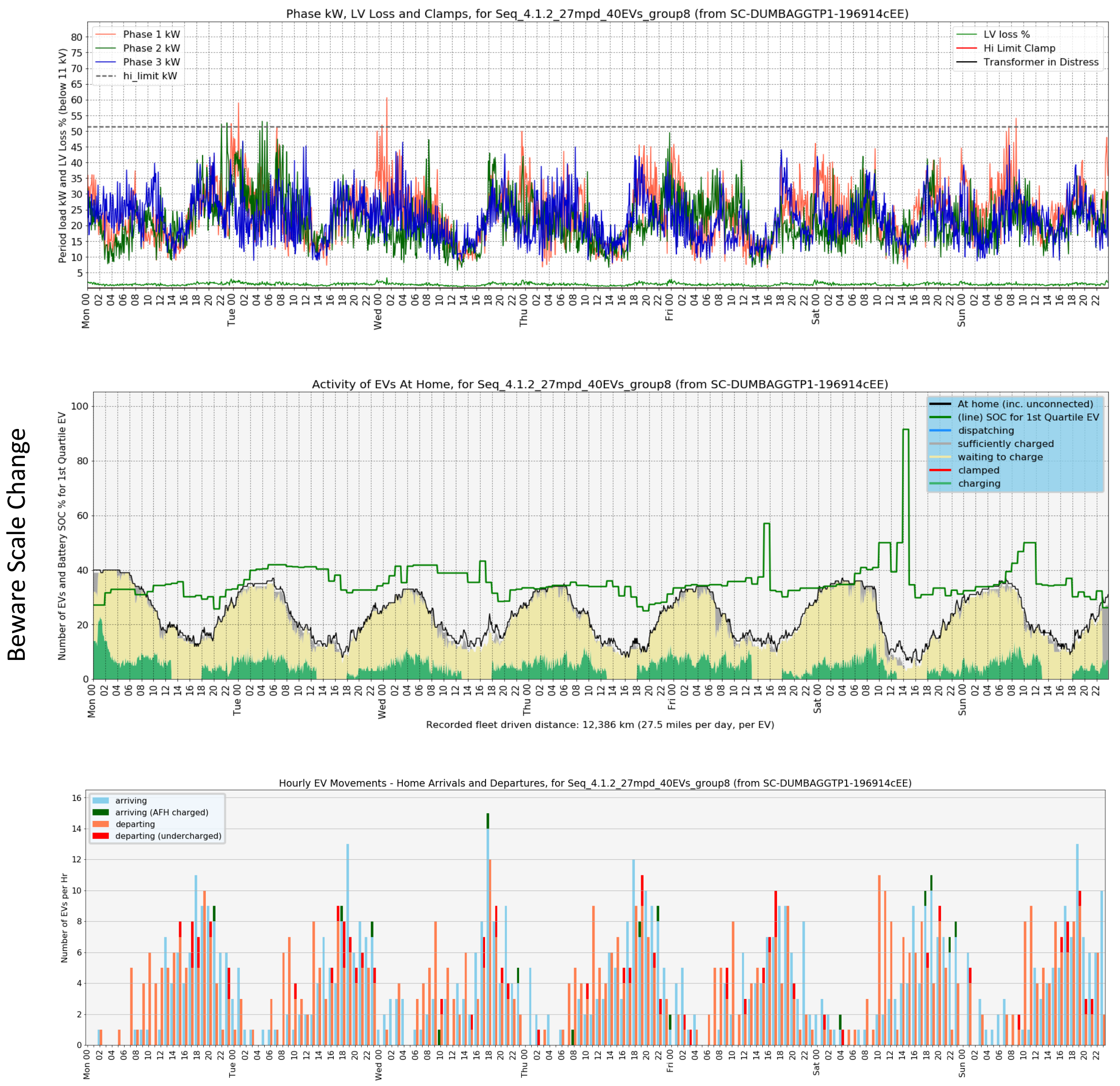
Broached plies are increased; see V3-3.1 B.

This shows that misused Aggregation commands can effect LV network by:

1) building up a demand, through stopping any charging
2) when the constraint is lifted, many EVs charge simultaneously hence broach network limits.

V3-3.3.2 Seq_4.1.2: Feeder and EV Plots

V3-3.3.2.1 Seq_4.1.2 Plots: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,350 Home: 1,972 AFH: 378 V2G: 0

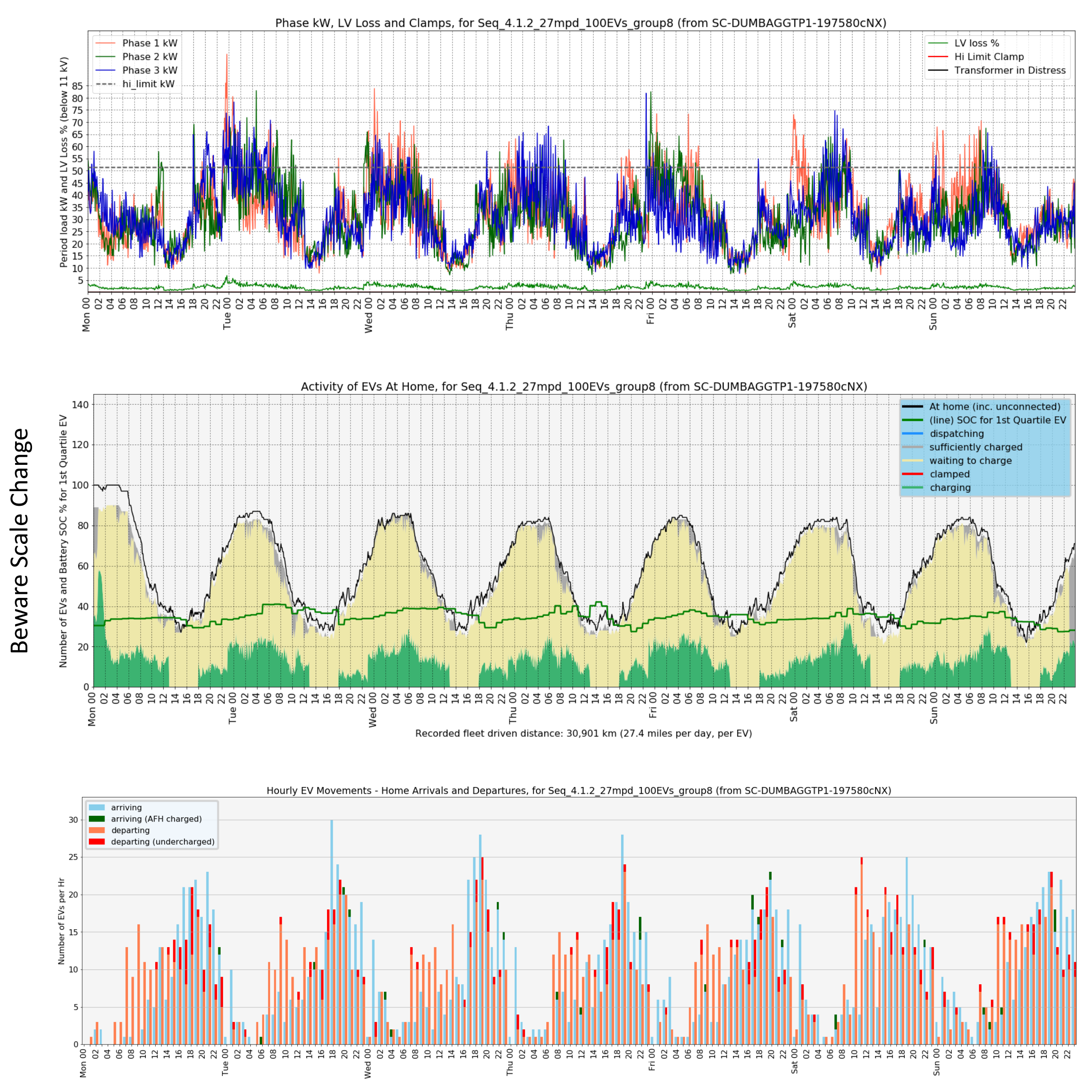
Figure 3-1: Seq_4.1.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,315

Notes re above plots:

- (Feeder) there are occasional feeder kW peaks which are too high, but not severe
- (CICD) aggregator commanded charging prohibitions from 1pm - 6pm daily is clearly being obeyed, indicated by gaps in charging (green) in the afternoon;
- (Arrive/Depart) this is almost identical to the baseline case, other than 3 EVs here departing undercharged late Monday afternoon.

...

V3-3.3.2.2 Seq_4.1.2: 27mpd 100EVs



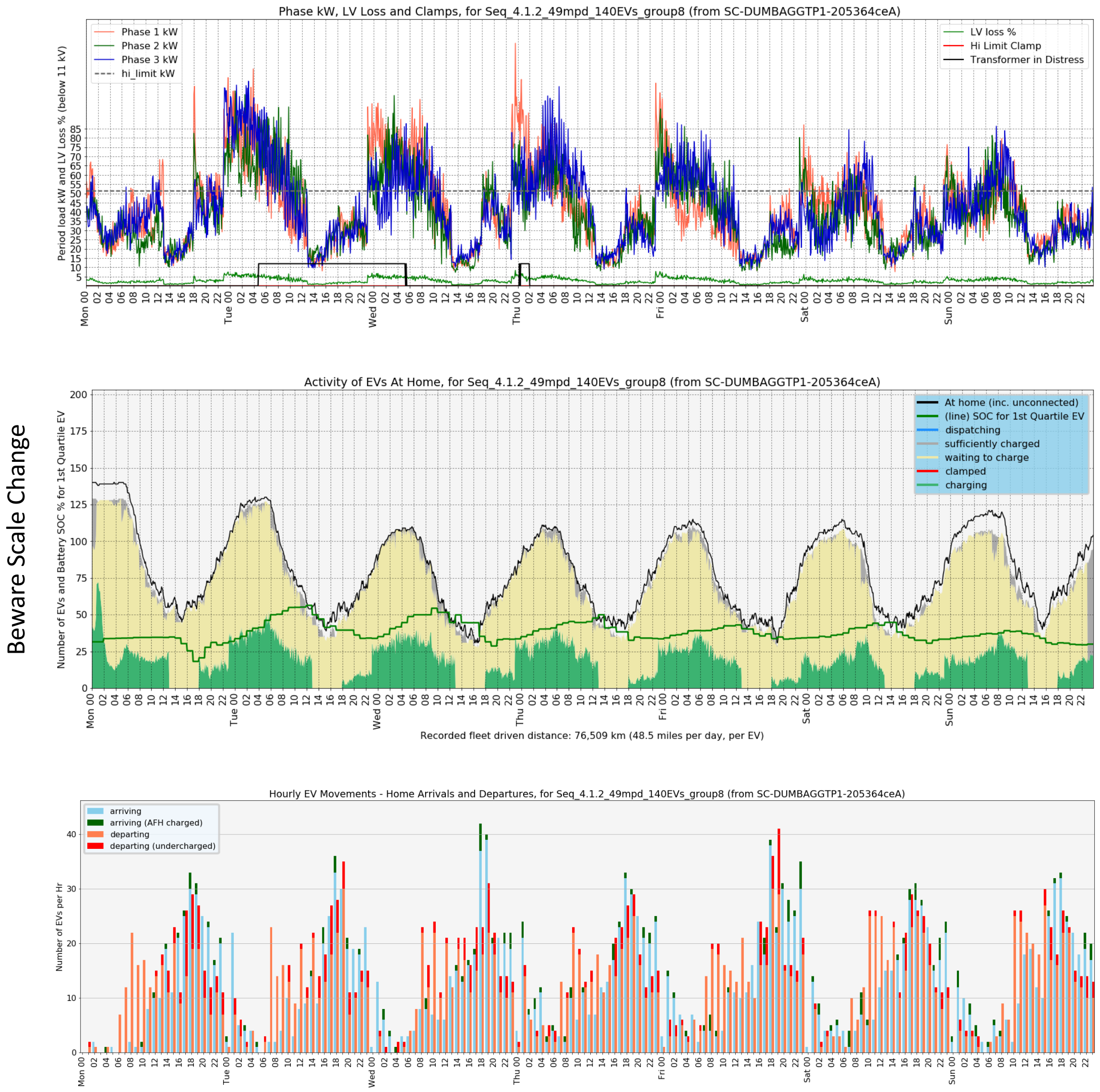
EoW stats: kWh[b] EV total: 5,936 Home: 4,931 AFH: 1,005 V2G: 0

Figure 3-2: Seq_4.1.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,988

Notes re above plots:

- (Feeder) here, peak kW spikes are near 100 kW, vs. c. 82 kW for the baseline
- (CICD) the prohibition on charging remains seen,
- (Arrive/Depart) again almost identical to the baseline.

V3-3.3.2.3 Seq_4.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,626 Home: 8,662 AFH: 4,965 V2G: 0

Figure 3-3: Seq_4.1.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,227

Notes re above plots:

- (Feeder) distinct peak profiles arise which follow the cessation of charging constraints at 11pm (a "cliff edge" is observable going from 22:00 to midnight, on most evenings), and have higher kW than on the baseline
- (CICD) other than charging prohibitions, this remains similar to the baseline CICD. The crowding event or cliff-edge is visible
- (Arrive/Depart) is again almost identical to the baseline.

At this point, there is little merit in picking apart the statistics in detail.

V3-3.3.3 Seq_4.1.2 Summary

The EVs:

a) obey the aggregator instructions e.g. to limit charging
b) causing a time-shift of their charging patterns
c) <u>on removal of charging constraints</u> crowding occurs (the simultaneous, independent and spontaneous decision to charge)
d) sans clamps, the EVs draw charge
e) but individually, EVs are relatively unaffected.

However, the network:

f) experiences (d) as broaches
g) thus has less net capacity to host EVs,
h) i.e. aggregation when operated for "external motives" can cause a reduction in the LV network's ability to support EVs (given: no clamps).

Note: DR is known to suffer with fixed total kWh loads. Constraining such a load via a DR signal results in later power draw, recouping the energy deficit. A classic example is an electric furnace; shutting off power for a few minutes mid-melt defers (not reduces) draw of the total energy required to melt furnace contents.

The EVs are so behaving. This does not invalidate the principle of aggregation control. Perhaps a more refined method would help; the three levels used are arguably too coarse. Application of the control signal to less than 100% of the EV population would also help.

Better yet, a monitoring and feedback system would greatly help; but is not available.

Thus what is concluded:

iv) aggregation control is demonstrated as effecting kW reduction at set times
v) this does not impede EVs in absolute terms, but
vi) has here an unexpected (to the aggregator) deleterious impact on the LV system i.e. <u>aggregation can operate as to reduce the LV networks ability to support EVs</u>
vii) any real-world EV aggregation method must improve on that shown.

V3-3.4 Sequence 4.2.2

Sequence	**Simulation ID**	**Description**
Seq_4.2.2	(S_97)	Variation vs. Seq_4.1.2: Clamps active, priority mode (2)
Baseline	***Description***	
Seq_2.1.2.9	*Winter, all dumb EVs, clamps ON (2), Typical network, hi_limit 51.3 kW, normal plugin regime*	

This is Seq_4.1.2 with clamps, which investigates how EVs fare when they cannot draw power / crowd the network after charging prohibitions are lifted. The priority mode is (2) which favours the most needy EVs.

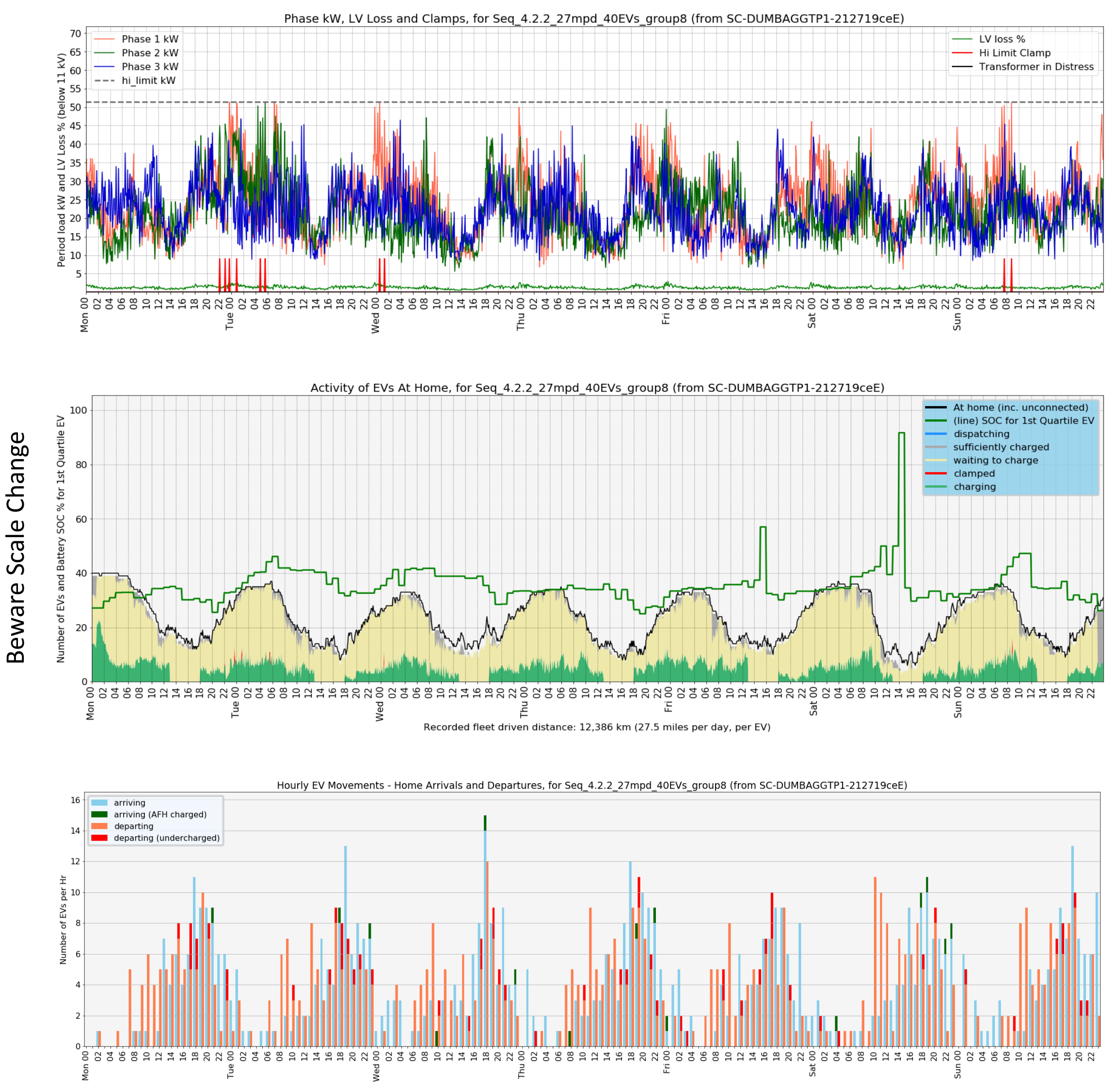
The author expects increased AFH charging and undercharged departs.

V3-3.4.1 Seq_4.2.2 in Summary

The clamps used in Seq_4.2.2 cures the network broaching but imposes severe undercharging on EVs.

V3-3.4.2 Seq_4.2.2: Feeder and EV Plots

V3-3.4.2.1 Seq_4.2.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,350 Home: 1,971 AFH: 378 V2G: 0

Figure 3-4: Seq_4.2.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,315

Notes re above plots:

- occasional clamps are seen, enforcing the hi_limit cut off level
- the EV plots are both very similar to the 4.1.2 images

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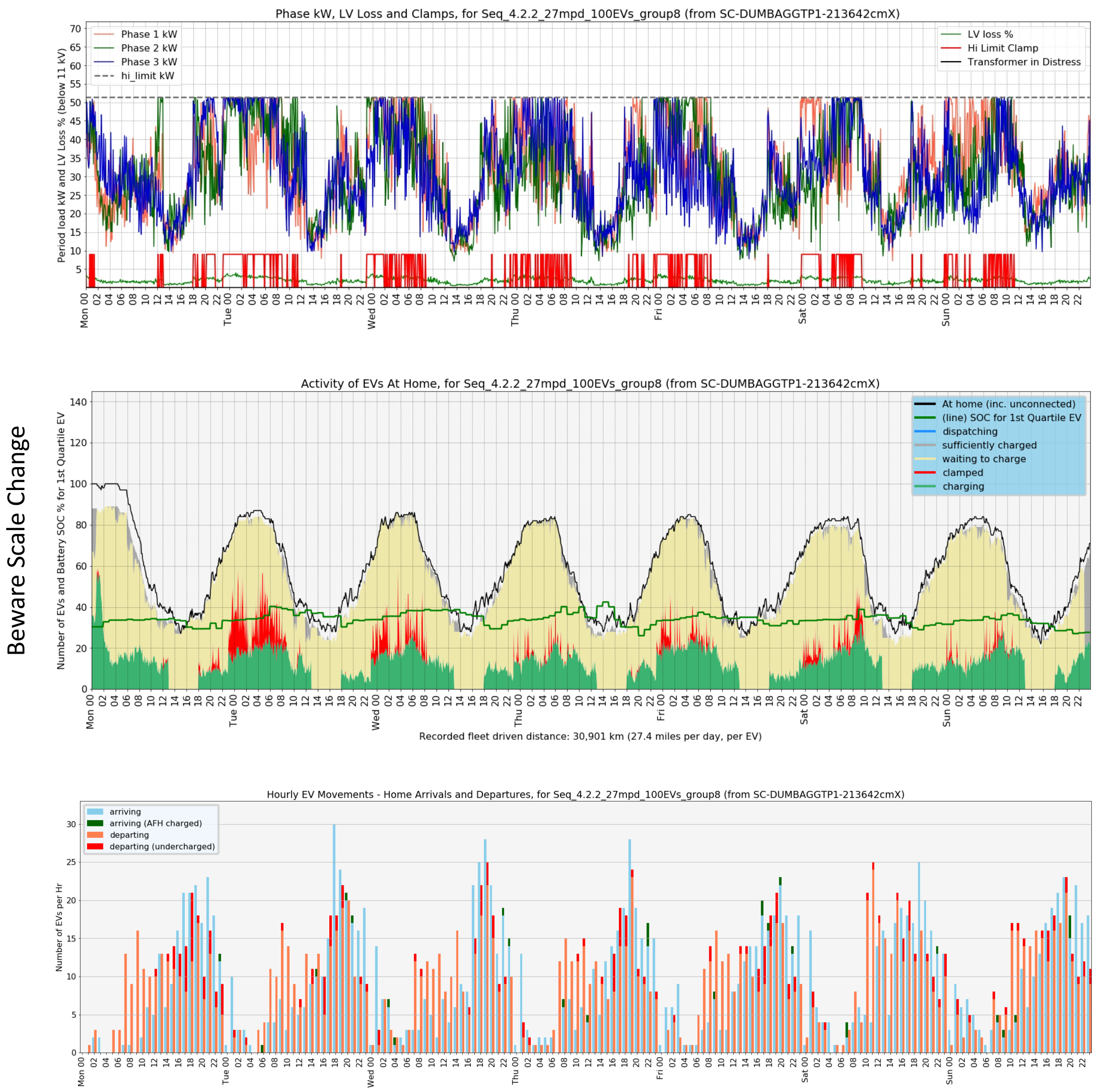
V3-3.4.2.2 Seq_4.2.2: 27mpd 100EVs



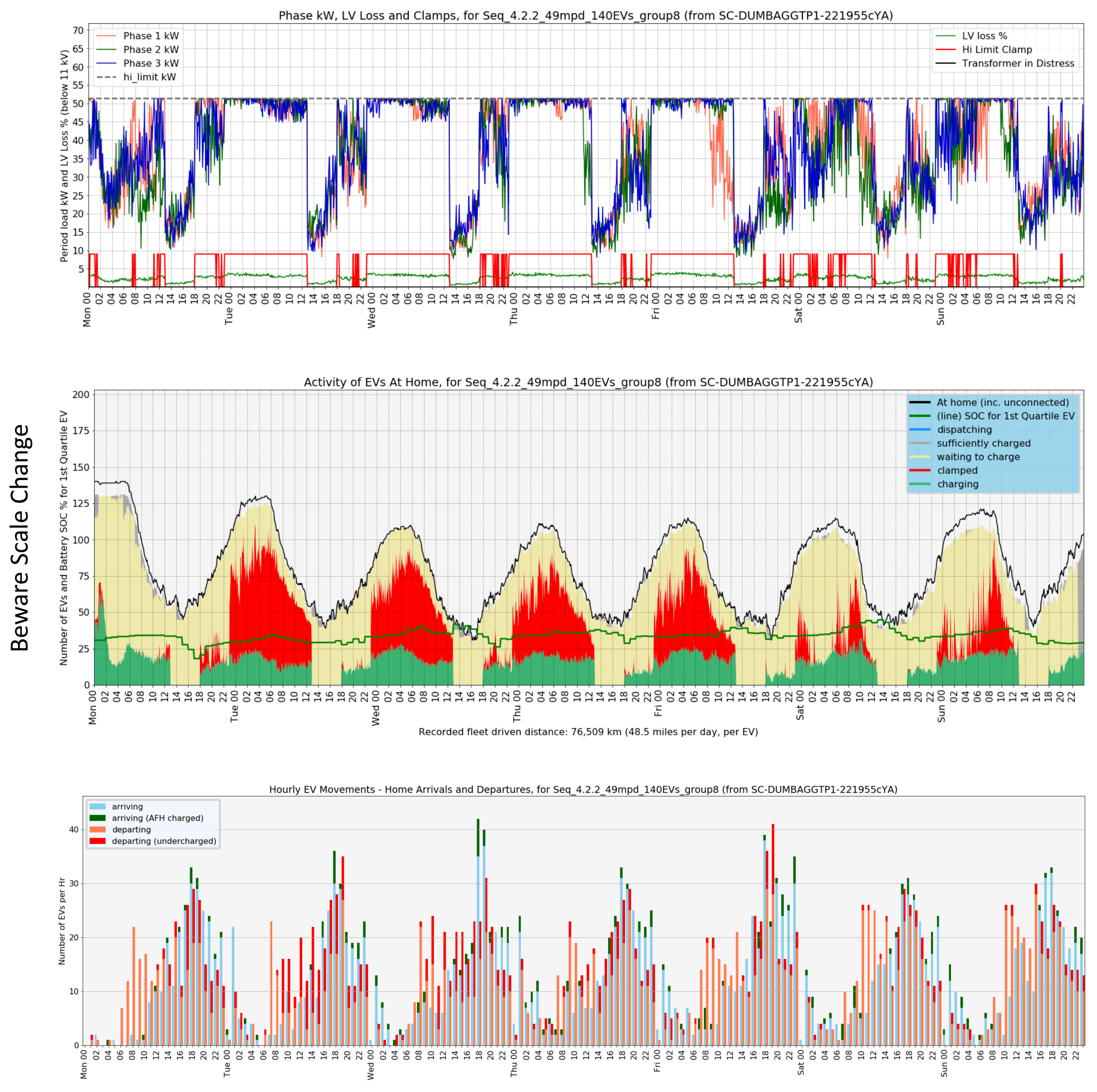
EoW stats: kWh[b] EV total: 5,934 Home: 4,926 AFH: 1,008 V2G: 0

Figure 3-5: Seq_4.2.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,988

Notes re above plots:

- (Feeder) many clamps are seen, eliminating the kW spikes approaching 100 kW on 4.1.2's 27mpd 100 EV plot
- (CICD) clamps and periods of prohibited charging are visible, but has no noticeable impact on the SOC line vs. 4.1.2
- (Arrive/Depart) again almost identical to that of 4.1.2
- so far, the EVs appear unaffected.

V3-3.4.2.3 Seq_4.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,573 Home: 7,819 AFH: 5,754 V2G: 0

Figure 3-6: Seq_4.2.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) clamping is the norm
- (CICD) clamps and periods of prohibited charging are visible, but have no noticeable impact on the SOC line vs. 4.1.2
- (Arrive/Depart) has diverged from 4.1.2
- the EVs continue to seem unaffected. This is unlikely so closer inspection of the data tables is necessary.

V3-3.4.3 Data Tables Seq_4.2.2

Data are from MetaMeta spreadsheets (as online) for Seq_4.2.2 and Seq_3.1.2. Broaches = 0, N out-of-volt range = 0, Fleet km = match both cases. The parity case (UK average mpd with 1:1 household EV penetration) is yellow.

Table 17: Unused kWh (weekly averages) for 4.2.2 vs. 2.1.2.9

Seq_2.1.2.9	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,094	16,401	15,017	13,637	12,285	10,938	9,661	8,338
		27mpd	16,983	16,161	14,546	12,931	11,392	9,865	8,380	3,135
		38mpd	16,893	15,986	14,144	12,315	10,579	8,833	1,848	0
		49mpd	16,814	15,836	13,827	11,864	10,022	5,801	14	0
Seq_4.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,115	16,458	15,145	13,826	12,541	11,263	10,059	8,845
		27mpd	17,020	16,243	14,712	13,194	11,742	10,302	8,954	7,643
		38mpd	16,953	16,105	14,381	12,668	11,060	9,463	8,123	6,910
		49mpd	16,886	15,982	14,134	12,338	10,674	9,032	7,774	6,677
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	20	57	128	188	256	325	398	507
		27mpd	37	82	166	262	351	437	574	4,508
		38mpd	60	119	236	353	480	630	6,275	6,910
		49mpd	72	146	306	474	652	3,231	7,761	6,677

Weekly Average Unused kWh: Baseline 2.1.2.9 (grey), Seq_4.2.2 (yellow).

NB the difference is B - A (Seq_4.2.2 values, less those of Seq_2.1.2.9)

Here, we can see that the network uninitialised capacity has increased. The aggregator, by stopping charging, limits the potential to deliver useful kWh to EVs.

The consequence is that EVs are obliged to get kWh elsewhere i.e. AFH kWh must rise; is this seen in the AFH kWh tables?

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Table 18: Per EV AFH Uptake kWh (weekly averages) for 4.2.2 vs. 2.1.2.9

		N EV	10	20	40	60	80	100	120	140
Seq_2.1.2.9	2. AFH kWh A	19mpd	2.7	3.3	3.3	3.3	3.4	3.6	3.5	3.5
		27mpd	6.6	7.8	7.7	8.0	8.4	8.4	8.3	8.2
		38mpd	17.4	17.5	17.8	18.4	18.2	18.7	18.5	19.1
		49mpd	35.6	33.3	31.7	31.5	31.2	31.2	32.2	34.1
Seq_4.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	3.4	4.0	4.2	4.1	4.3	4.5	4.4	4.5
		27mpd	8.7	9.8	9.5	9.8	10.2	10.1	10.1	10.1
		38mpd	20.6	20.2	21.0	21.5	21.2	21.7	22.4	24.2
		49mpd	40.1	37.3	35.8	35.6	35.6	36.0	38.3	41.1
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.6	0.7	0.8	0.8	0.9	0.8	0.9	0.9
		27mpd	2.1	2.1	1.8	1.9	1.7	1.6	1.8	2.0
		38mpd	3.2	2.8	3.1	3.1	3.0	3.1	3.9	5.1
		49mpd	4.5	4.0	4.1	4.1	4.4	4.8	6.0	7.0

Weekly Average Unused kWh: Baseline 2.1.2.9 (grey), Seq_4.2.2 (yellow).

The EVs need to charge more kWh Away from Home.

Table 19: Per EV N Connects in Week (averages) for 4.2.2 vs. 2.1.2.9

Seq_2.1.2.9

3.	N EV	10	20	40	60	80	100	120	140
A	19mpd	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15
	27mpd	0.29	0.30	0.29	0.30	0.32	0.32	0.31	0.31
	38mpd	0.62	0.61	0.60	0.61	0.61	0.62	0.62	0.65
	49mpd	1.14	1.03	0.96	0.95	0.95	0.95	0.99	1.06

Seq_4.2.2

B	N EV	10	20	40	60	80	100	120	140
	19mpd	0.16	0.18	0.18	0.18	0.18	0.19	0.19	0.19
	27mpd	0.40	0.40	0.37	0.39	0.40	0.40	0.40	0.41
	38mpd	0.76	0.73	0.74	0.74	0.74	0.76	0.79	0.87
	49mpd	1.33	1.19	1.13	1.12	1.13	1.15	1.24	1.34

Difference B - A

C	N EV	10	20	40	60	80	100	120	140
Diff.	19mpd	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	27mpd	0.11	0.10	0.08	0.09	0.08	0.08	0.09	0.10
	38mpd	0.14	0.12	0.13	0.13	0.13	0.13	0.17	0.22
	49mpd	0.19	0.17	0.17	0.17	0.18	0.20	0.25	0.28

Weekly Average Unused kWh: Baseline 2.1.2.9 (grey), Seq_4.2.2 (yellow).

The impact on driver behaviour seems acceptably low. A parity case driver charges away from home on average:

- Seq_2.1.2.9: 1 / 0.32 ≈ once every 3 weeks
- Seq_4.2.2: 1 / 0.4 = once every 2.5 weeks.

However, this does not consider the probability dispersal of AFH plugins; long distance drivers are likely disproportionately effected i.e. carry the burden of the extra plugins.

This implies the need for an unplotted graph: Count of AFH plugins vs. mpd.

Table 20: Severe Undercharging per EV (weekly averages) for 4.2.2 vs. 2.1.2.9

3. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0312	0.0332	0.0355	0.0346	0.0364	0.0382	0.0370	0.0372
	27mpd	0.0734	0.0767	0.0694	0.0647	0.0727	0.0706	0.0730	0.0787
	38mpd	0.1266	0.1395	0.1354	0.1321	0.1320	0.1388	0.1628	0.2231
	49mpd	0.2218	0.1933	0.1920	0.1972	0.1997	0.2274	0.2967	0.3954

(limit: < 0.007)

Light red: failed in 2.1.2.9, deep red: also fails in 4.2.2. Severe undercharging increases; no ply is free. These show:

- there is a significant rise in severe undercharging
- Table 20 shows (by eye) severe undercharging correlates to mpd, less to N EV
- in general, there is an increase in severe undercharging, yet (from the Arrive / Departs plots) we know departing EVs have similar counts of undercharging hence in general there is a tenancy for undercharging:
  - not to increase in count, but
  - to increase in severity of undercharge.

V3-3.4.3.1 Seq_4.2.2 Results Discussion

For the DNO, this sequence has been a great improvement over Seq_4.1.2 but at the expense of the EVs experience. Specifically, longer distance drivers likely encountering:

- increased need of AFH charging, and
- unacceptably increased severe undercharging.

V3-3.5 Sequence 4.3.2

Sequence	Simulation ID	Description
Seq_4.3.2	(S_96)	Variation vs. Seq_4.1.2: Clamps active, priority mode (2); 1 in 4 EVs are V2G; pre-burn_V2G ON and under MCS control (**NB** Time of Use charging restrictions still apply)
Baseline	***Description***	
Seq_4.2.2	*Variation vs. Seq_4.1.2: Aggregator control plus local clamps active, priority mode (2)*	

This is Seq_4.2.2 with clamps plus 1 in 4 EVs can support via V2G. The priority mode is (2) which favours the most needy EVs.

The author expects increased AFH charging and undercharged departs.

V3-3.5.1 Seq_4.3.2 in Summary

Clamps are effective with some improvement in undercharging, however even with V2G there are too many undercharges. No ply is free for excessive undercharging:

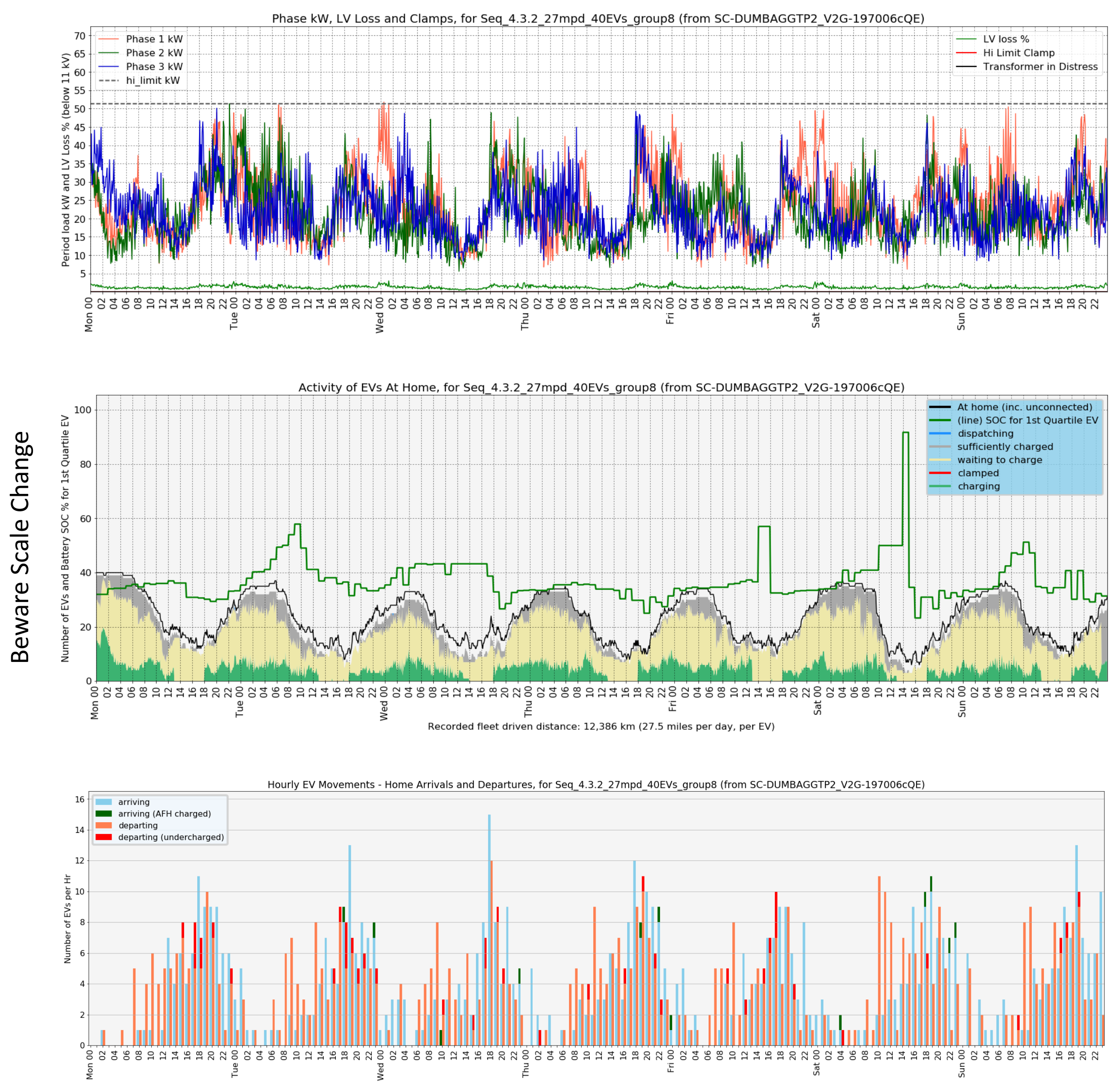
Table 21: Severe Undercharging per EV (weekly averages) for 4.3.2

3. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0268	0.0256	0.0250	0.0254	0.0268	0.0287	0.0277	0.0274
	27mpd	0.0546	0.0587	0.0512	0.0475	0.0528	0.0507	0.0510	0.0499
	38mpd	0.1068	0.1086	0.1050	0.0999	0.1012	0.1019	0.1044	0.1334
	49mpd	0.1966	0.1486	0.1517	0.1544	0.1520	0.1560	0.1863	0.2662

(limit: < 0.007)

V3-3.5.2 Seq_4.3.2: Feeder and EV Plots

V3-3.5.2.1 Seq_4.3.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,314 Home: 1,986 AFH: 355 V2G: 1

Figure 3-7: Seq_4.3.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,315

Notes re above plots:

- the Feeder clamps seen in 4.2.2 are now gone
- EV SOC however remains in the 30 - 50% band
- there is a small diminution of undercharged departs and use of AFH charging.

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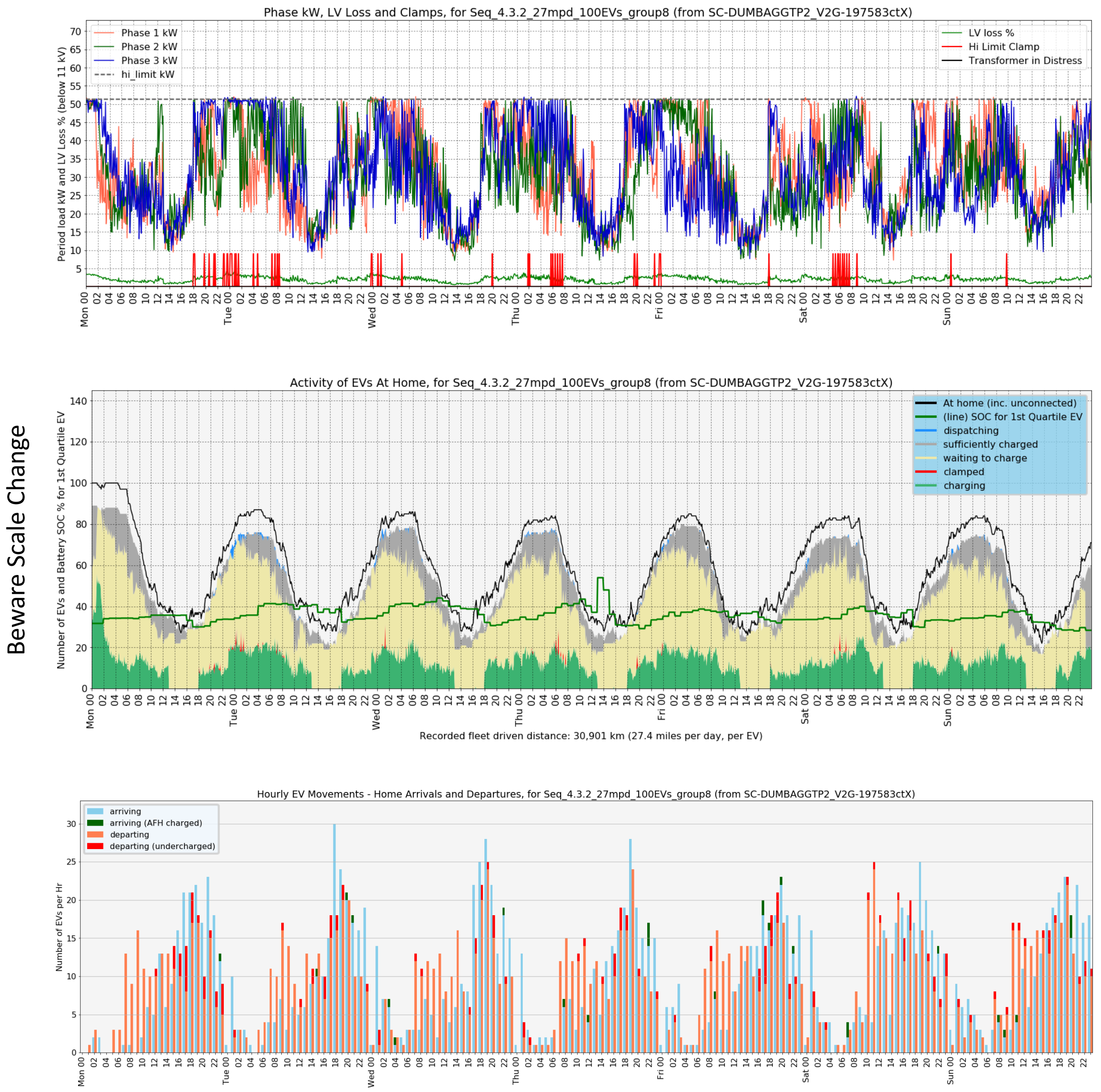
V3-3.5.2.2 Seq_4.3.2: 27mpd 100EVs



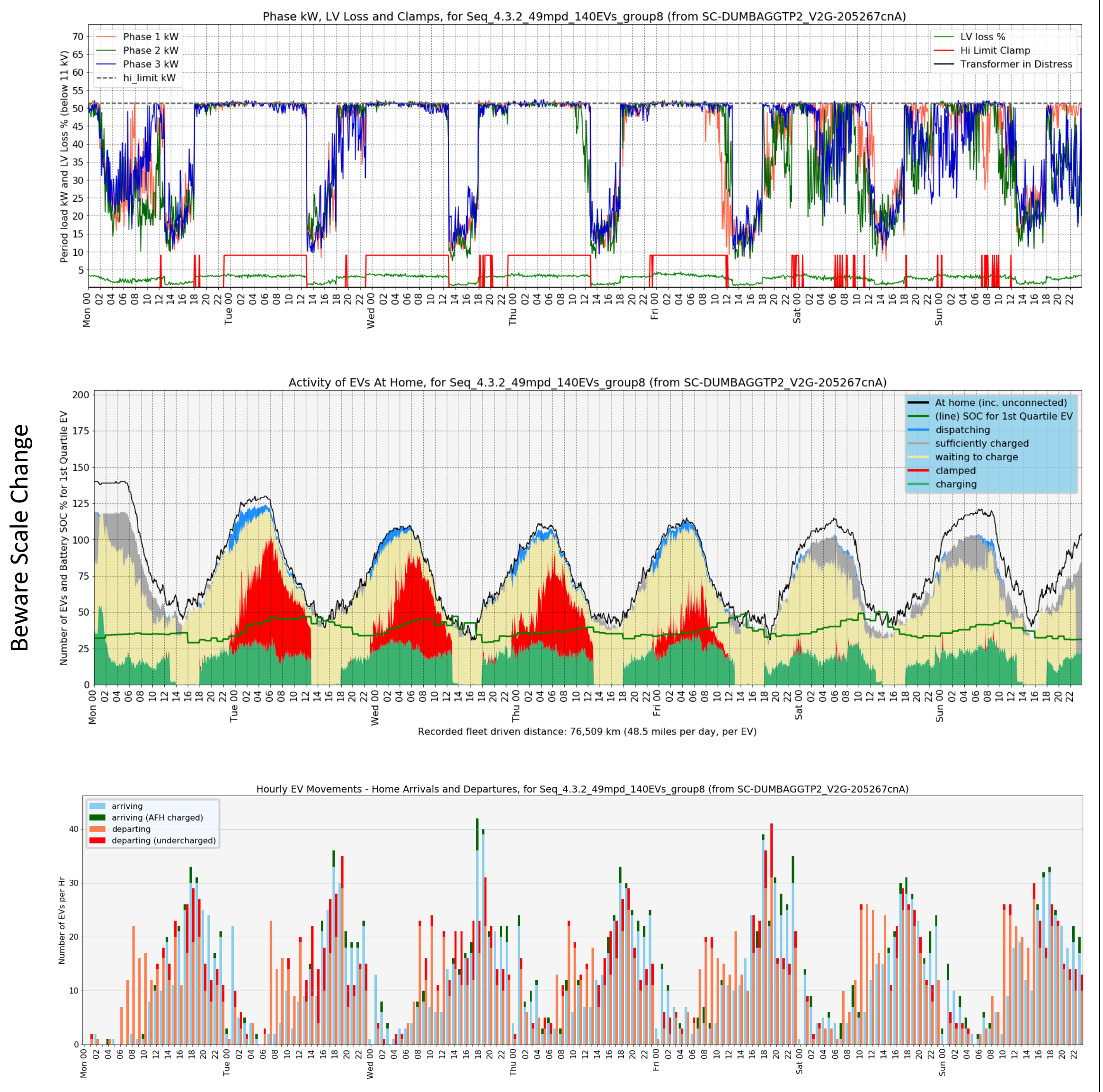
EoW stats: kWh[b] EV total: 5,923 Home: 5,068 AFH: 944 V2G: 109

Figure 3-8: Seq_4.3.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,988

Notes re above plots:

- the incidence of clamping is visibly diminished vs. 4.2.2
- in the CICD plot, clamping which was clear in 4.2.2 is now near absent. There is occasional V2G (in blue)
- undercharging and AFH charging is very similar to that in 4.2.2.

V3-3.5.2.3 Seq_4.3.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,400 Home: 9,205 AFH: 5,195 V2G: 834

Figure 3-9: Seq_4.3.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,227

Notes re above plots:

- the Feeder plot shows much more use of available capacity vs. 4.2.2
- in CICD plot, clamping is reduced and V2G is seen
- undercharging and AFH charging appears similar to 4.2.2.

Why is this? The author suspects the available network kWh (be definition, less the portion excluded by aggregator control) is down. Ultimately, V2G is a lossy method. Frequent V2G use of may erode kWh for driving, wasting kWh as heat.

V3-3.5.3 Data Tables Seq_4.3.2

Data are from MetaMeta spreadsheets (as online) for Seq_4.2.2 and Seq_4.3.2. Broaches = 0, N out-of-volt range = 0, Fleet km = match both cases. The parity case (UK average mpd with 1:1 household EV penetration) is yellow.

Table 22: Unused kWh (weekly averages) for 4.3.2 vs 4.2.2

Seq_4.2.2	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,115	16,458	15,145	13,826	12,541	11,263	10,059	8,845
		27mpd	17,020	16,243	14,712	13,194	11,742	10,302	8,954	7,643
		38mpd	16,953	16,105	14,381	12,668	11,060	9,463	8,123	6,910
		49mpd	16,886	15,982	14,134	12,338	10,674	9,032	7,774	6,677
Seq_4.3.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,114	16,469	15,180	13,885	12,609	11,329	10,064	8,742
		27mpd	17,014	16,243	14,725	13,208	11,739	10,233	8,735	7,174
		38mpd	16,941	16,088	14,361	12,625	10,956	9,193	7,561	5,952
		49mpd	16,875	15,953	14,086	12,243	10,479	8,581	6,941	5,496
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-1	11	35	59	69	66	5	-103
		27mpd	-7	0	13	14	-3	-68	-219	-469
		38mpd	-12	-17	-19	-43	-104	-269	-563	-958
		49mpd	-12	-29	-48	-95	-195	-451	-833	-1,180

Here, the network unutilised capacity has dropped. As suggested by the Feeder graphs, the EVs are making greater use of network capacity. What impact does this have on the AFH kWh tables?

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Table 23: Per EV AFH Uptake kWh (weekly averages) for 4.3.2 vs. 4.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_4.2.2	2. AFH kWh A	19mpd	3.4	4.0	4.2	4.1	4.3	4.5	4.4	4.5
		27mpd	8.7	9.8	9.5	9.8	10.2	10.1	10.1	10.1
		38mpd	20.6	20.2	21.0	21.5	21.2	21.7	22.4	24.2
		49mpd	40.1	37.3	35.8	35.6	35.6	36.0	38.3	41.1
Seq_4.3.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	3.2	3.7	3.8	3.8	4.0	4.2	4.1	4.1
		27mpd	8.1	9.3	8.9	9.2	9.6	9.4	9.5	9.3
		38mpd	19.6	19.2	19.9	20.5	20.2	20.5	20.6	21.4
		49mpd	39.1	35.8	34.4	34.2	34.1	33.9	35.0	37.1
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.16	-0.32	-0.33	-0.30	-0.30	-0.31	-0.32	-0.34
		27mpd	-0.59	-0.53	-0.58	-0.60	-0.59	-0.64	-0.68	-0.89
		38mpd	-1.04	-1.06	-1.05	-1.01	-1.00	-1.24	-1.86	-2.81
		49mpd	-0.98	-1.48	-1.40	-1.41	-1.48	-2.07	-3.29	-3.99

The EVs required less kWh Away from Home.

Table 24: Per EV N Connects in Week (averages) for 4.3.2 vs. 4.2.2

Seq_4.2.2

3. A	N EV	10	20	40	60	80	100	120	140
	19mpd	0.16	0.18	0.18	0.18	0.18	0.19	0.19	0.19
	27mpd	0.40	0.40	0.37	0.39	0.40	0.40	0.40	0.41
	38mpd	0.76	0.73	0.74	0.74	0.74	0.76	0.79	0.87
	49mpd	1.33	1.19	1.13	1.12	1.13	1.15	1.24	1.34

Seq_4.3.2

B	N EV	10	20	40	60	80	100	120	140
	19mpd	0.15	0.16	0.16	0.16	0.17	0.18	0.18	0.18
	27mpd	0.37	0.38	0.35	0.36	0.37	0.37	0.37	0.36
	38mpd	0.71	0.68	0.69	0.69	0.69	0.70	0.71	0.74
	49mpd	1.28	1.12	1.06	1.06	1.06	1.06	1.10	1.18

Difference B - A

C Diff.	N EV	10	20	40	60	80	100	120	140
	19mpd	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.02
	27mpd	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04
	38mpd	-0.05	-0.05	-0.05	-0.05	-0.05	-0.06	-0.09	-0.13
	49mpd	-0.05	-0.07	-0.06	-0.06	-0.07	-0.09	-0.14	-0.16

The impact here is a c. 10% reduction in the need to AFH charge.

Table 25: Per EV Severe Undercharging Events in Week (averages) for 4.3.2 vs. 4.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_4.2.2	4. A	19mpd	0.0312	0.0332	0.0355	0.0346	0.0364	0.0382	0.0370	0.0372
		27mpd	0.0734	0.0767	0.0694	0.0647	0.0727	0.0706	0.0730	0.0787
		38mpd	0.1266	0.1395	0.1354	0.1321	0.1320	0.1388	0.1628	0.2231
		49mpd	0.2218	0.1933	0.1920	0.1972	0.1997	0.2274	0.2967	0.3954
Seq_4.3.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0268	0.0256	0.0250	0.0254	0.0268	0.0287	0.0277	0.0274
		27mpd	0.0546	0.0587	0.0512	0.0475	0.0528	0.0507	0.0510	0.0499
		38mpd	0.1068	0.1086	0.1050	0.0999	0.1012	0.1019	0.1044	0.1334
		49mpd	0.1966	0.1486	0.1517	0.1544	0.1520	0.1560	0.1863	0.2662
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.0044	-0.0076	-0.0105	-0.0092	-0.0097	-0.0095	-0.0093	-0.0098
		27mpd	-0.0188	-0.0180	-0.0182	-0.0173	-0.0199	-0.0199	-0.0219	-0.0288
		38mpd	-0.0198	-0.0309	-0.0304	-0.0322	-0.0309	-0.0369	-0.0584	-0.0897
		49mpd	-0.0252	-0.0447	-0.0403	-0.0428	-0.0477	-0.0714	-0.1104	-0.1292

These show a useful but modest diminution of severe undercharging, yet all are unacceptable vs. the maximum allowed 0.007 events per week.

V3-3.5.3.1 Seq_4.3.2 Results Discussion

This sequence has explored the introduction of “blind” aggregator control, demonstrating that such control has the capacity to effect both the LV network and EVs negatively.

From this, it can be said:

- the aggregator control strategies adopted need to spread loads rather than impose “cliff edges”, however
- that might not be what the aggregator is contracted for, for they are involved with unaware 3rd parties and may be doing exactly what is required by contract
- thus: a conflict of interest.

Is there a need to tie the contracts together OR for Ofgem to require a compensatory clause which imposes a financial burden? Yet, from the DNO viewpoint,

- clamps are clearly very necessary
- the presence of V2G under MCS control is useful for all parties
- however the author still suspects that in extremis V2G cannot alone be an answer - the lossy aspect of V2G which robs kWh for driving raises overall losses.

What constructive suggestions flow? Perhaps further investigation on the potential for fine-grained aggregator control levels e.g. 10% steps 10% to 80%.

A major case not investigated: Multiple aggregators controlling EVs on the network, with similar or contradictory contracts. This is likely in the real world. Nissan sell a range of DR services based on their existing ability to control Leaf EVs remotely. The drivers have bought into whatever deal Nissan arranges, as built into Nissan contracts (Leaf batteries are hired monthly; drivers are in a contract with Nissan).

However power retailers now offer discounted charging schemes “for EVs” which make use of discounted overnight rates. What happen when a Nissan EV is involved via the household domestic contract, on a network owned by a DNO who employ a clamping scheme similar to WPD’s Electric Nation model?

There is clear opportunity for a three-way control split / left hands vs. right hands confusions. An example: Nissan may be contracted to NGESO for V2G support. Suppose NGESO choose to call on this as generation is low - yet at the same time, EV X on the same phase is charging on “cheap overnight electricity” which does no more than consume charge from the V2G Leaf. The call to Nissan has not assisted, for EV X has consumed the power. The overall grid sees no extra power, so NGESO call on a gas-fuelled generator.

Also, V2G incurs losses of up to 50% arise (see Thesis section on V2G) and all that happens is that power is wasted => excess CO2 from generation occurs.

The extent of this issue cannot be determined at this time, for it is conditional on the contracts in force and the interplay of these.

The key problem is that there is no party with top-level management remit exists, who has an overview of whole system dynamic operation. Clearly, the system needs to be managed as a whole, not as a set of Balkanised pieces.

Further, the DNO is strongly advised to have some form of local MCS which can manage clamps and keep phases in reasonable balance; at this time there is no constraint on the execution of contracts which damage their networks.

The situation in Seq_4.1.2 is possible today; extremes of charging happening overnight.

From the EVs viewpoint, this is better but not adequate:

Table 26: Severe Undercharging per EV (weekly averages) for 4.3.2

5. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0268	0.0256	0.0250	0.0254	0.0268	0.0287	0.0277	0.0274
	27mpd	0.0546	0.0587	0.0512	0.0475	0.0528	0.0507	0.0510	0.0499
	38mpd	0.1068	0.1086	0.1050	0.0999	0.1012	0.1019	0.1044	0.1334
	49mpd	0.1966	0.1486	0.1517	0.1544	0.1520	0.1560	0.1863	0.2662

(limit: < 0.007)

Red: failed in 4.3.2. No ply is adequate.

Conclusion

Both MCS and V2G assist the situation from the viewpoint of the EV. Yet, exactly what outcomes of this effort is of worth to the DNO? They have forestalled the need for upgrades, sought to retain the good temper of their domestic customers, other than in Seq_4.3.2, in which EVs become severely undercharged.

V3-3.6 Sequence 4 in Summary

Aggregator-effected DSR signalling to enforce high-level control, to offer national peak load management without local MCS or similar, has been shown to cause serious side-effects to both local networks (provocation of broaching) and EVs (undercharging).

The author cannot recommend the method.

However, the recent DfT call for input ("Open consultation: Electric Vehicle Smart Charging") expresses intent of the UK Government to implement exactly such a system. The author replied to the call in "SRB_DfT_Response_EVSC.pdf" (present in the data repository Folder 1) militating against such Aggregator-effected DSR and explaining why.

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Vol 3 Chapter 4: Sequence Set 5: 5.1.1 to 5.7.2

These sequences model a Managed Charging System (MCS) without clamps, to control a range of scenarios. These include with / without V2G, adjusting residential loads, adding static batteries and another Aggregator scenario as follows:

Sequence	**Simulation ID**	**Description**
Seq_5.1.1	(S_BM)	Winter, Weak network, NEV, mpd sets, 19% dumb EVs, 48% SV1G, 33% V2G, no clamps, pre-burn_V2G default ON, hi_limit 39 kW, normal plugin regime. There is no DR/FFR signal. *(Baseline: Seq_1.1.1)*
Seq_5.1.2	(S_66)	Variation vs. Seq_1.1.2: MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit. *(Baseline: Seq_1.1.2)*
Seq_5.1.2.1	(S_AW)	As 5.1.2, but residential loads are reduced to 1 kW, from apparent load ADMD 1.3 kW aka “Res Loads Down” *(Baseline: Seq_5.1.2)*
Seq_5.1.2.2	(S_AX)	As 5.1.2, but residential loads are increased to 1.6 kW, from apparent load ADMD 1.3 kW aka “Res Loads Up” *(Baseline: Seq_5.1.2)*
Seq_5.1.3	(S_B3)	Variation vs. Seq_1.1.2: MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Strong (2.0 kW ADMD) network; 65 kW hi_limit per phase. *(Baseline: Seq_1.1.3)*
Seq_5.2.2	(S_87)	As 5.1.2, now with the DR-B FFR value-added service pattern, added by modulation of the hi_limit. *(Baseline: Seq_5.1.2)*
Seq_5.3.2	(S_86)	As 5.2.2 plus Agg-B (daily ToU rules: No Charging from 1pm, then from 6pm only charge if < 1/3rd SOC, then unconstrained charging 11pm on) applied as a direct instruction to Aggregator controlled EVs (all). *(Baseline: Seq_5.2.2)*
Seq_5.4.2	(S_AU)	As 5.2.2 plus 9 Static Batteries (3 per phase). *(Baseline: Seq_5.2.2)*

Sequence	Simulation ID	Description
Seq_5.5.2	(S_B8)	As 5.4.2 with 2kW PV per home. *(Baseline: Seq_5.4.2)*
Seq_5.6.2	(S_BB)	As 5.1.2 with SV1G smart EVs replacing V2G types. EV mix is now 19% dumb, 81% SV1G. *(Baseline: Seq_5.1.2)*
Seq_5.7.2	(S_A0)	Agg-B (daily ToU rules) reduced from 100% EV control to 1 in 4 EVs. There is no DRFFR signal. *(Baseline: Seq_5.1.2)*

V3-4.1 Broaching

All sequences experienced broaches, with 5.1.3 being exceptional at only experiencing 6 for the most extreme case of 49mpd, 140 EVs. This shows a 2 kW network, operated with MCS, is almost adequate.

Table 27: Average Weekly Broaches for 1.1.2 and 5.1.2

Seq_1.1.2

1. A	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	11	60	249	349	333
	27mpd	0	0	2	53	203	383	358	344
	38mpd	0	0	7	125	357	371	352	380
	49mpd	0	0	10	188	383	360	392	439

Baseline 1.1.2

Seq_5.1.2

B	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	0	0	7	1	1
	27mpd	0	0	0	0	3	35	4	27
	38mpd	0	0	0	1	14	87	75	380
	49mpd	0	0	0	13	30	202	354	478

Improved plies free of broaches in 5.1.2 are colourised green

There are improvements for all plies, except the extreme case.

V3-4.2 Summary of Set 5 Findings

Overall there is progress in reducing broaches while aiding EV charging. The Weak network remains severely challenged, the Typical does cope better with Strong providing a near perfect outcome - given no external disrupters such as DRFFR or Aggregator Time of Use signals. These impact performance, the Aggregator severely degrading undercharging.

Varying residential loads in 5.1.2.1 and 5.1.2.2 shows an inverse impact on ability for EVs to charge; as residential loads rise so EV charging and broaches suffer.

Local support from embedded PV panels and Static Batteries (local energy reserves) is found useful. Static Batteries can stand in for V2G, especially as static energy stores enjoy daytime PV charging, a period when EVs are likely absent so go without PV benefit.

V3-4.3 Results for Sequence 5.1.1

Sequence	**Simulation ID**	**Description**
Seq_5.1.1	(S_BM)	Winter, Weak network, NEV, mpd sets, 19% dumb EVs, 48% SV1G, 33% V2G, no clamps, pre-burn_V2G default ON, hi_limit 39 kW, normal plugin regime. There is no DR/FFR signal. *(Baseline: Seq_1.1.1)*
Baseline	***Description***	
Seq_1.1.1	*Winter, all EVs dumb, no clamps, no MCS, Typical network, hi_limit 39 kW, normal plugin regime*	

V3-4.3.1 Broaching

Broaching is slightly lowered vs. Seq_1.1.1, but still effects 25 of 32 ply cells.

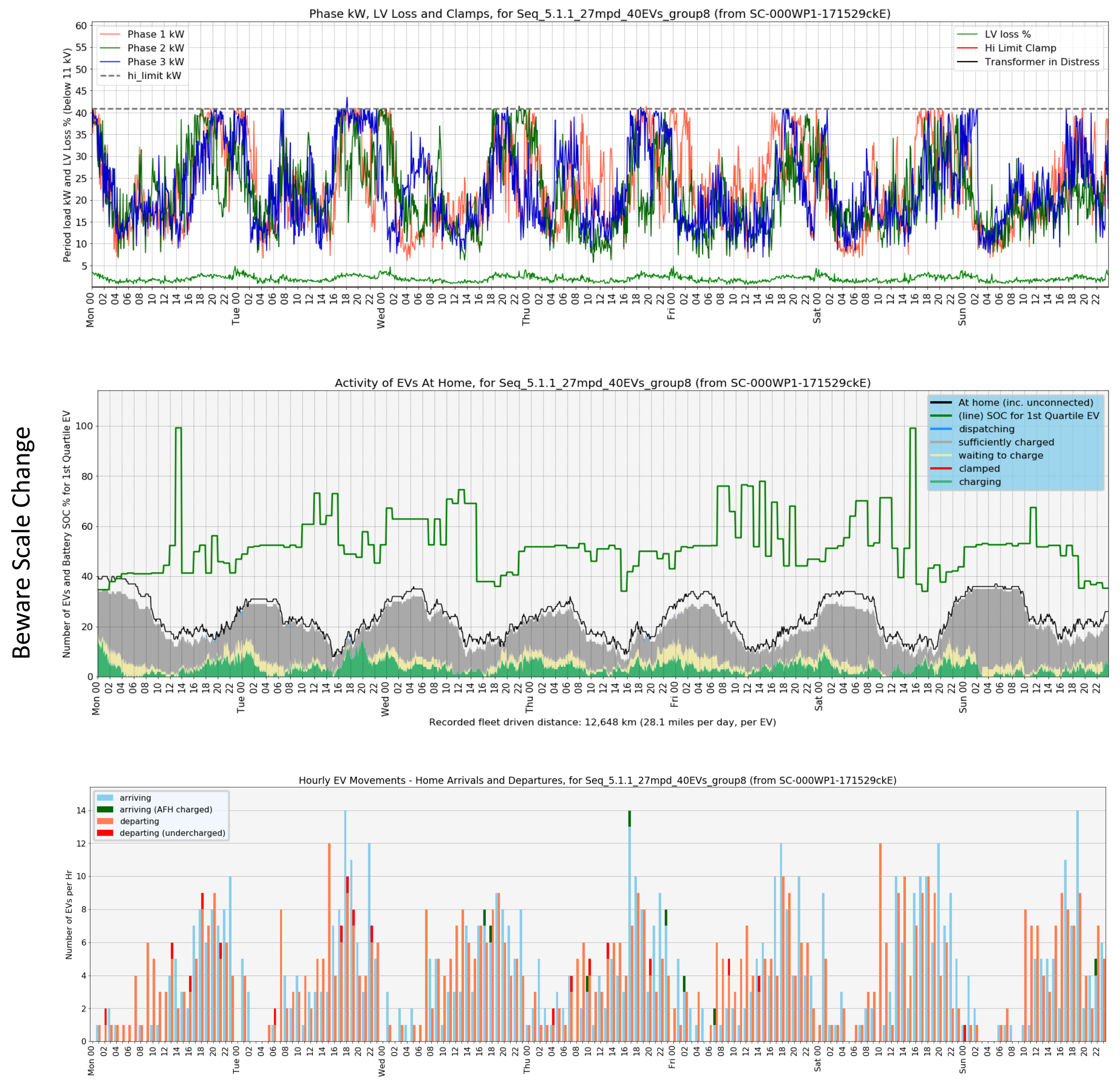
V3-4.3.2 Seq_5.1.1 in Summary

Seq_5.1.1 advances on 1.1.1 in terms of reduced broaches and better EV charging.

However, the solution is still inadequate; local overloads remain.

V3-4.3.3 Seq_5.1.1: Feeder and EV Plots

V3-4.3.3.1 Seq_5.1.1 Plots: 27mpd 40EVs



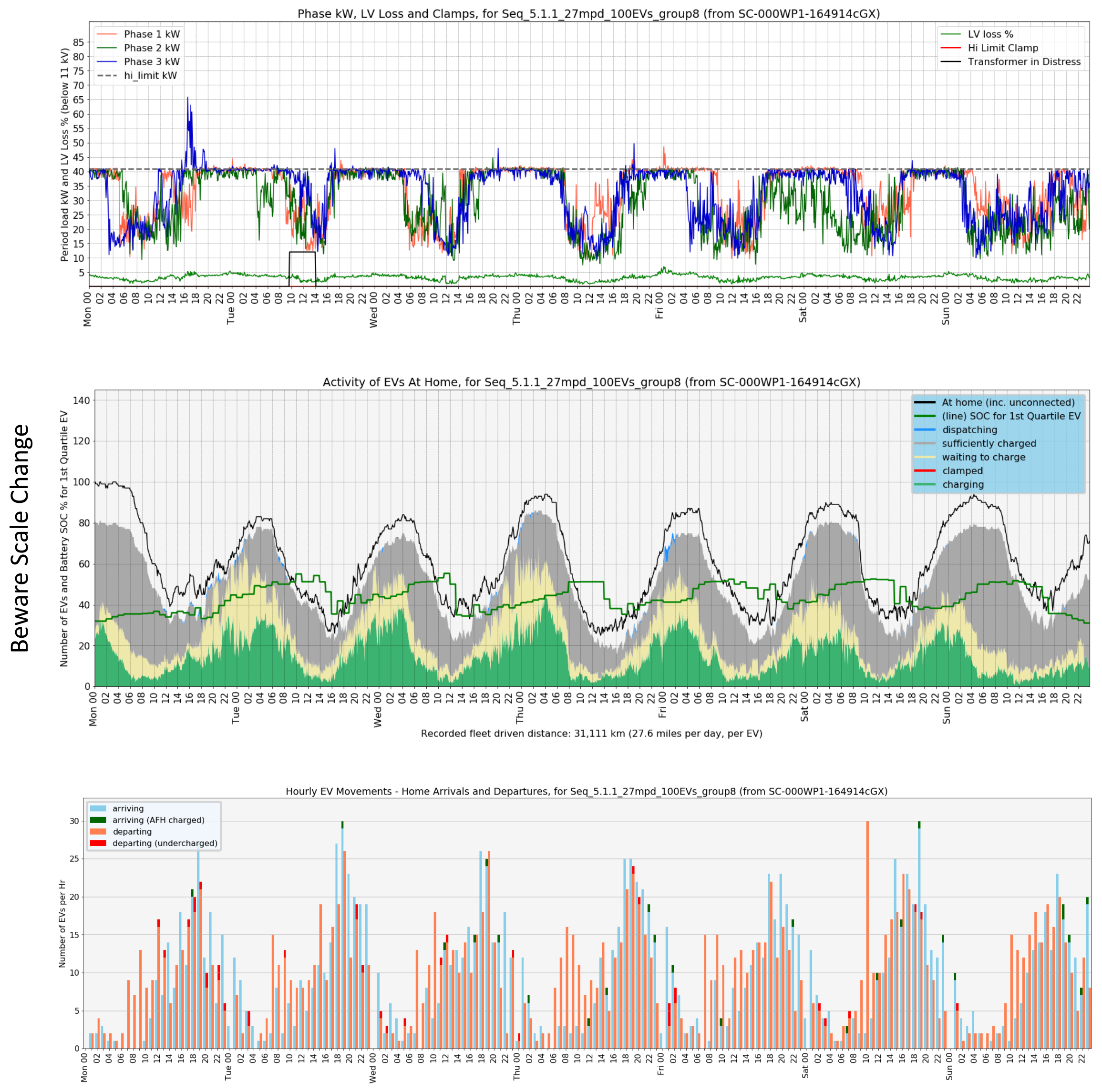
EoW stats: kWh[b] EV total: 2,320 Home: 2,028 AFH: 293 V2G: 6

Figure 4-1: Seq_5.1.1 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,262

Notes re above plots:

- (Feeder) there are occasional feeder kW peaks which are too high
- (CICD) the majority of EVs are charged and waiting to depart; a radical difference vs. the corresponding 1.1.1 CICD plot which has near-all non-charging EVs cream / waiting to charge (Vol. 1, Fig. 3-1). EV SOC levels here are c. 10% higher than 1.1.1
- (Arrive/Depart) has few departing undercharged or AFH charging, broadly similar to 1.1.1.

V3-4.3.3.2 Seq_5.1.1: 27mpd 100EVs



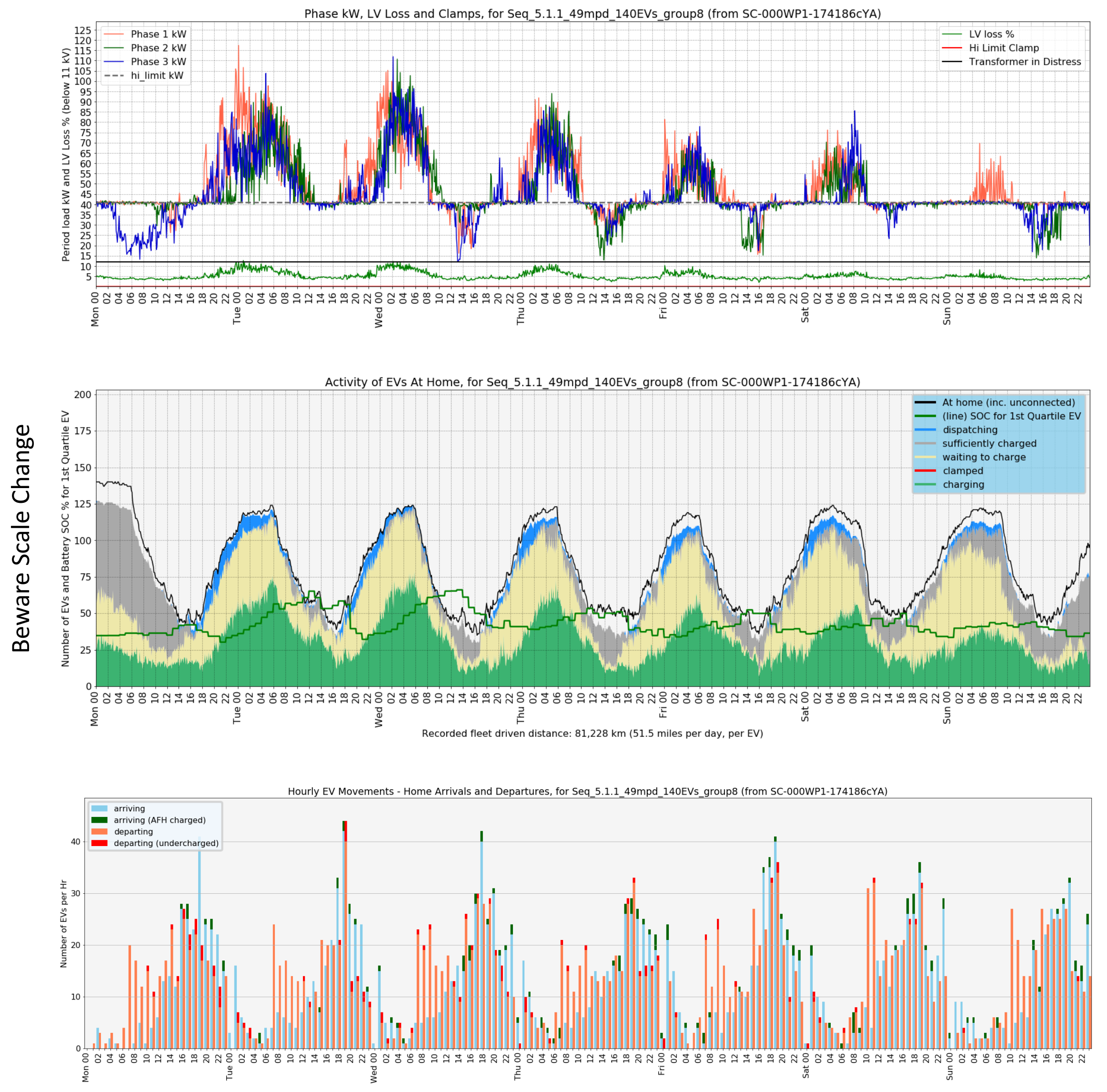
EoW stats: kWh[b] EV total: 6,039 Home: 5,234 AFH: 804 V2G: 125

Figure 4-2: Seq_5.1.1 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,976

Notes re above plots:

- (Feeder) here, occasional spikes peak kW c. 65 kW, with clear broaching of mandatory chargers
- (CICD) many EVs are ready to depart, with some V2G activity. SOC levels are higher than for the corresponding 1.1.1 CICD plot;
- (Arrive/Depart) elevated undercharged departs and AFH charging.

V3-4.3.3.3 Seq_5.1.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 15,181 Home: 10,883 AFH: 4,298 V2G: 1,586

Figure 4-3: Seq_5.1.1 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,220

Notes re above plots:

- (Feeder) extreme broaching is present; the transformer is persistently overloaded
- (CICD) few weekday EVs are charged and waiting to depart; considerable V2G activity. Charging counts are up vs. 1.1.1 CICD
- (Arrive/Depart) elevated undercharging and AFH activity.

The charging rate increase is associated with a home-charging kWh increase vs 1.1.1, up from 13,560 to 15,181 kWh. The author supposes this is due to V2G activity; the V2G spend of 1,586 kWh causing extra local charging.

V3-4.3.4 Data Tables Seq_5.1.1

Data are from MetaMeta spreadsheets (as online) for Seq_1.1.1 and Seq_5.1.1. There were 25 plies with broaches, 7 plies (worst: c. 1hour a week) under-volts. The parity case (UK average mpd with 1:1 household EV penetration) is yellow. Broached plies are red.

Table 28: Unused kWh (weekly averages) for 1.1.1 vs 5.1.1

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.1	1. Unused kWh A	19mpd	11,814	11,128	9,771	8,408	7,072	5,721	4,436	3,085
		27mpd	11,701	10,884	9,293	7,688	6,151	4,582	3,071	1,495
		38mpd	11,621	10,719	8,889	7,071	5,327	3,518	1,840	14
		49mpd	11,540	10,563	8,578	6,625	4,760	2,798	968	-994
Seq_5.1.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	11,831	11,199	9,944	8,659	7,342	5,977	4,646	3,263
		27mpd	11,716	10,946	9,426	7,872	6,300	4,649	3,003	1,198
		38mpd	11,620	10,752	8,966	7,138	5,298	3,316	1,389	-730
		49mpd	11,532	10,577	8,613	6,606	4,634	2,426	305	-1,932
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	17	71	173	251	270	256	209	178
		27mpd	16	62	132	184	149	67	-68	-297
		38mpd	-1	33	77	67	-29	-203	-451	-744
		49mpd	-8	14	35	-19	-126	-372	-663	-938

The difference table shows higher consumption (less headroom) at extremes of N EV, but the author does not regard this as significant.

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Table 29: Per EV AFH Uptake kWh (weekly averages) for 1.1.1 vs 5.1.1

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.1	2. AFH kWh A	19mpd	2.7	3.2	3.3	3.2	3.3	3.5	3.5	3.5
		27mpd	6.9	7.8	7.6	7.9	8.1	8.1	8.1	7.9
		38mpd	17.0	16.6	17.4	18.0	18.0	18.2	18.2	18.1
		49mpd	34.3	32.4	30.8	30.9	30.7	30.5	31.0	30.8
Seq_5.1.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	2.9	3.1	3.0	3.2	3.4	3.3	3.4
		27mpd	6.4	7.5	7.3	7.6	8.1	8.0	8.0	7.9
		38mpd	16.5	16.2	16.8	17.4	17.4	17.8	17.9	18.0
		49mpd	34.0	31.7	30.1	30.0	30.1	30.1	30.6	30.7
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1
		27mpd	-0.5	-0.4	-0.3	-0.3	0.0	-0.1	-0.1	0.0
		38mpd	-0.5	-0.4	-0.6	-0.6	-0.6	-0.4	-0.3	-0.2
		49mpd	-0.3	-0.7	-0.7	-0.8	-0.6	-0.5	-0.4	-0.1

EVs require less kWh AFH, implying driving kWh are met “the more adequately” at home.

Table 30: Difference in total counts of Undercharges Seen in Week for 1.1.1 vs 5.1.1

		N EV	10	20	40	60	80	100	120	140
Difference B - A	3. Diff.	19mpd	-5.0	-9.6	-14.2	-20.1	-22.3	-24.7	-32.3	-31.2
		27mpd	-6.0	-11.5	-19.4	-25.4	-27.2	-31.3	-36.7	-29.8
		38mpd	-5.6	-11.5	-17.8	-25.4	-25.2	-25.7	-26.4	-20.9
		49mpd	-4.9	-9.4	-15.5	-21.6	-22.9	-24.3	-22.3	-15.0

There is a consistent improvement in numbers of undercharged EVs. NB Parity case undercharges for 1.1.1 is: 177 i.e. 18% improvement.

Table 31: Per EV N Connects in Week (averages) for 1.1.1 vs 5.1.1

Seq_1.1.1	4. A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.13	0.14	0.14	0.13	0.14	0.15	0.15	0.14
		27mpd	0.30	0.31	0.29	0.30	0.31	0.31	0.31	0.30
		38mpd	0.60	0.58	0.59	0.59	0.60	0.61	0.61	0.61
		49mpd	1.11	1.01	0.94	0.94	0.94	0.93	0.95	0.94
Seq_5.1.1	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14
		27mpd	0.28	0.29	0.27	0.28	0.31	0.30	0.30	0.30
		38mpd	0.57	0.56	0.56	0.57	0.58	0.59	0.59	0.60
		49mpd	1.08	0.96	0.90	0.90	0.91	0.91	0.92	0.93
Difference B - A	**C Diff.**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	0.00
		27mpd	-0.03	-0.02	-0.01	-0.01	0.00	0.00	-0.01	0.00
		38mpd	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.01	-0.01
		49mpd	-0.03	-0.05	-0.04	-0.04	-0.03	-0.02	-0.03	-0.01

The impact here is a small, near insignificant reduction in the need to AFH charge.

Table 32: Per EV Severe Undercharging Events in Week (averages) for 1.1.1 vs 5.1.1

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.1	5. A	19mpd	0.0000	0.0003	0.0003	0.0003	0.0004	0.0002	0.0002	0.0002
		27mpd	0.0002	0.0005	0.0008	0.0011	0.0009	0.0009	0.0008	0.0008
		38mpd	0.0004	0.0025	0.0020	0.0029	0.0022	0.0027	0.0028	0.0029
		49mpd	0.0020	0.0036	0.0036	0.0044	0.0051	0.0053	0.0046	0.0049
Seq_5.1.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0006	0.0004	0.0002	0.0001	0.0002	0.0002	0.0003	0.0002
		27mpd	0.0000	0.0006	0.0006	0.0010	0.0010	0.0012	0.0010	0.0009
		38mpd	0.0006	0.0013	0.0014	0.0023	0.0022	0.0025	0.0029	0.0030
		49mpd	0.0028	0.0036	0.0033	0.0040	0.0048	0.0059	0.0047	0.0048
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0006	0.0001	-0.0001	-0.0002	-0.0002	-0.0001	0.0000	0.0000
		27mpd	-0.0002	0.0001	-0.0002	-0.0002	0.0001	0.0003	0.0002	0.0001
		38mpd	0.0002	-0.0012	-0.0007	-0.0006	0.0000	-0.0002	0.0001	0.0001
		49mpd	0.0008	0.0000	-0.0003	-0.0003	-0.0003	0.0006	0.0001	-0.0001

These show a variable, modest diminution of severe undercharging.

V3-4.3.4.1 Seq_5.1.1 Results Discussion

This sequence has explored using the MCS to control EVs on a Weak (1.2 kW ADMD) network. Compared to Seq_1.1.1, which has no control, there is modest but noticeable improvement; broaches still occur but the lot of both EVs and the network are improved.

Conclusion

Both the MCS and V2G assist the situation. However other than for modest number of EVs the scenario is inadequate; local overloads still occur.

V3-4.4 Sequence 5.1.2

Sequence	Simulation ID	Description
Seq_5.1.2	(S_66)	Variation vs. Seq_1.1.2: MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.
Baseline	***Description***	
Seq_1.1.2	*Winter, all dumb EVs on Typical network (1.5 kW ADMD)*	

This is Seq_1.1.2 with Smart EVs and an MCS controller. The 19% dumb EVs have BLPs but ignore local control.

V3-4.4.1 Broaching

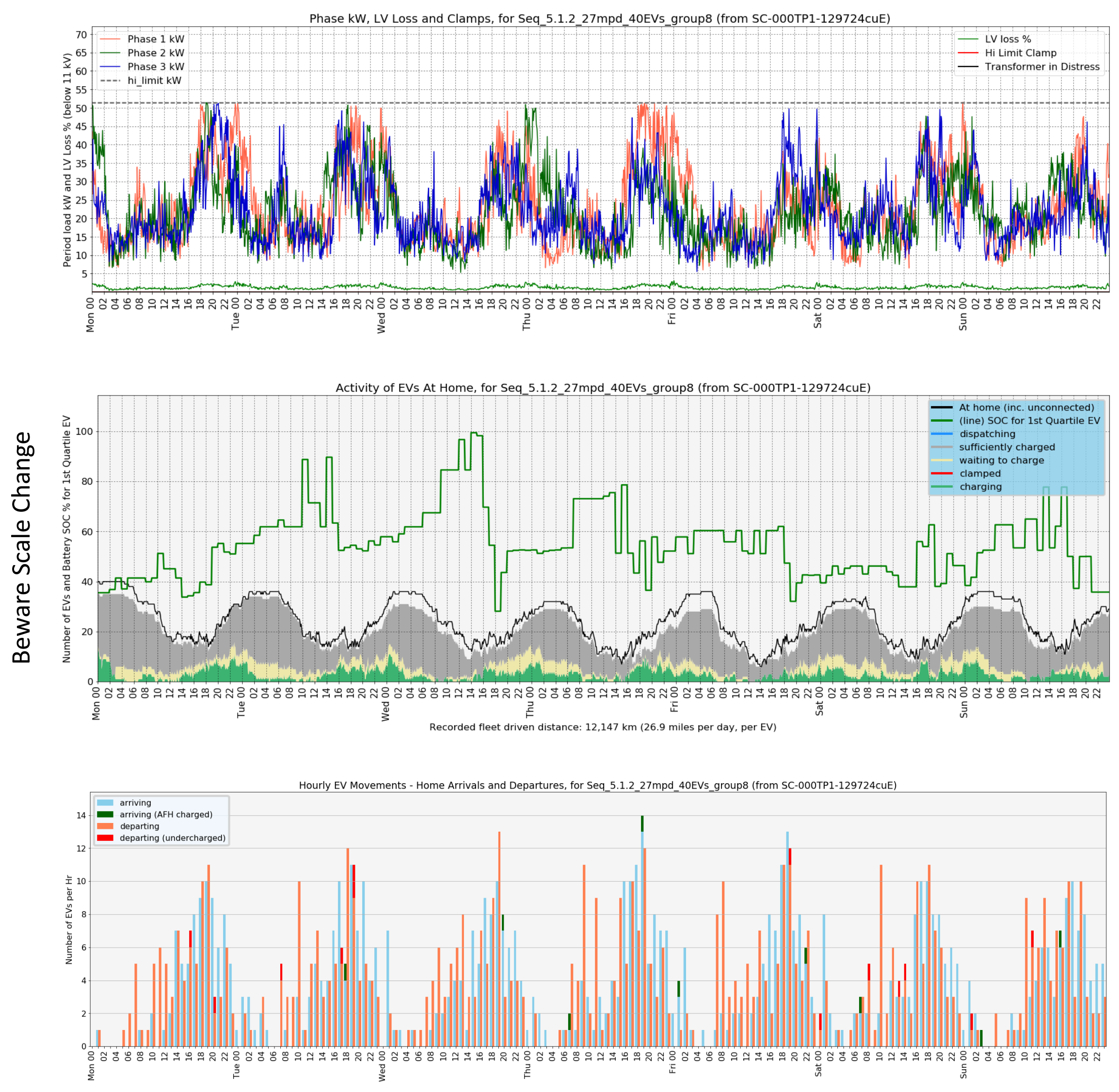
Broaching is slightly lowered vs. Seq_1.1.2, but still effects 25 of 32 ply cells.

V3-4.4.2 Seq_5.1.2 in Summary

A clear improvement on 1.1.2, but remains inadequate for general deployment.

V3-4.4.3 Seq_5.1.2: Feeder and EV Plots

V3-4.4.3.1 Seq_5.1.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,305 Home: 2,018 AFH: 287 V2G: 0

Figure 4-4: Seq_5.1.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no visible broaches
- (CICD) EV SOC is very high vs. Seq_1.1.2
- (Arrive/Depart) very few EVs are departing undercharged or using AFH.

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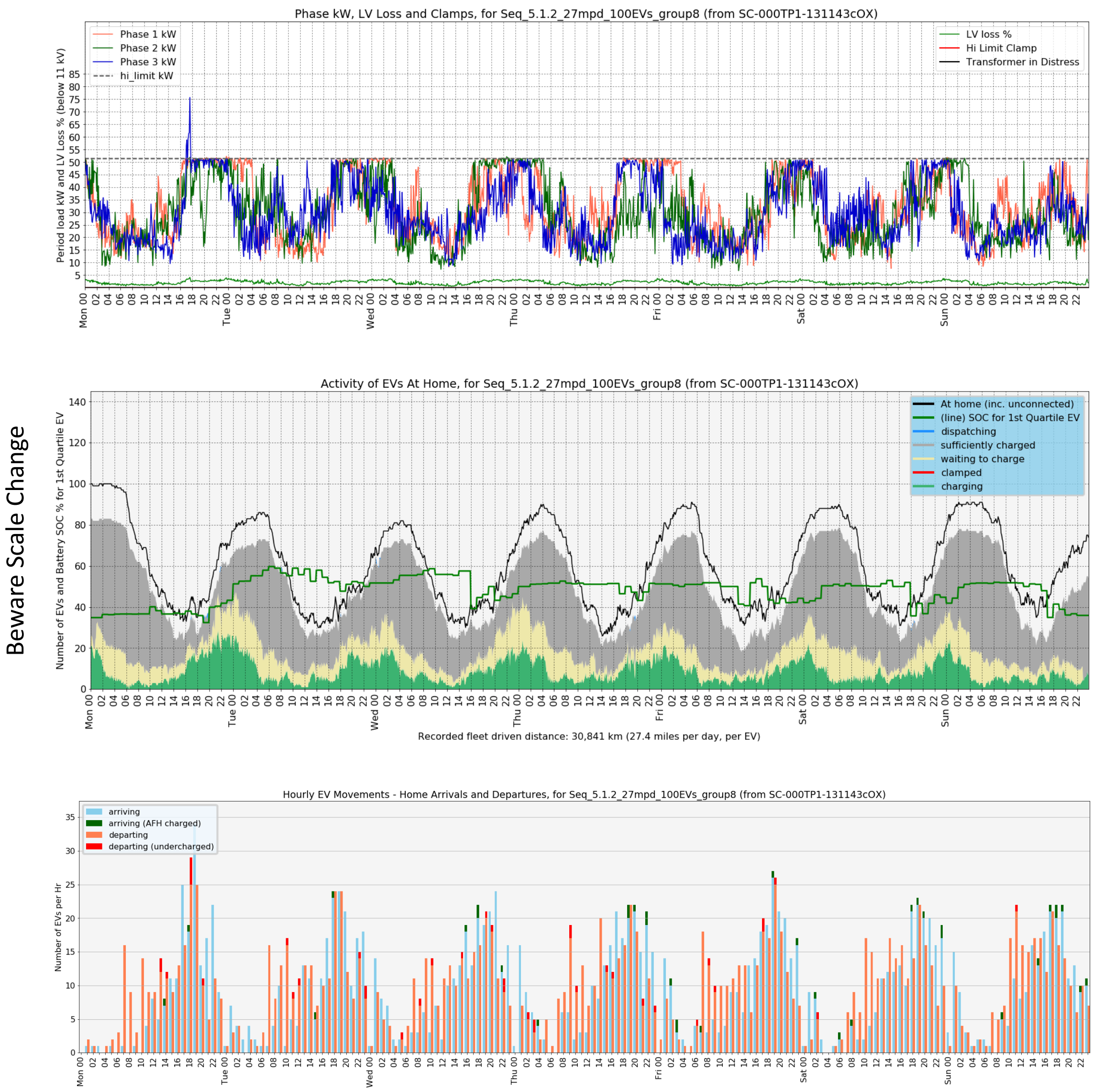
V3-4.4.3.2 Seq_5.1.2: 27mpd 100EVs



EoW stats: kWh**b** EV total: 5,882 Home: 5,083 AFH: 799 V2G: 9

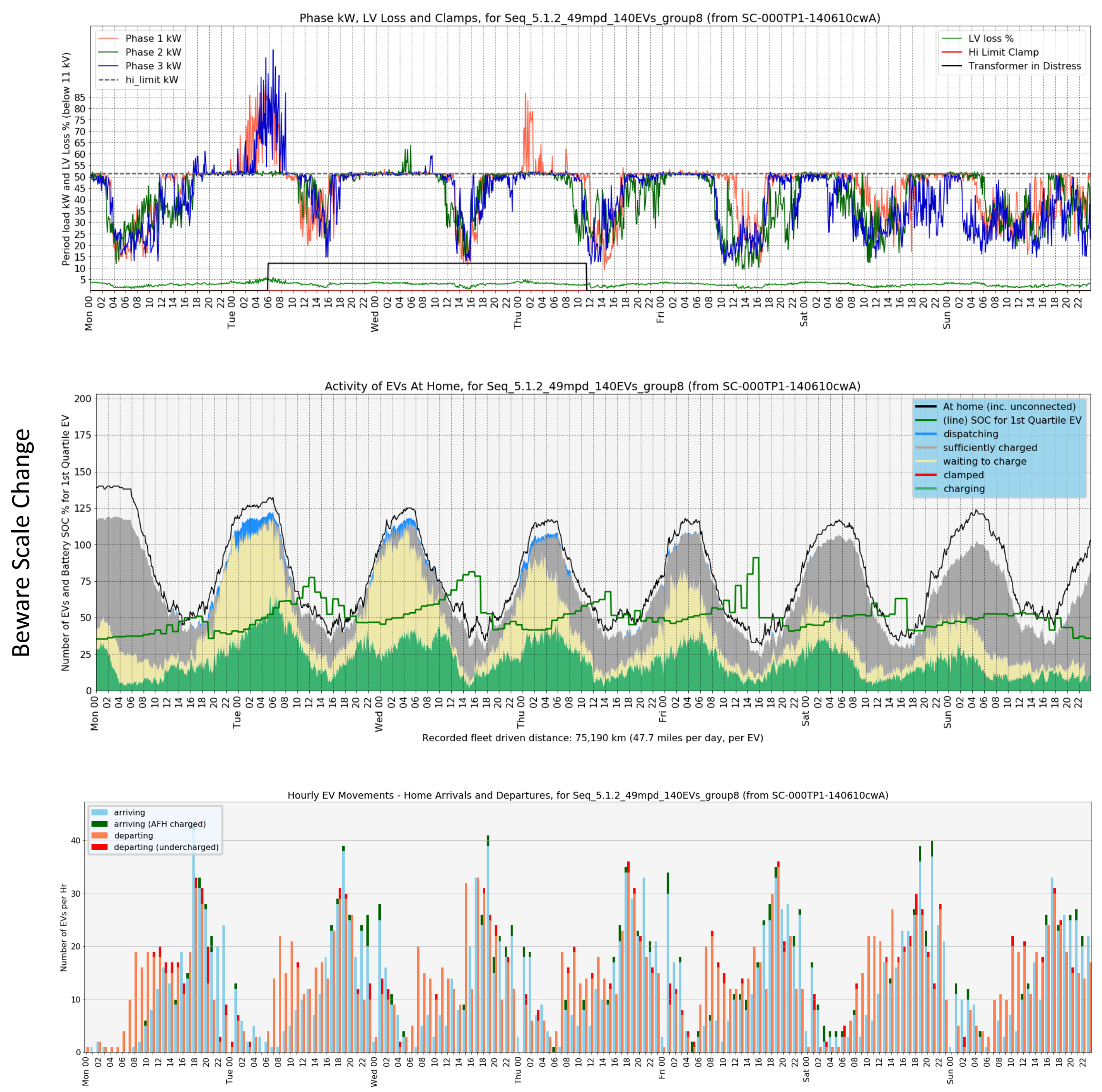
Figure 4-5: Seq_5.1.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- (Feeder) broaching is rare
- (CICD) SOC remains c. 10% above that in Seq_1.1.2; many EVs are done charging and waiting to depart
- (Arrive/Depart) use of AFH and departing undercharged seem similar to 1.1.2.

The author wonders what impact the tranches for the EV types have; are the dumb EVs waiting for charge? This however would not explain the higher SOC, given that Home energy consumption in 1.1.2 is 5,097 kWh (almost identical to the values seen here). The impacts of tranches on EV behaviour need to be clarified.

V3-4.4.3.3 Seq_5.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,077 Home: 9,831 AFH: 4,246 V2G: 570

Figure 4-6: Seq_5.1.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) occasionally severe broaches plus transformer distress flag (in black)
- (CICD) V2G in blue and higher SOC than in 1.1.2 are seen, plus EVs being MCS commanded to wait for charging, during the early hours of Tuesday;
- (Arrive/Depart) overall similar to 1.1.2.

- the EV energy use is c. x2.5 higher here than for 27mpd x 100 EVs, yet both AFH and V2G use are up more than x2.5 amount, indicating the local network cannot deliver sufficient kWh.

V3-4.4.4 Data Tables Seq_5.1.2

Data are from MetaMeta spreadsheets for Seq_1.1.2 and Seq_5.1.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 33: Unused kWh (weekly averages) for 1.1.2 vs. 5.1.2

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.2	1. Unused kWh A	19mpd	17,090	16,395	15,015	13,627	12,271	10,897	9,594	8,223
		27mpd	16,980	16,157	14,533	12,912	11,356	9,778	8,245	6,648
		38mpd	16,897	15,986	14,129	12,291	10,532	8,699	7,008	5,163
		49mpd	16,811	15,832	13,823	11,853	9,984	7,976	6,147	4,163
Seq_5.1.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	27	94	231	359	449	552	611	721
		27mpd	21	77	198	302	370	442	445	468
		38mpd	5	50	152	223	264	278	220	175
		49mpd	5	36	102	144	152	145	31	-72

Other than the extreme case at 49mpd 140 EVs, headroom has lifted implying that better use is being made of capacity.

The consequence is that EVs are obliged to get kWh elsewhere i.e. AFH kWh must rise; is this seen in the AFH kWh tables?

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Table 34: Per EV AFH Uptake kWh (weekly averages) for 1.1.2 vs. 5.1.2

Seq_1.1.2	2. AFH kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	2.7	3.1	3.3	3.3	3.4	3.6	3.6	3.6
		27mpd	6.9	8.1	7.8	8.1	8.4	8.3	8.3	8.1
		38mpd	17.7	17.3	17.9	18.5	18.2	18.5	18.5	18.5
		49mpd	35.6	33.0	31.5	31.3	31.2	30.8	31.3	31.2
Seq_5.1.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.3	-0.1	-0.2	-0.3	-0.3	-0.2	-0.3	-0.3
		27mpd	-0.7	-0.8	-0.6	-0.6	-0.4	-0.3	-0.4	-0.3
		38mpd	-1.5	-1.1	-1.1	-1.1	-0.8	-0.7	-0.9	-0.9
		49mpd	-1.7	-1.5	-1.3	-1.2	-1.2	-0.8	-0.9	-0.9

The EVs need to charge less kWh Away from Home, in 5.1.2.

Table 35: Per EV N Connects in Week (averages) for 1.1.2 vs. 5.1.2

Seq_1.1.2	3. EV N AFH A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15
		27mpd	0.30	0.32	0.29	0.30	0.32	0.31	0.31	0.31
		38mpd	0.62	0.60	0.60	0.61	0.61	0.61	0.62	0.62
		49mpd	1.14	1.02	0.95	0.94	0.95	0.94	0.96	0.95

Seq_5.1.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
		27mpd	-0.03	-0.03	0.0	0.0	0.0	0.0	-0.02	-0.02
		38mpd	-0.06	-0.05	-0.05	-0.04	-0.03	-0.03	-0.04	-0.04
		49mpd	-0.07	-0.06	-0.05	-0.05	-0.05	-0.04	-0.04	-0.04

As might be anticipated, with less need for AFH kWh, there is less instances of EVs connecting to AFH chargers.

Table 36: Severe Undercharging Difference per EV (weekly averages) for 1.1.2 vs. 5.1.2

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	-0.0004	0.0000	0.0002	-0.0002	-0.0001	-0.0003	-0.0001	-0.0002
	27mpd	-0.0002	-0.0004	-0.0004	-0.0001	-0.0002	-0.0002	-0.0002	-0.0001
	38mpd	0.0004	-0.0010	-0.0005	-0.0002	-0.0012	-0.0007	-0.0008	-0.0004
	49mpd	-0.0018	-0.0023	-0.0007	-0.0016	-0.0009	-0.0004	-0.0007	-0.0009

(limit: < 0.007)

All plies pass for severe undercharges, yet 5.1.2 improves the rates (at parity: 0.0008).

V3-4.4.4.1 Seq_5.1.2 Results Discussion

For both DNO and the EV this sequence has been an improvement over Seq_1.1.2.

The evident diminution of “waiting to charge” EVs seen in the CICD plot (5.1.2 vs. 1.1.2) is likely an artefact of presentation. When dumb EVs use BLPs, there is a pre-depart charge to top EVs up to the SOC depart level. Thus for the majority of the overnight period they will flag “not finished charging” whereas Smart types may gain opportunistic charge, so have a better SOC state i.e. be over SOC depart. This would explain why SOC levels are also seen as higher in 5.1.2, and why severe undercharging rates are improved.

However broaches still remain; from the DNO viewpoint the use of an MCS in isolation is inadequate.

V3-4.5 Sequence 5.1.2.1

Sequence	**Simulation ID**	**Description**
Seq_5.1.2.1	(S_AW)	As 5.1.2, but residential loads are scaled to 1 kW apparent load ADMD from 1.3 kW aka “Res Loads Down”
Baseline	***Description***	
Seq_5.1.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.*	

This is a version of 5.1.2 scaling residential loads by 1.0/1.3 i.e. 300W per home reduction.

Note that the loads are (over a standard Winter week):

- the Typical network, if run at 100% hi_limit throughput, can deliver 25,869 kWh
- 1.3 kW ADMD residential load draws 8,173 kWh (remaining unused: 17,696 kWh)
- 1 kW ADMD residential load draws 6,287 kWh (remaining unused: 19,582 kWh, an increase of 1,886 kWh i.e. a capacity limit increase of 3.7 kW per phase)
- 1.6 kW ADMD residential load draws 10,059 kWh (unused: 15,810 kWh, a drop of 1,886 kWh i.e. a capacity limit reduction of 3.7 kW per phase).

See also Seq_5.1.2.2, “Res Loads Up”, the converse case to Seq_5.1.2.1 in which headroom reduces by the same amount.

V3-4.5.1 Broaching

Broaching drops (from 25 in 5.1.2) to 9 of 32 ply cells, i.e. 23 do not broach.

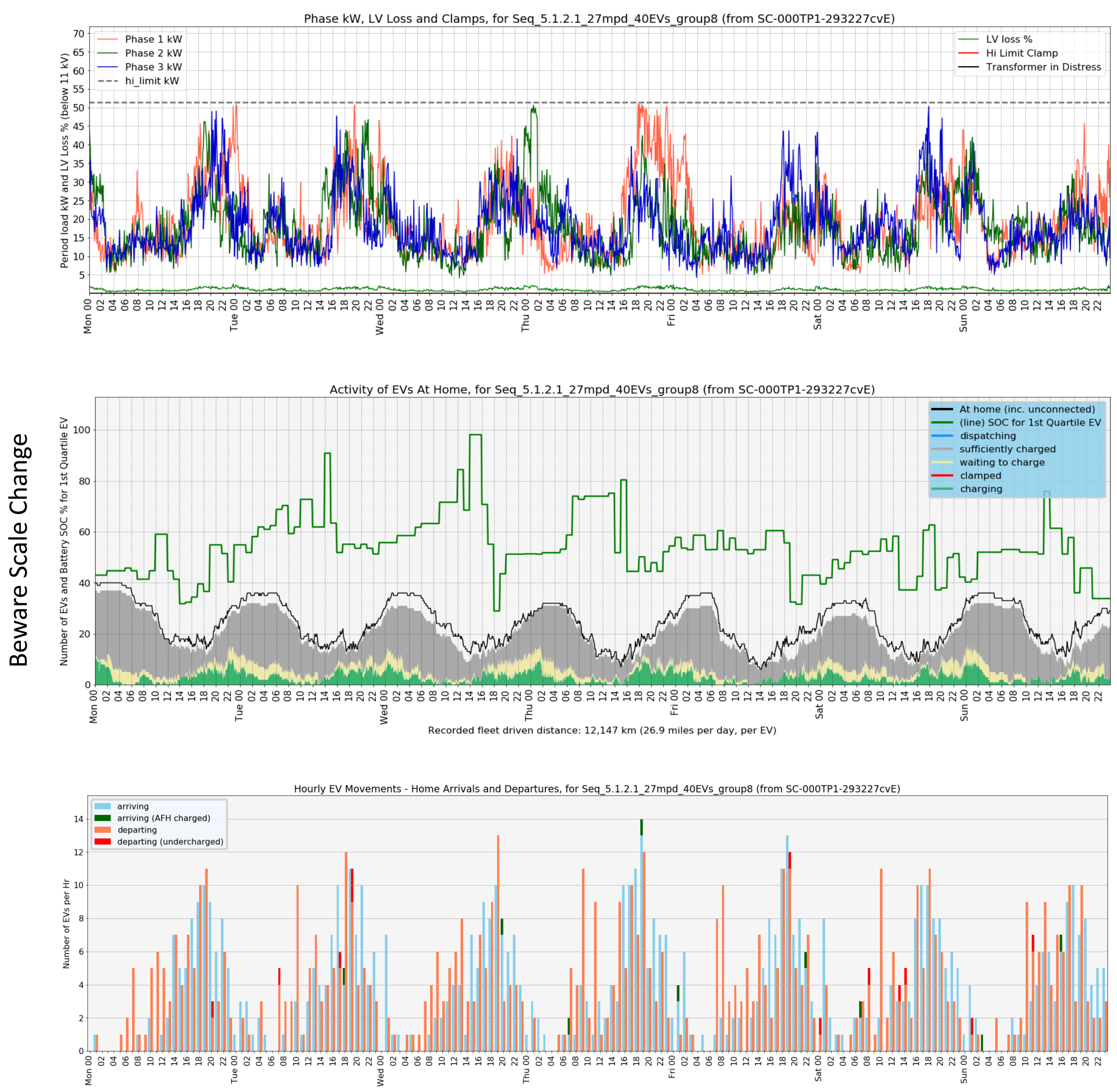
Another instance of happenstance is seen: A ply cell with higher demand is free of broaches, yet a companion cell with lower demand has broaches.

V3-4.5.2 Seq_5.1.2.1 in Summary

The the headroom improvement caused by reducing the residential loads has eased broaching; in all other regards there are only trivial changes. V2G use is though reduced.

V3-4.5.3 Seq_5.1.2.1: Feeder and EV Plots

V3-4.5.3.1 Seq_5.1.2.1: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,304 Home: 2,016 AFH: 288 V2G: 0

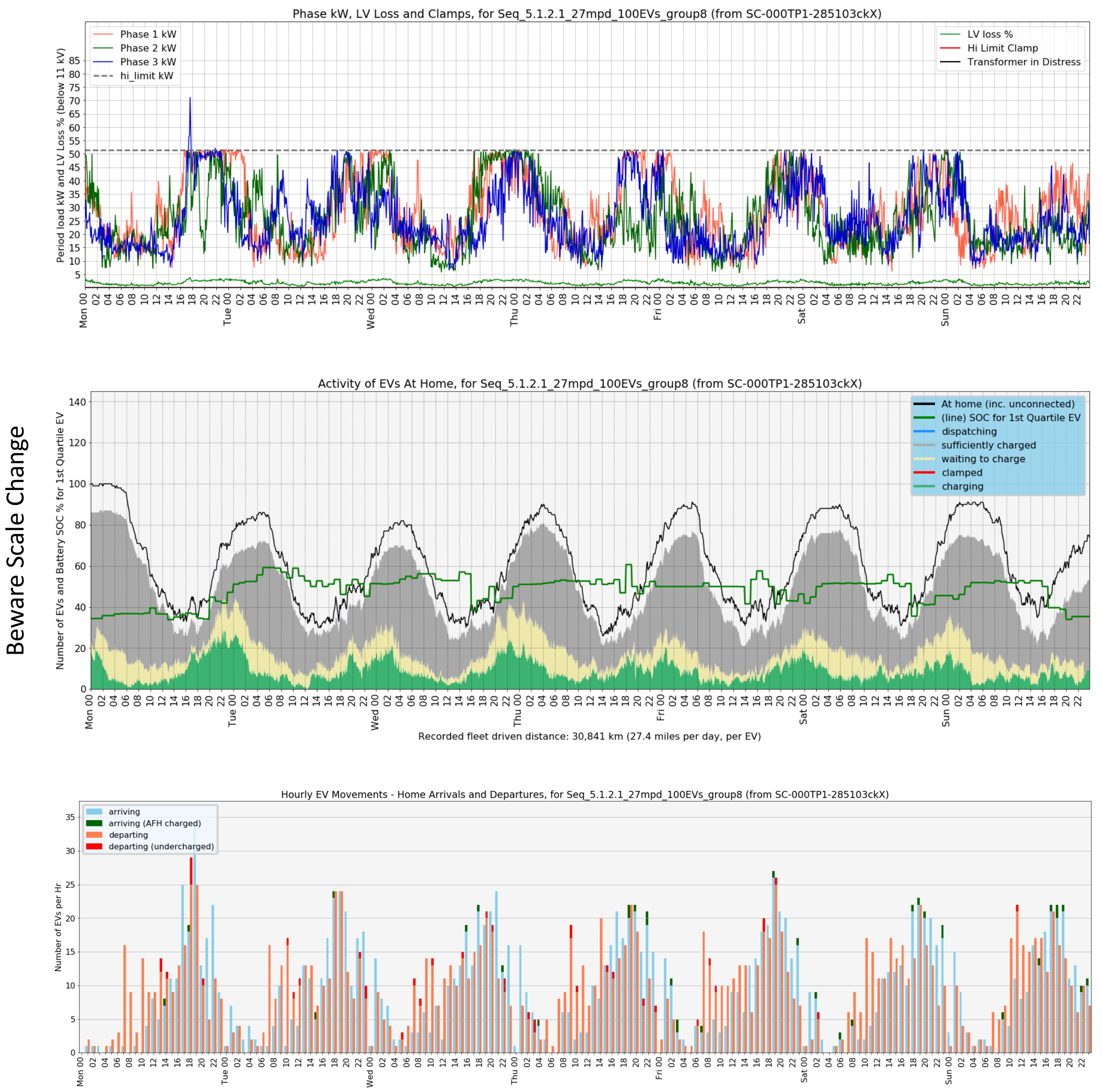
Figure 4-7: Seq_5.1.2.1 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no broaches visible,
- (CICD) EV SOC is very high vs. Seq_1.1.2
- (Arrive/Depart) very few EVs are departing undercharged or using AFH.

These plots are almost identical to those of 5.1.2.

V3-4.5.3.2 Seq_5.1.2.1: 27mpd 100EVs



EoW stats: kWh[b] EV total: 5,872 Home: 5,069 AFH: 803 V2G: 1.6

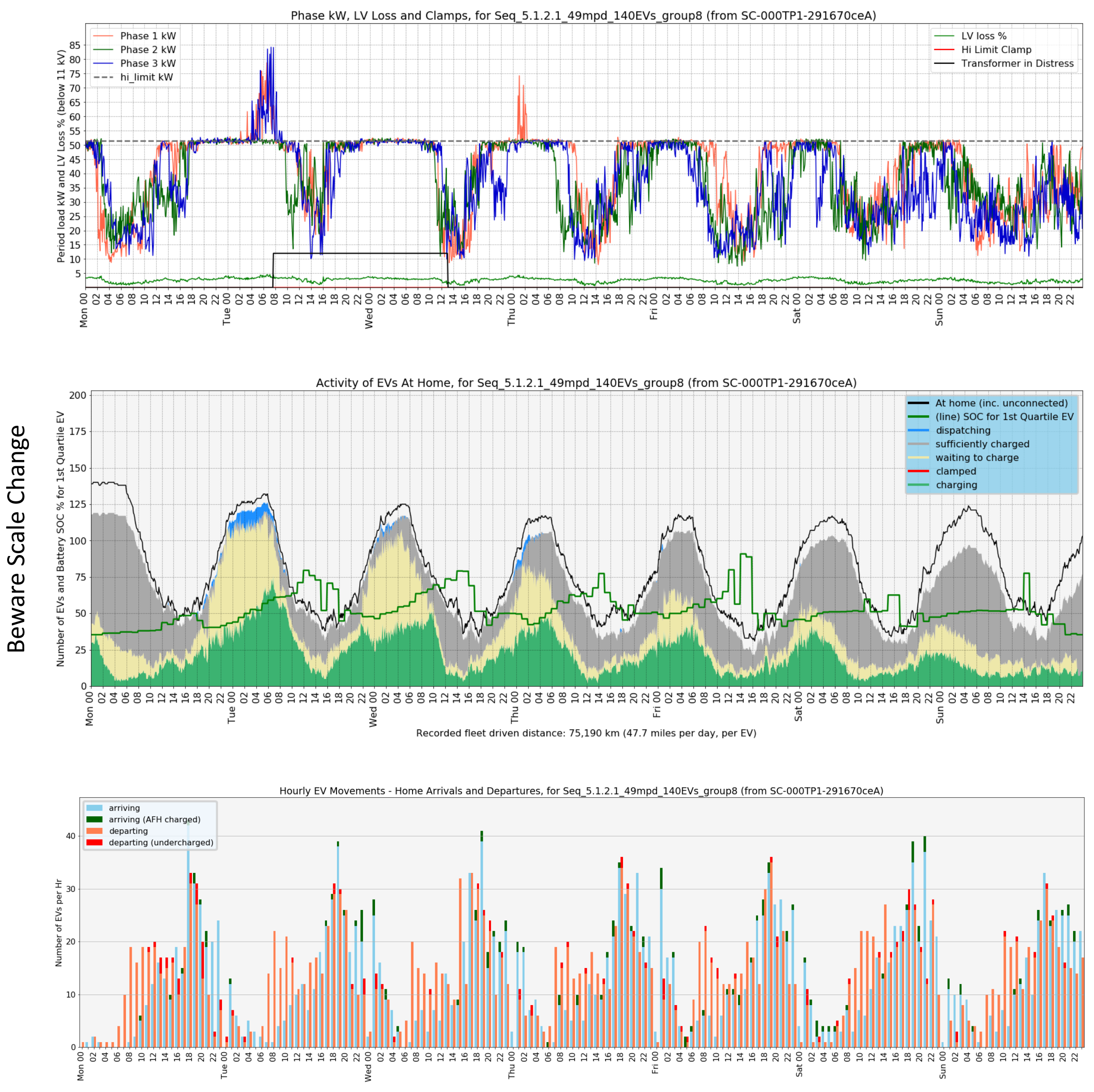
Figure 4-8: Seq_5.1.2.1 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- all plots are extremely close to those seen in 5.1.2

Total EV demand has dropped by 10 kWh, with Home charging 14 kWh down and AFH 4. V2G has dropped to 1.6 kWh from 9.

V3-4.5.3.3 Seq_5.1.2.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,861 Home: 9,600 AFH: 4,260 V2G: 288

Figure 4-9: Seq_5.1.2.1 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) reduced broaching is seen and the Transformer distress signal in black has c. 12 hours less span, vs. 5.1.2
- (CICD) V2G in blue has dropped (kWh show c. 1/2 use of V2G)
- (Arrive/Depart) overall similar to 5.1.2.

EV energy use is down c. 200 kWh, being a drop of 230 for Home and 14 kWh for AFH. V2G use has fallen by 282 kWh. The correlation seen here suggests as V2G rises, net energy draw rises which is reasonable as V2G raises losses.

V3-4.5.4 Data Tables Seq_5.1.2.1

Data are from MetaMeta spreadsheets for Seq_5.1.2 and Seq_5.1.2.1. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 37: Unused kWh (weekly averages) for 5.1.2 vs. 5.1.2.1

Seq_5.1.2	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091

Seq_5.1.2.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	19,003	18,375	17,125	15,864	14,591	13,333	12,094	10,843
		27mpd	18,887	18,119	16,613	15,095	13,609	12,112	10,593	9,025
		38mpd	18,788	17,924	16,165	14,399	12,690	10,889	9,143	7,259
		49mpd	18,703	17,753	15,813	13,886	12,037	10,034	8,088	5,978

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	1,885	1,886	1,879	1,878	1,871	1,884	1,888	1,899
		27mpd	1,886	1,884	1,882	1,882	1,883	1,892	1,902	1,908
		38mpd	1,886	1,888	1,884	1,885	1,894	1,911	1,915	1,920
		49mpd	1,887	1,885	1,888	1,890	1,901	1,913	1,910	1,886

The difference table reflects the 1,886 kWh extra available over the week, yet shows that 5.1.2 in the higher demand areas is drawing more; being less stressed (other than at 49mpd 140 EVs) 5.1.2.1 draws less, showing the effect of V2G losses which will be higher in these areas.

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Table 38: Per EV AFH Uptake kWh (weekly averages) for 5.1.2 vs. 5.1.2.1

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	2. AFH kWh A	19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3
Seq_5.1.2.1	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.2	3.4	3.3	3.3
		27mpd	6.2	7.3	7.2	7.5	8.0	8.0	7.9	7.8
		38mpd	16.3	16.3	16.9	17.5	17.4	17.9	17.6	17.7
		49mpd	34.0	31.6	30.4	30.2	30.1	30.1	30.5	30.4
Difference B - A	C Diff.	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		27mpd	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		38mpd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		49mpd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

The reduction in residential loading slightly increases Away from Home charging, but the difference is extremely marginal and might be ascribed to a rounding error.

Table 39: Per EV N Connects in Week (averages) for 5.1.2 vs. 5.1.2.1

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	3. EV N AFH A	19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91
Seq_5.1.2.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.13	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.59	0.58
		49mpd	1.07	0.96	0.91	0.90	0.91	0.91	0.92	0.91
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		27mpd	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
		38mpd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		49mpd	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00

There is no discernable difference in the number of times AFH charging is accessed.

Table 40: Severe Undercharging Difference per EV (weekly averages) for 5.1.2 vs. 5.1.2.1

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001
	27mpd	0.0000	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
	38mpd	0.0002	0.0001	0.0002	0.0004	0.0003	0.0004	0.0002	0.0001
	49mpd	0.0004	0.0001	0.0004	0.0006	0.0004	0.0005	0.0005	0.0005

(limit: < 0.007)

Severe undercharging is consistently very slightly up, yet 5.1.2.1 is still below a limit of concern (worst being 0.0056, vs. the pass limit of 0.007).

V3-4.5.4.1 Seq_5.1.2.1 Results Discussion

5.1.2.1 is in many ways an anticlimax, showing little differences from 5.1.2 other than in terms of broaching, which shows useful improvement. In this regard it is clear that headroom matters; an extra 3.7 kW phase headroom (c. 113 W per home) equivalent has been of assistance; the question next is: what does a similar increase do?

V3-4.6 Sequence 5.1.2.2

Sequence	**Simulation ID**	**Description**
Seq_5.1.2.2	(S_AX)	As 5.1.2, but residential loads are scaled to 1.6 kW apparent load ADMD from 1.3 kW aka "Res Loads Up"
Baseline	***Description***	
Seq_5.1.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.*	

This is a version of 5.1.2 scaling residential loads by 1.0/1.3 i.e. 300W per home reduction.

Note that the loads are (over a standard Winter week):

- the Typical network, if run at 100% hi_limit throughput, can deliver 25,869 kWh
- 1.3 kW ADMD residential load draws 8,173 kWh (remaining unused: 17,696 kWh)
- 1 kW ADMD residential load draws 6,287 kWh (remaining unused: 19,582 kWh, an increase of 1,886 kWh i.e. a capacity limit increase of 3.7 kW per phase)
- 1.6 kW ADMD residential load draws 10,059 kWh (unused: 15,810 kWh, a drop of 1,886 kWh i.e. a capacity limit reduction of 3.7 kW per phase).

See also Seq_5.1.2.1, "Res Loads Down", the converse case to Seq_5.1.2.2 in which headroom increases by the same amount.

V3-4.6.1 Broaching

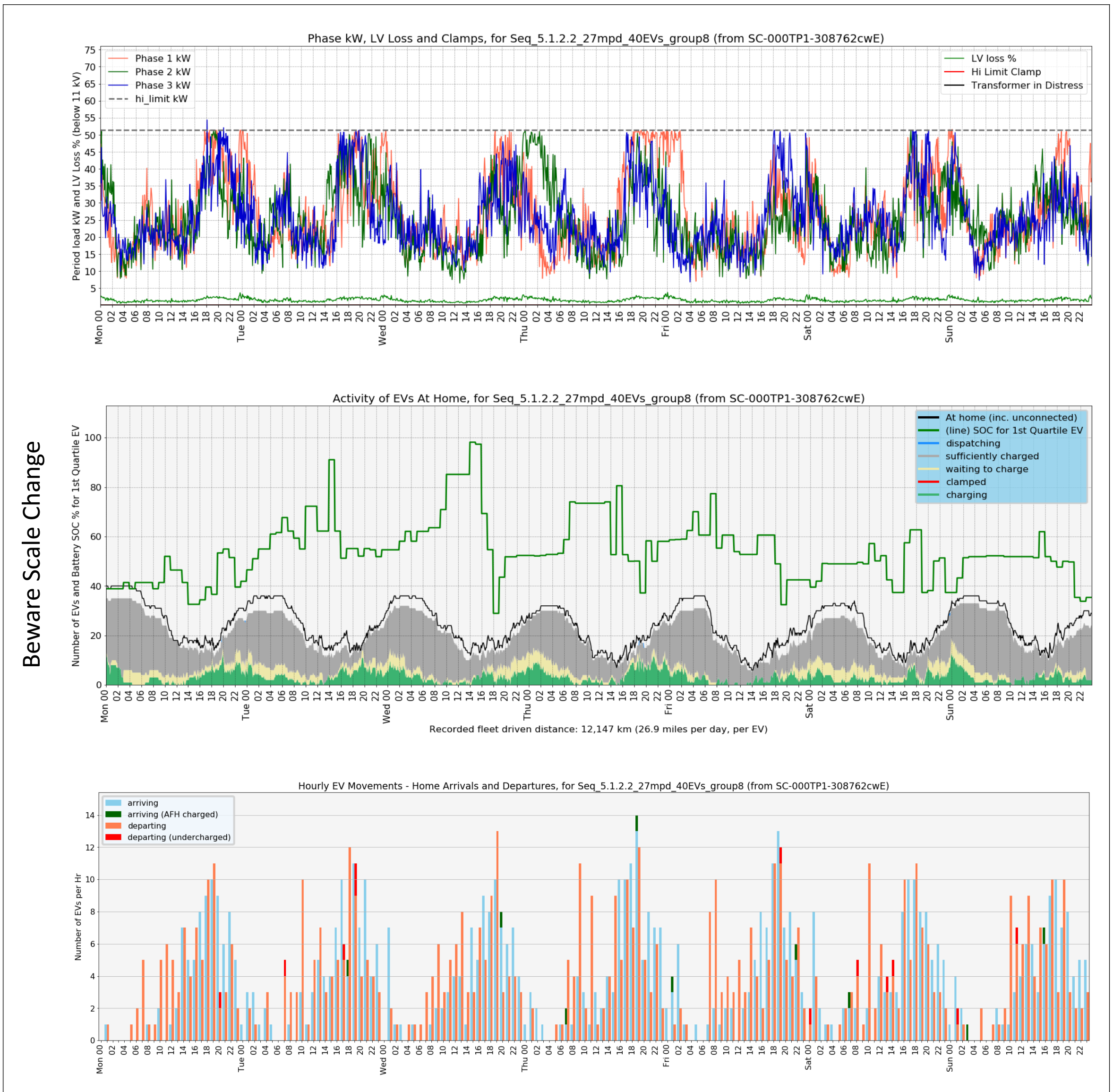
Broaching is slightly lowered vs. Seq_1.1.2, but still effects 25 of 32 ply cells.

V3-4.6.2 Seq_5.1.2.2 in Summary

The impact of increased residential loads (hence reduced headroom) on EVs is seen, but is surprisingly minimal, with the biggest impact being on the number of network broaches.

V3-4.6.3 Seq_5.1.2.2: Feeder and EV Plots

V3-4.6.3.1 Seq_5.1.2.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,310 Home: 2,022 AFH: 288 V2G: 3

Figure 4-10: Seq_5.1.2.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- by eye, the plots are near identical to 5.1.2
- EV kWh are up by no more than 5 kWh.

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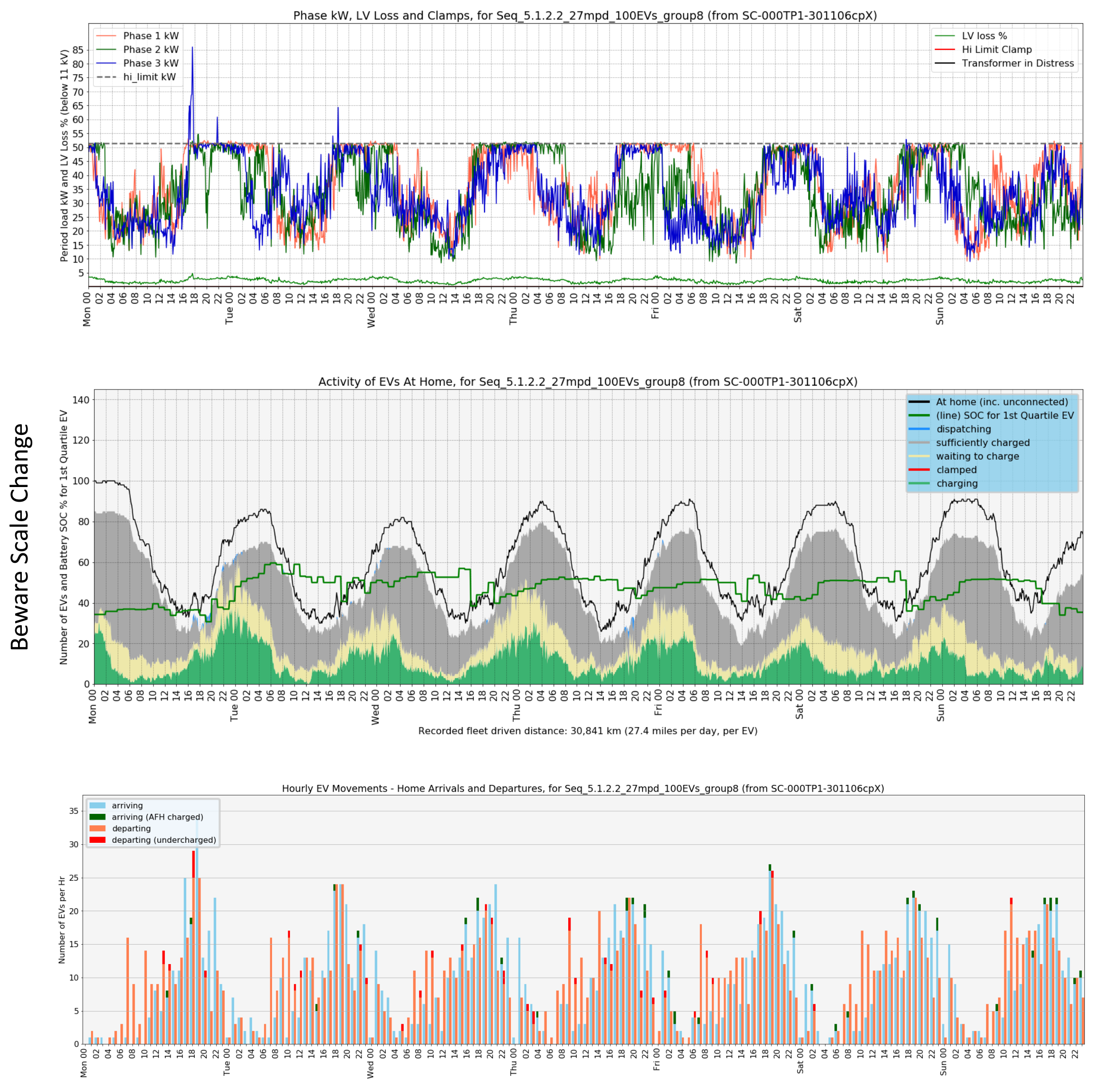
V3-4.6.3.2 Seq_5.1.2.2: 27mpd 100EVs



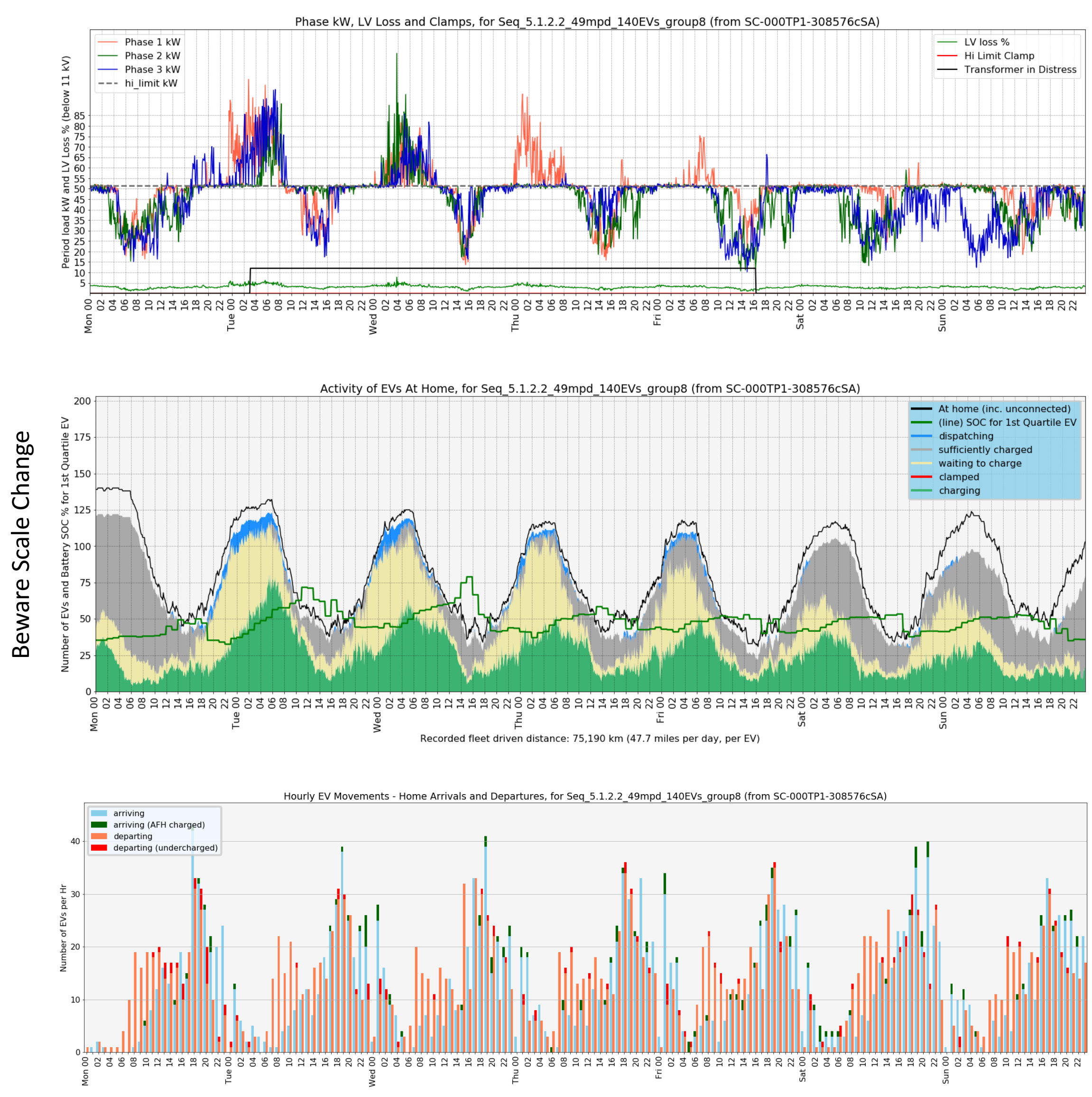
EoW stats: kWh[b] EV total: 5,923 Home: 5,119 AFH: 804 V2G: 41

Figure 4-11: Seq_5.1.2.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- (Feeder) broaching is slightly up, with an incident in Tuesday evening not in 5.1.2
- the other plots are by eye indistinguishable from 5.1.2
- loads are c. 40 kWh up on 5.1.2 with a noticeable increase in V2G (from 9 kWh).

V3-4.6.3.3 Seq_5.1.2.2: 49mpd 140EVs



EoW stats: kWh[b]   EV total: 14,497   Home: 10,218   AFH: 4,297   V2G: 904

Figure 4-12: Seq_5.1.2.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) broaches x6 overnight periods, plus 1 day extended transformer distress flag (in black)
- (CICD) increased V2G in blue and slightly subdued SOC than in 5.1.2 are seen;
- (Arrive/Depart) by eye identical to 5.1.2.
- the EV energy use is 420 kWh up on 5.1.2, being attributable to the V2G increase plus losses (c. (904 - 570) * 1.3).

V3-4.6.4 Data Tables Seq_5.1.2.2

Data are from MetaMeta spreadsheets for Seq_5.1.2 and Seq_5.1.2.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 41: Unused kWh (weekly averages) for 5.1.2 vs. 5.1.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	1. Unused kWh A	19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091
Seq_5.1.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	15,228	14,600	13,350	12,079	10,790	9,491	8,208	6,888
		27mpd	15,112	14,341	12,830	11,303	9,781	8,226	6,642	4,995
		38mpd	15,013	14,146	12,382	10,595	8,830	6,956	5,134	3,132
		49mpd	14,928	13,978	12,025	10,072	8,161	6,079	4,038	1,829
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-1,890	-1,889	-1,897	-1,907	-1,930	-1,958	-1,997	-2,056
		27mpd	-1,889	-1,893	-1,901	-1,910	-1,945	-1,993	-2,048	-2,121
		38mpd	-1,889	-1,891	-1,899	-1,919	-1,965	-2,021	-2,095	-2,206
		49mpd	-1,889	-1,890	-1,900	-1,925	-1,975	-2,041	-2,140	-2,262

The capacity loss of 1,886 kWh accelerates by c. 440 kWh as V2G use increases, at extremes of duty.

.

Table 42: Per EV AFH Uptake kWh (weekly averages) for 5.1.2 vs. 5.1.2.2

Seq_5.1.2	2. AFH kWh A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3
Seq_5.1.2.2	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.2	3.4	3.3	3.3
		27mpd	6.2	7.3	7.2	7.5	8.1	8.0	7.9	7.8
		38mpd	16.3	16.3	16.9	17.5	17.5	17.9	17.7	17.8
		49mpd	34.0	31.6	30.4	30.3	30.1	30.2	30.6	30.6
Difference B - A	**C Diff.**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		27mpd	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
		38mpd	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
		49mpd	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2

This is quite a surprise, the author expecting AFH kWh draw to be up. Perhaps this is not so much taken per AFH visit, rather the number of visits?

Table 43: Per EV N Connects in Week (averages) for 5.1.2 vs. 5.1.2.2

Seq_5.1.2	3.	N EV	10	20	40	60	80	100	120	140
	EV N AFH A	19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91
Seq_5.1.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.13	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.30
		38mpd	0.57	0.55	0.56	0.57	0.58	0.59	0.59	0.59
		49mpd	1.07	0.96	0.91	0.90	0.91	0.91	0.92	0.92
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
	Diff.	19mpd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		27mpd	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
		38mpd	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
		49mpd	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01

There is a negligible rise in AFH connections.

Table 44: Severe Undercharging Difference per EV (weekly averages) for 5.1.2 vs. 5.1.2.2

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000
	27mpd	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	38mpd	0.0002	0.0001	0.0003	0.0003	0.0003	0.0004	0.0002	0.0002
	49mpd	0.0004	0.0001	0.0003	0.0005	0.0004	0.0005	0.0005	0.0005

(limit: < 0.007)

All plies pass for severe undercharges. 5.1.2.2 suffers degradation to 0.0056 worst case.

V3-4.6.4.1 Seq_5.1.2.2 Results Discussion

The impact of increased residential loads hence reduced headroom on EVs is surprisingly minimal, with the biggest impact being on the number of network broaches, dropping by 1 or 2 N EV categories per mpd.

Clamping is the only means available to control these.

V3-4.7 Sequence 5.1.3

Sequence	**Simulation ID**	**Description**
Seq_5.1.3	(S_B3)	Variation vs. Seq_1.1.2: MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Strong (2.0 kW ADMD) network; 65 kW hi_limit per phase.
Baseline	***Description***	
Seq_1.1.3	*Winter, all dumb EVs on Strong network (2 kW ADMD)*	

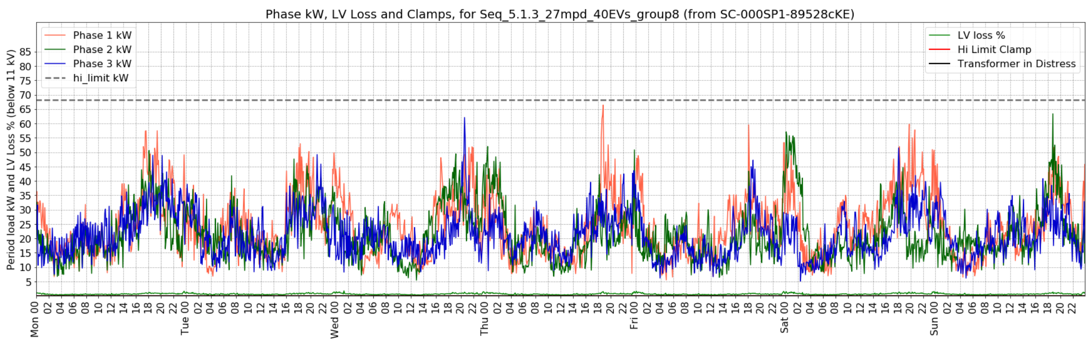
The simulation uses a Strong network, which, with MCS, is likely to show few broaches and good EV charging performance.

V3-4.7.1 Seq_5.1.3 in Summary

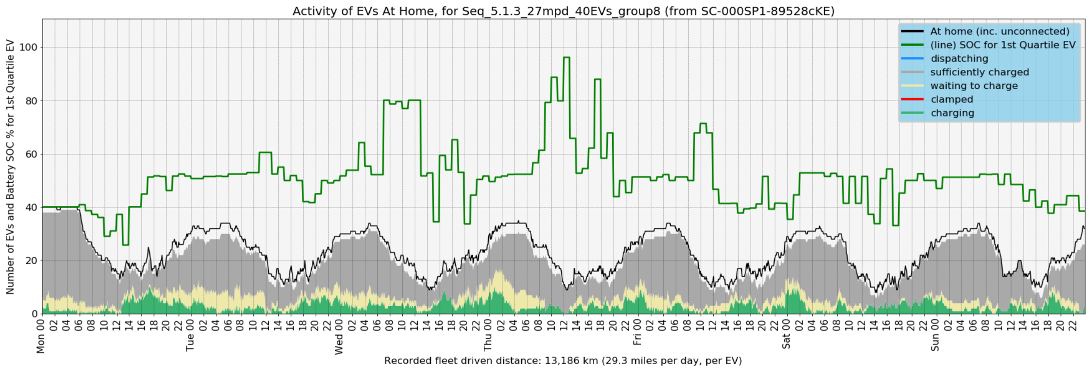
This sequence is an improvement over Seq_1.1.3; other than the transformer broaches seen in 49mpd 140 EVs 5.1.3 delivers a perfect score.

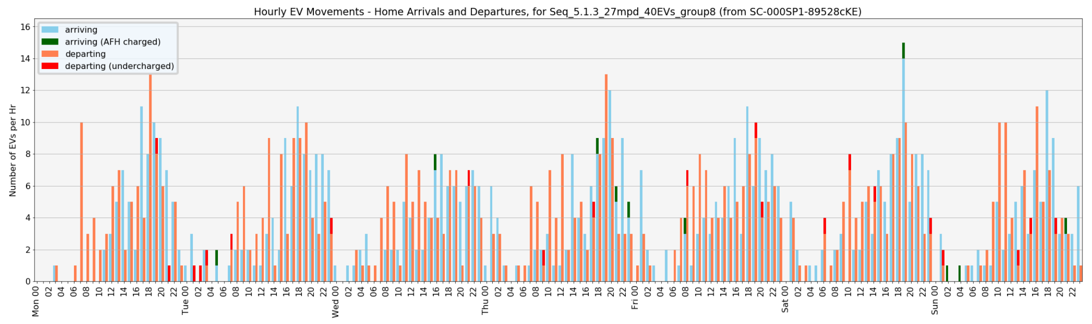
V3-4.7.2 Seq_5.1.3: Feeder and EV Plots

V3-4.7.2.1 Seq_5.1.3: 27mpd 40EVs



Beware Scale Change





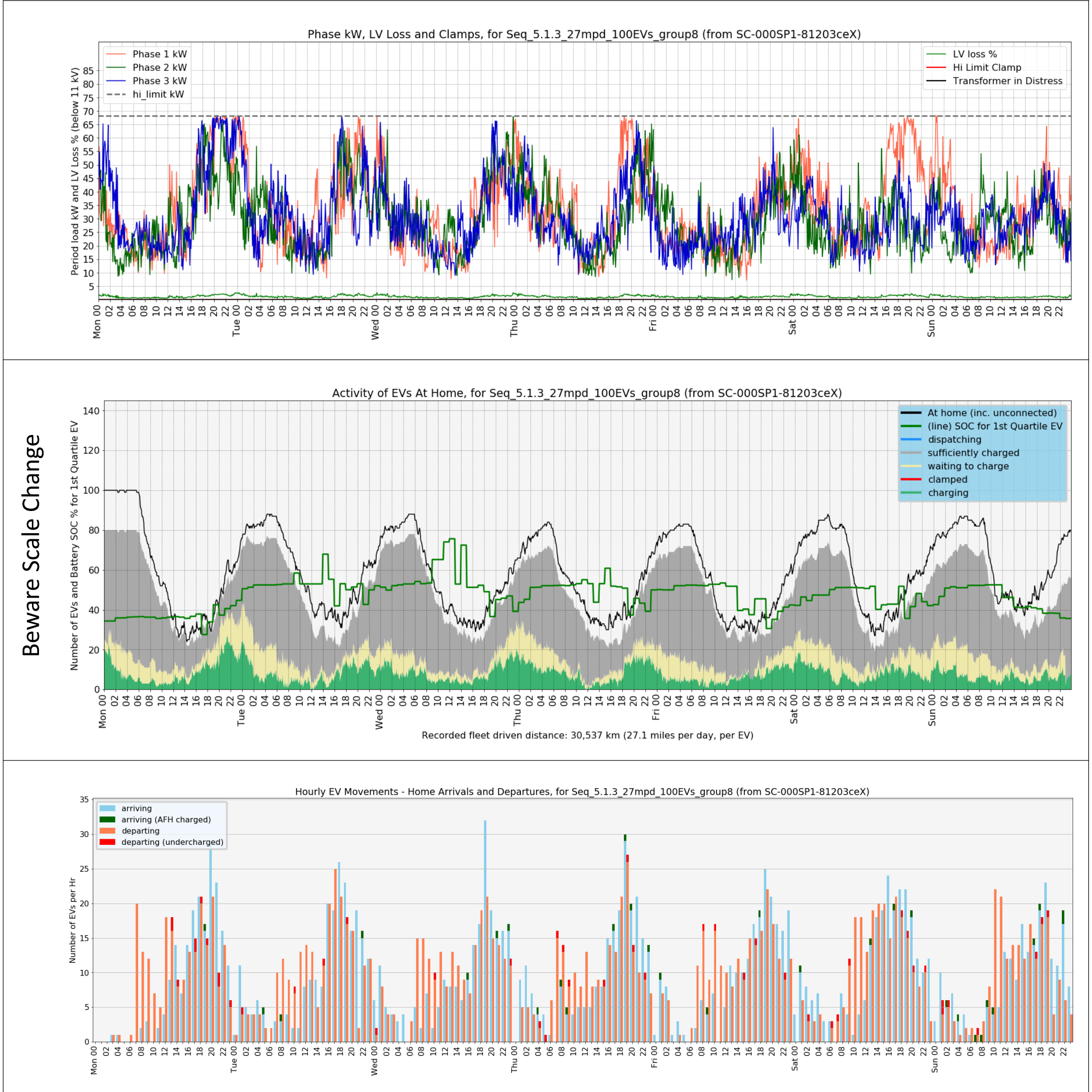
EoW stats: kWh[b]	EV total: 2,303	Home: 2,017	AFH: 287	V2G: 0

Figure 4-13: Seq_5.1.3 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- different tripsets have been used; however the SOC levels appear raised and the kWh are similar.

V3-4.7.2.2 Seq_5.1.3: 27mpd 100EVs



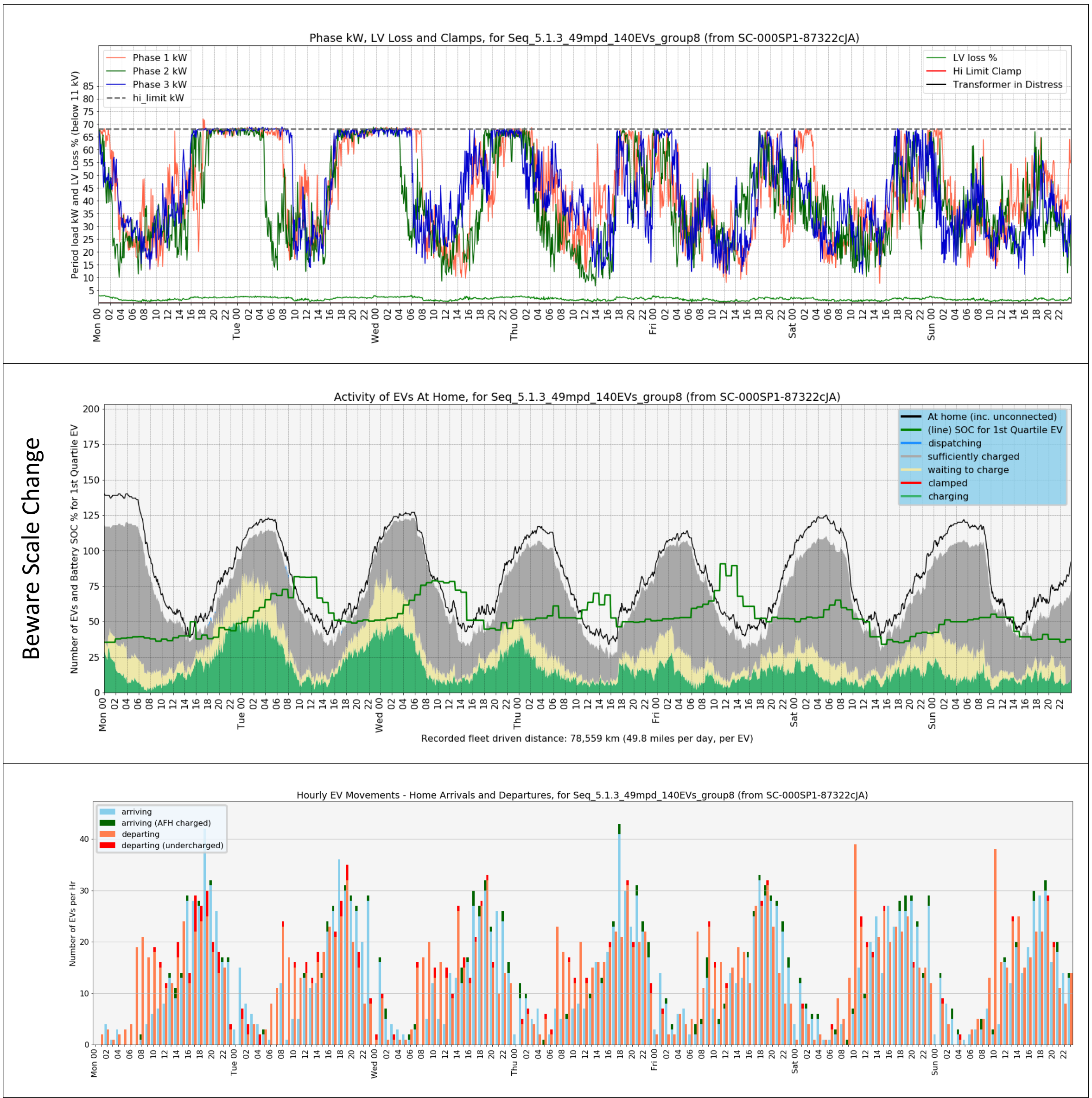
EoW stats: kWh[b] EV total: 5,862 Home: 5,064 AFH: 798 V2G: 0

Figure 4-14: Seq_5.1.3 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- 1.1.3 has some broaches; those are missing from 5.1.3
- kWh are no more than 1% different vs. 1.1.3.

V3-4.7.2.3 Seq_5.1.3: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,558 Home: 9,335 AFH: 4,223 V2G: 15

Figure 4-15: Seq_5.1.3 49mpd 140EVs group 8 plots. Av. weekly fleet km: 77,227

Notes re above plots:

- compared to 1.1.3, the broaching rate is very low
- EV kWh are down here by c. 60 kWh, with most lost from AFH which was c. 160 kWh higher in 1.1.3. This suggests that managed charging is more capable; however the trips are different so this is not a certain conclusion.

V3-4.7.3 Data Tables Seq_5.1.3

Data are from MetaMeta spreadsheets for Seq_1.1.3 and Seq_5.1.3. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 45: Unused kWh (weekly averages) for 1.1.3 vs. 5.1.3

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.3	1. Unused kWh A	19mpd	25,545	24,851	23,470	22,082	20,731	19,362	18,052	16,679
		27mpd	25,436	24,613	22,994	21,383	19,826	18,261	16,729	15,123
		38mpd	25,348	24,440	22,588	20,755	18,996	17,174	15,479	13,633
		49mpd	25,262	24,285	22,276	20,300	18,430	16,444	14,593	12,600
Seq_5.1.3	B	N EV	10	20	40	60	80	100	120	140
		19mpd	25,570	24,942	23,698	22,440	21,181	19,929	18,716	17,504
		27mpd	25,453	24,686	23,185	21,673	20,203	18,733	17,257	15,770
		38mpd	25,353	24,488	22,735	20,978	19,288	17,538	15,862	14,084
		49mpd	25,268	24,321	22,381	20,464	18,643	16,706	14,847	12,862
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	25	91	228	359	450	567	664	824
		27mpd	17	74	191	290	377	472	527	647
		38mpd	5	48	147	223	292	364	383	451
		49mpd	6	36	105	164	213	262	254	262

It is clear from this plot that a built-for 2 kW ADMD network, with MCS, is the major choice from the view of the DNO.

Note that only 6 broaches were seen in the 49mpd 140 EV case; these were all exceeding the transformer thermal limit (see sheet 49, row 94 of MetaMeta2.3_Seq_5.1.3.xlsx), suggesting that transformer enhancements may be of assistance. However transformers face other issues (ageing and harmonics).

.

Table 46: Per EV AFH Uptake kWh (weekly averages) for 1.1.3 vs. 5.1.3

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.3	**2. AFH kWh A**	19mpd	2.8	3.2	3.4	3.3	3.4	3.6	3.6	3.5
		27mpd	6.8	7.9	7.7	8.1	8.4	8.4	8.3	8.1
		38mpd	17.8	17.5	17.8	18.4	18.1	18.6	18.4	18.4
		49mpd	36.0	33.4	31.6	31.3	31.1	31.0	31.4	31.3
Seq_5.1.3	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.8	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.5
		49mpd	33.9	31.5	30.3	30.1	30.0	29.9	30.3	30.2
Difference B - A	**C Diff.**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-0.3	-0.2	-0.3	-0.3	-0.3	-0.2	-0.3	-0.3
		27mpd	-0.6	-0.6	-0.5	-0.6	-0.5	-0.4	-0.4	-0.4
		38mpd	-1.6	-1.2	-1.0	-1.0	-0.8	-0.8	-0.9	-1.0
		49mpd	-2.1	-1.9	-1.3	-1.2	-1.1	-1.1	-1.1	-1.1

The EVs need to charge less kWh Away from Home in 5.1.3, echoing results seen in 5.1.2.

Table 47: Per EV N Connects in Week (averages) for 1.1.3 vs. 5.1.3

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.3	3. EV N AFH A	19mpd	0.13	0.14	0.14	0.13	0.14	0.15	0.15	0.15
		27mpd	0.30	0.31	0.29	0.30	0.32	0.32	0.31	0.31
		38mpd	0.63	0.61	0.60	0.61	0.61	0.62	0.62	0.62
		49mpd	1.15	1.03	0.96	0.95	0.95	0.94	0.96	0.95
Seq_5.1.3	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.89	0.91	0.90	0.91	0.90
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
		27mpd	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
		38mpd	-0.07	-0.06	-0.04	-0.04	-0.03	-0.03	-0.04	-0.04
		49mpd	-0.09	-0.07	-0.06	-0.05	-0.05	-0.04	-0.05	-0.05

Again this echo 5.1.2 with less visits to destination charge points.

Table 48: Severe Undercharging Difference per EV (weekly averages) for 1.1.3 vs. 5.1.3

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	-0.0002	0.0002	0.0003	-0.0001	-0.0004	-0.0003	0.0001	0.0000
	27mpd	0.0000	-0.0005	-0.0005	-0.0003	0.0000	-0.0002	-0.0001	-0.0001
	38mpd	0.0002	-0.0007	-0.0011	-0.0008	-0.0008	-0.0008	-0.0009	-0.0007
	49mpd	-0.0012	-0.0019	-0.0006	-0.0025	-0.0005	-0.0010	-0.0014	-0.0012

(limit: < 0.007)

All plies pass for severe undercharges, yet 5.1.3 improves the rates (at parity: 0.0008). The worst seen 5.1.3. severe undercharging rate was 0.0051.

V3-4.7.3.1 Seq_5.1.3 Results Discussion

For both DNO and the EV this sequence is an improvement over Seq_1.1.3; other than the transformer broaches seen in 49mpd 140 EVs this was a perfect score.

Note that a proportion of dumb (uncontrolled) EVs are still present. It would be interesting to charge the proportion of these up and down (from say 19% +/- 6%). It may be that elimination of dumb EVs will remove broaches; however the DNO has no ability to guarantee that is the case in real-life; an EV may “become dumb” overnight e.g. by a faulty software update (in EV, EVSE or other part of the comms chain).

Thus the rationale for including dumb EVs: they cannot be gainsaid.

V3-4.8 Sequence 5.2.2

Sequence	**Simulation ID**	**Description**
Seq_5.2.2	(S_87)	As 5.1.2, now with the DR-B FFR value-added service pattern, added as modulation of the hi_limit.
Baseline	***Description***	
Seq_5.1.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.*	

The DR-B FFR signal includes a demand reduction component and a Frequency Response component (which sums to zero up vs down kW over a day). See Volume 2 Results, section 4.5 for a description of this signal, which repeats each day.

V3-4.8.1 Broaching

Some 15 plies broach in 5.2.2, matching the number seen in 5.1.2; although the counts vary both up and down; broaches are initially down but rise as EV kWh duty rises. This effect is likely due to the reduced regulation limits from the DRFFR signal.

Again, happenstance is seen: A ply cell with higher demand is free of broaches, yet a companion cell with lower demand has broaches. This seems to be consistent so the author ascribes this to variation between trip happenstance (as the same trips are being repeated).

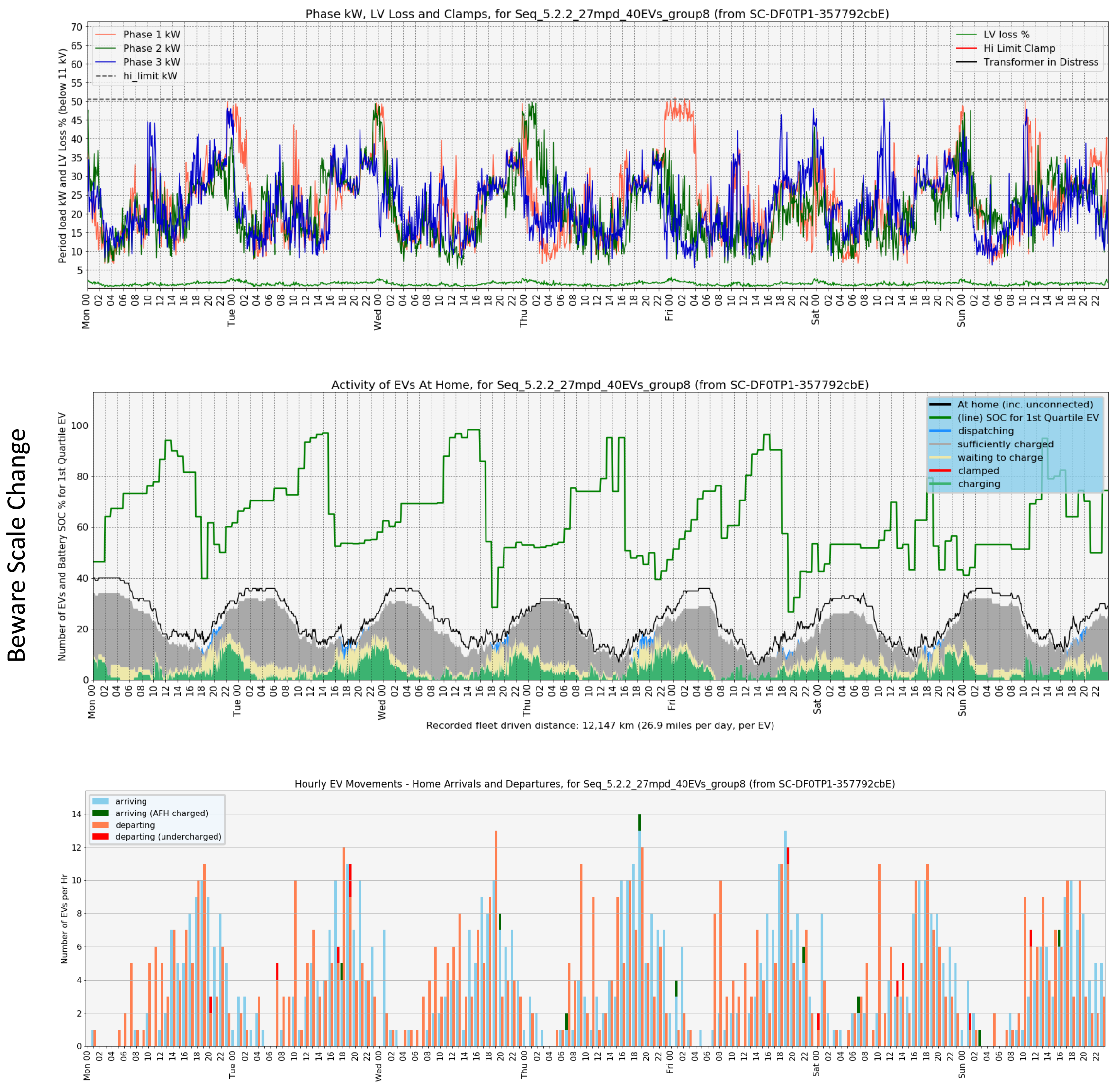
V3-4.8.2 Seq_5.2.2 in Summary

5.2.2 is unusual, with V2G being extensively used.

The concern that DRFFR would be deleterious has not been born out; the net effect showing that, with MCS and V2G at hand, DRFFR is possible and has no great drawback.

V3-4.8.3 Seq_5.2.2: Feeder and EV Plots

V3-4.8.3.1 Seq_5.2.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,416 Home: 2,134 AFH: 282 V2G: 103

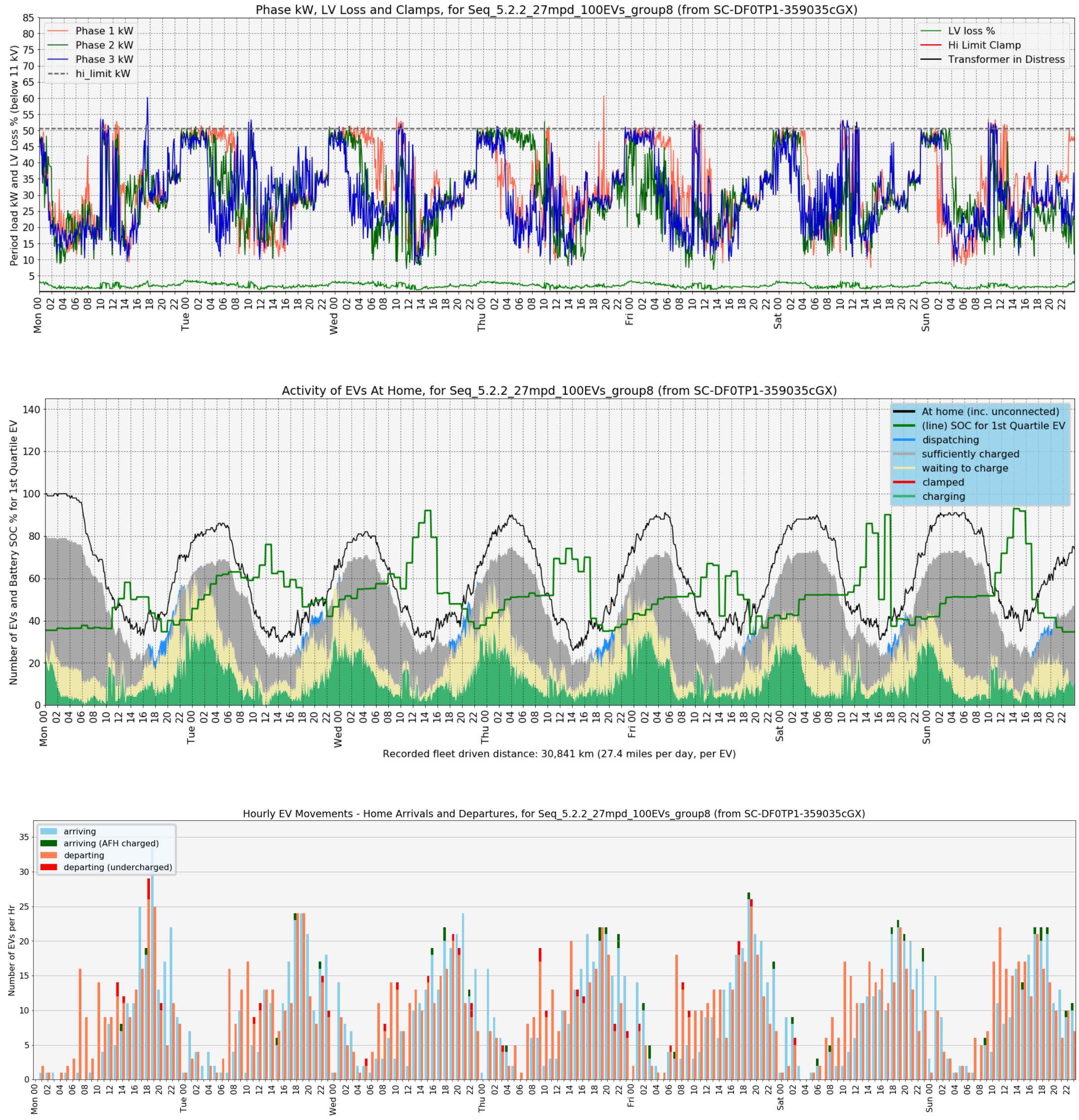
Figure 4-16: Seq_5.2.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no broaches visible,
- (CICD) EV SOC is higher than in Seq_5.1.2, by about 10% or more
- (Arrive/Depart) very few EVs are departing undercharged or using AFH; the plot is almost identical to 5.1.2
- there is now V2G spend, not seen in 5.1.2.

V3-4.8.3.2 Seq_5.2.2: 27mpd 100EVs

Beware Scale Change



EoW stats: kWh[b] EV total: 6,227 Home: 5,440 AFH: 787 V2G: 327

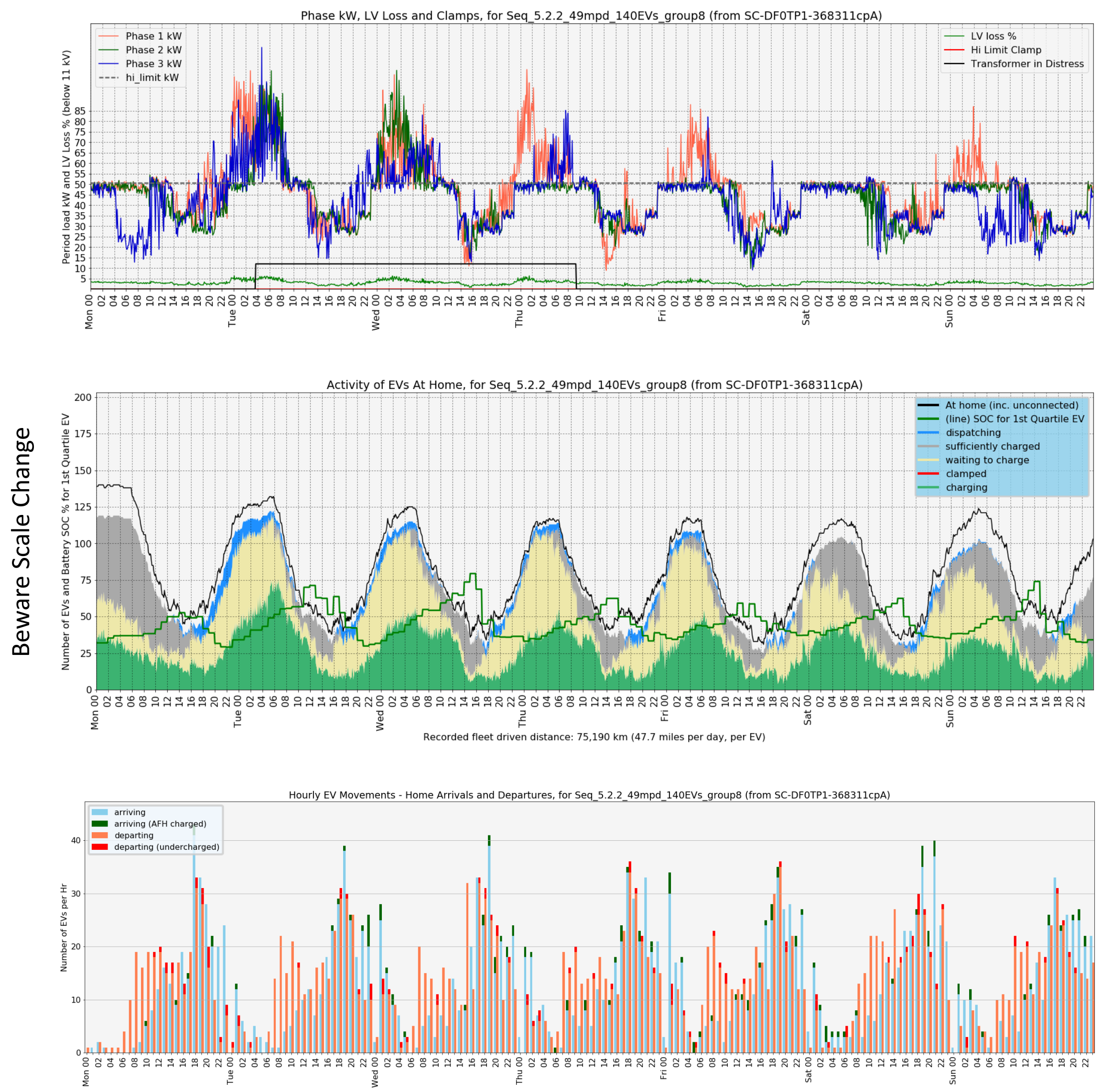
Figure 4-17: Seq_5.2.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- there are two visible spike sin the Feeder plot, whereas there was only one in 5.1.2; the outline of the DRFFR signal is occasionally apparent
- EV SOC is slightly up vs. 5.1.2, with bursts of V2G blue accompanying the DR period,
- (Arrive/Depart) is by eye identical to the corresponding 5.1.2 plot.

Total EV demand has risen by c. 350 kWh, with Home charging 360 kWh up and AFH 12 down. V2G has risen by 318, from 9 kWh.

V3-4.8.3.3 Seq_5.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 15,620 Home: 11,381 AFH: 4,239 V2G: 2,009

Figure 4-18: Seq_5.2.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) considerable broaching is seen with the Transformer distress signal in black, which was also apparent in 5.1.2.
- (CICD) V2G in blue is now very apparent; SOC by eye is slightly down vs. 5.1.2
- (Arrive/Depart) overall similar to 5.1.2.

EV energy use up c. 1,600 kWh which the author ascribes to elevated V2G use and an increase of accompanying losses.

V3-4.8.4 Data Tables Seq_5.2.2

Data are from MetaMeta spreadsheets for Seq_5.1.2 and Seq_5.2.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 49: Unused kWh (weekly averages) for 5.1.2 vs. 5.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	1. Unused kWh A	19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091
Seq_5.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,104	16,470	15,214	13,947	12,655	11,342	10,036	8,708
		27mpd	16,986	16,209	14,685	13,130	11,591	10,021	8,390	6,688
		38mpd	16,883	16,004	14,209	12,382	10,586	8,684	6,771	4,650
		49mpd	16,796	15,829	13,834	11,825	9,870	7,742	5,585	3,302
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-14	-19	-32	-39	-64	-107	-170	-236
		27mpd	-15	-25	-46	-84	-136	-198	-301	-429
		38mpd	-18	-32	-72	-133	-210	-294	-458	-689
		49mpd	-21	-39	-91	-172	-266	-378	-594	-789

The tables show that 5.2.2 is consuming more power than 5.1.2, even though there is DR and FFR operating. This is likely due to V2G losses being encountered.

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Table 50: Per EV AFH Uptake kWh (weekly averages) for 5.1.2 vs. 5.2.2

Seq_5.1.2	2. AFH kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3

Seq_5.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	2.9	3.0	3.0	3.1	3.4	3.3	3.3
		27mpd	6.1	7.1	7.0	7.3	7.8	7.9	7.8	7.7
		38mpd	15.9	16.1	16.6	17.2	17.1	17.6	17.4	17.6
		49mpd	33.5	31.2	29.9	29.8	29.6	29.7	30.2	30.3

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0	0.0
		27mpd	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.1
		38mpd	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	0.0
		49mpd	-0.4	-0.3	-0.4	-0.4	-0.4	-0.3	-0.2	0.0

In general, there is a small drop of AFH kWh taken on; a surprising result.

Is this compensated for by more AFH visits?

Table 51: Per EV N Connects in Week (averages) for 5.1.2 vs. 5.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	3. EV N AFH A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91
Seq_5.2.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.12	0.12	0.13	0.14	0.14	0.14
		27mpd	0.26	0.28	0.26	0.27	0.30	0.29	0.29	0.29
		38mpd	0.55	0.54	0.55	0.56	0.56	0.58	0.57	0.58
		49mpd	1.04	0.93	0.88	0.87	0.88	0.88	0.90	0.90
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		27mpd	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
		38mpd	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.00
		49mpd	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01

There is a slight downturn of N AFH visits, per EV.

Table 52: Severe Undercharging Difference per EV (weekly averages) for 5.1.2 vs. 5.2.2

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	27mpd	0.0000	0.0001	-0.0001	0.0000	-0.0001	0.0000	-0.0001	0.0000
	38mpd	0.0004	-0.0001	-0.0001	0.0000	0.0001	-0.0001	0.0000	0.0000
	49mpd	0.0004	0.0004	-0.0001	0.0002	-0.0002	-0.0001	0.0001	0.0001

(limit: < 0.007)

Severe undercharging sees no significant changes. 5.2.2 is below a limit of concern (worst being 0.0052, vs. the pass limit of 0.007).

Table 53: DRFFR responsiveness: Percent Effective Hours in Week 5.2.2

5. DRFFR PEH metric	N EV	10	20	40	60	80	100	120	140
	19mpd	33.3%	35.1%	40.5%	47.0%	53.6%	63.1%	71.4%	78.6%
	27mpd	31.5%	36.3%	42.9%	51.2%	63.1%	70.2%	80.4%	87.5%
	38mpd	32.7%	36.9%	44.0%	56.0%	69.0%	73.2%	85.7%	88.1%
	49mpd	31.5%	36.3%	47.6%	57.7%	70.8%	76.2%	82.1%	81.0%

(limit: < 0.007)

The PEH metric looks for deltas of same net load movement vs. the FFR signal, in which the maximum score is 100% and the minimum score is 25% (correspondence of noise movements vs. signal, using Pearson's r correlation). The magnitude is not considered, rather, the control engagement (effectivity). As can be seen, for cases of 60 EVs per 100 houses and over, there is sign of useful service capability. Note that this considers EVs at home only, so implies a response during the daytime i.e. when most EVs are away.

V3-4.8.4.1 Seq_5.2.2 Results Discussion

V2G is being extensively used.

Use of DRFFR has caused no observable deleterious side effects.

V3-4.9 Sequence 5.3.2

Sequence	**Simulation ID**	**Description**
Seq_5.3.2	(S_86)	As 5.2.2 plus Agg-B (daily ToU rules: No Charging from 1pm, then from 6pm only charge if < 1/3rd SOC, then unconstrained charging 11pm on) applied as a direct instruction to Aggregator controlled EVs (all).
Baseline	***Description***	
Seq_5.2.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit plus DRB-FFR signal.*	

An EV type can be marked for control by a remove Aggregator signal, which is provided via a Agg command, placed into the simulator schedule. In this case, all EVs are so marked.

Internally, the MCS uses “SOC spoofing”; that is, when the Aggregator prohibits charging, the SOC reported for effected EVs is “fully charged” (the actual EV SOC level is not changed). The Aggregator Time of Use (ToU) signals are as follows:

- from 1pm: idle only (no charging or dispatch)
- from 6pm: charging only allowed if SOC < 33%
- from 11pm: unrestricted operation.

V3-4.9.1 Broaching

Broaching is slightly changed but has the same overall coverage (number of broaching plies) as 5.1.2 and 5.2.2.

V3-4.9.2 Seq_5.3.2 in Summary

The Aggregator Time of Use commands are effective in so far as can can be seen operating at the correct time, but provoke severe EV undercharging for all but 2 of 32 ply cells.

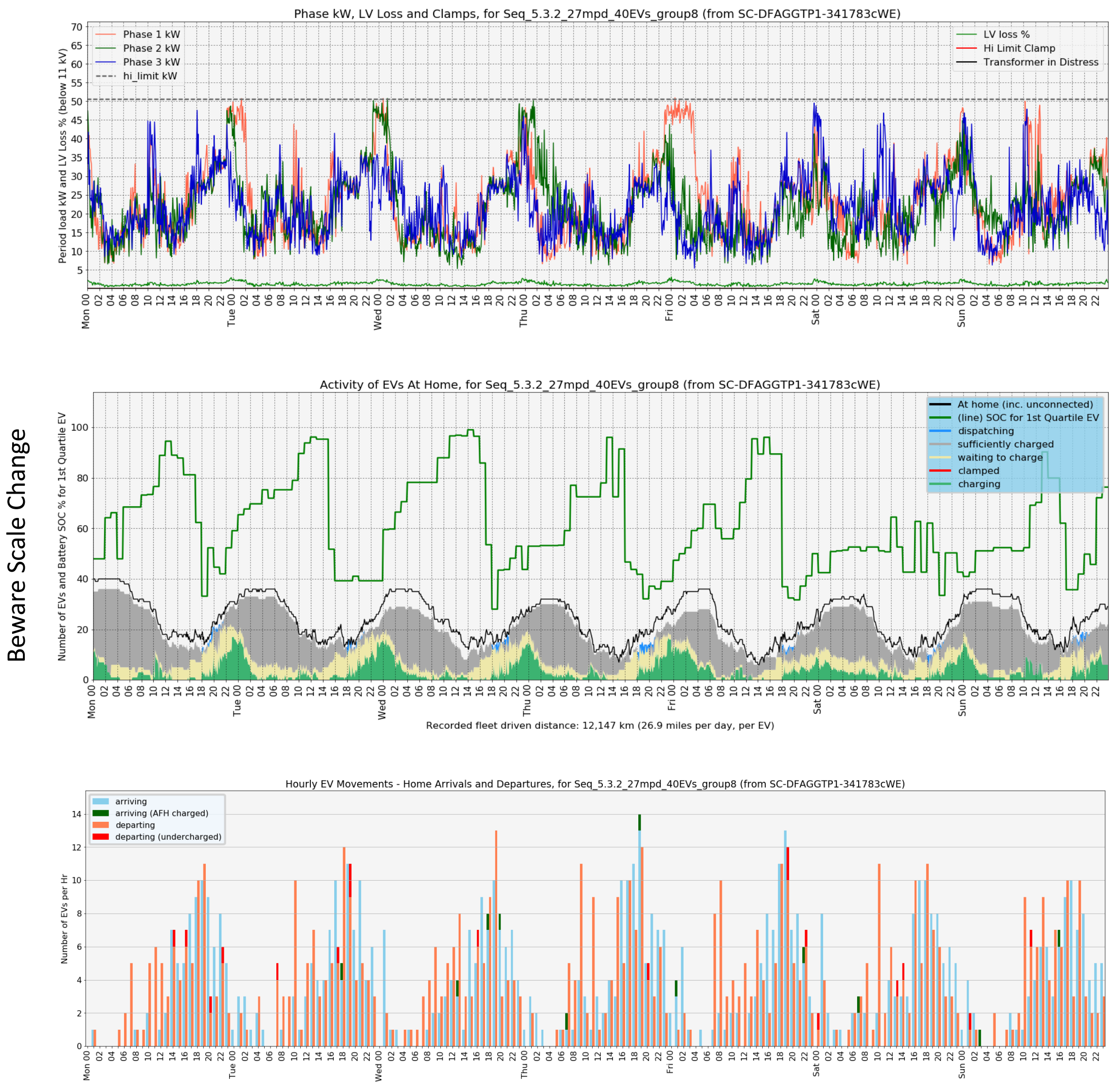
This approach cannot be recommended, although that does not preclude alternatives.

The primary problem is “in the blind” with 100% EV numbers being controlled. If the Aggregator has insight as to local conditions, or would commanded a subset of EVs, the situation may moderate.

See also 5.7.2 with 1 in 4 EVs under Aggregator control and an extended discussion.

V3-4.9.3 Seq_5.3.2: Feeder and EV Plots

V3-4.9.3.1 Seq_5.3.2: 27mpd 40EVs



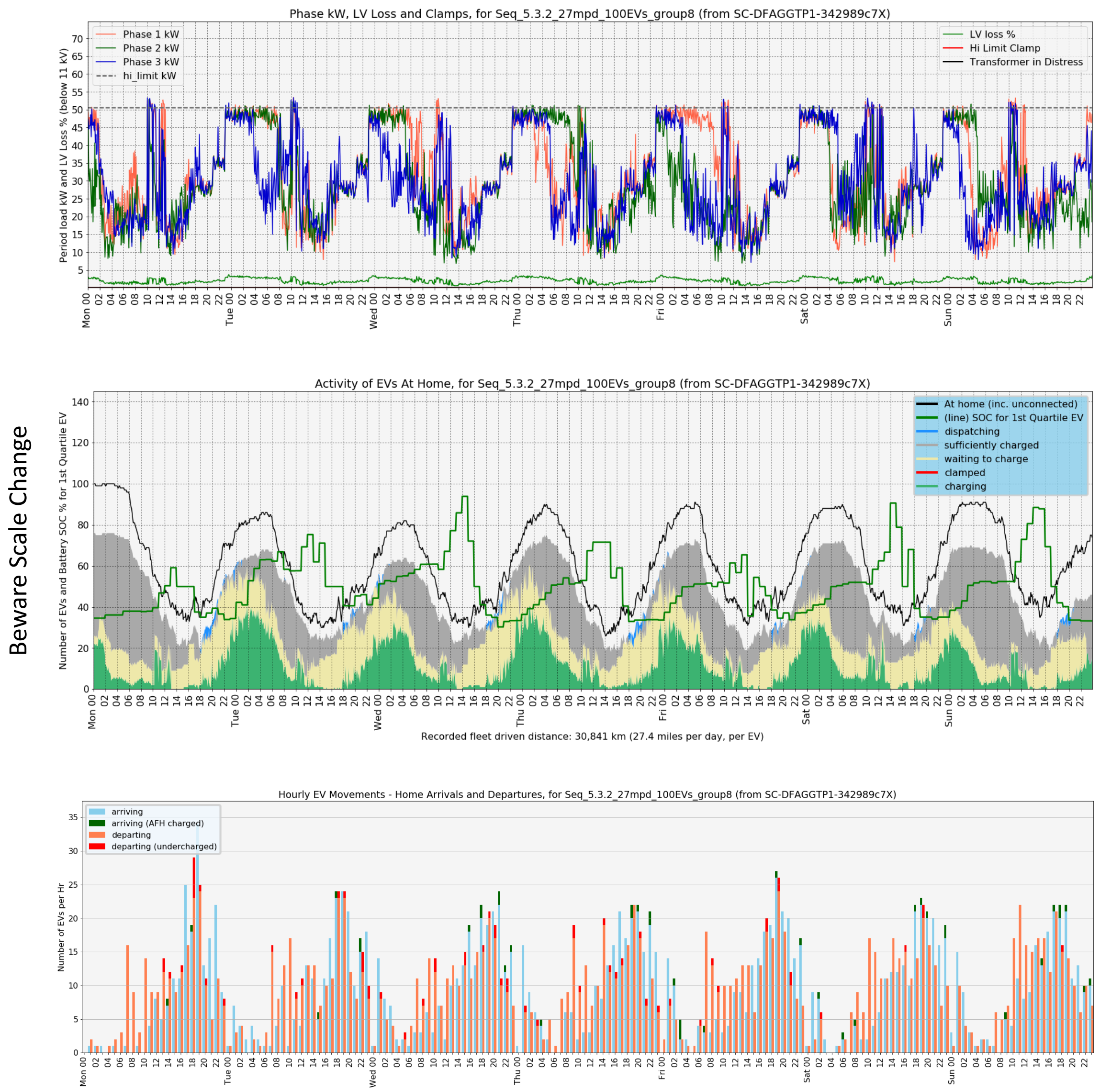
EoW stats: kWh[b] EV total: 2,397 Home: 2,091 AFH: 306 V2G: 75

Figure 4-19: Seq_5.3.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no broaches visible,
- (CICD) EV SOC is slightly down by eye vs. 5.2.2
- (Arrive/Depart) very few EVs are departing undercharged or using AFH; the plot is almost identical to 5.2.2
- Total kWh consumption is down 21 kWh, with both Home and AFH level having dropped; V2G spend is down 28 kWh from 5.2.2.

V3-4.9.3.2 Seq_5.3.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 6,125 Home: 5,263 AFH: 862 V2G: 213

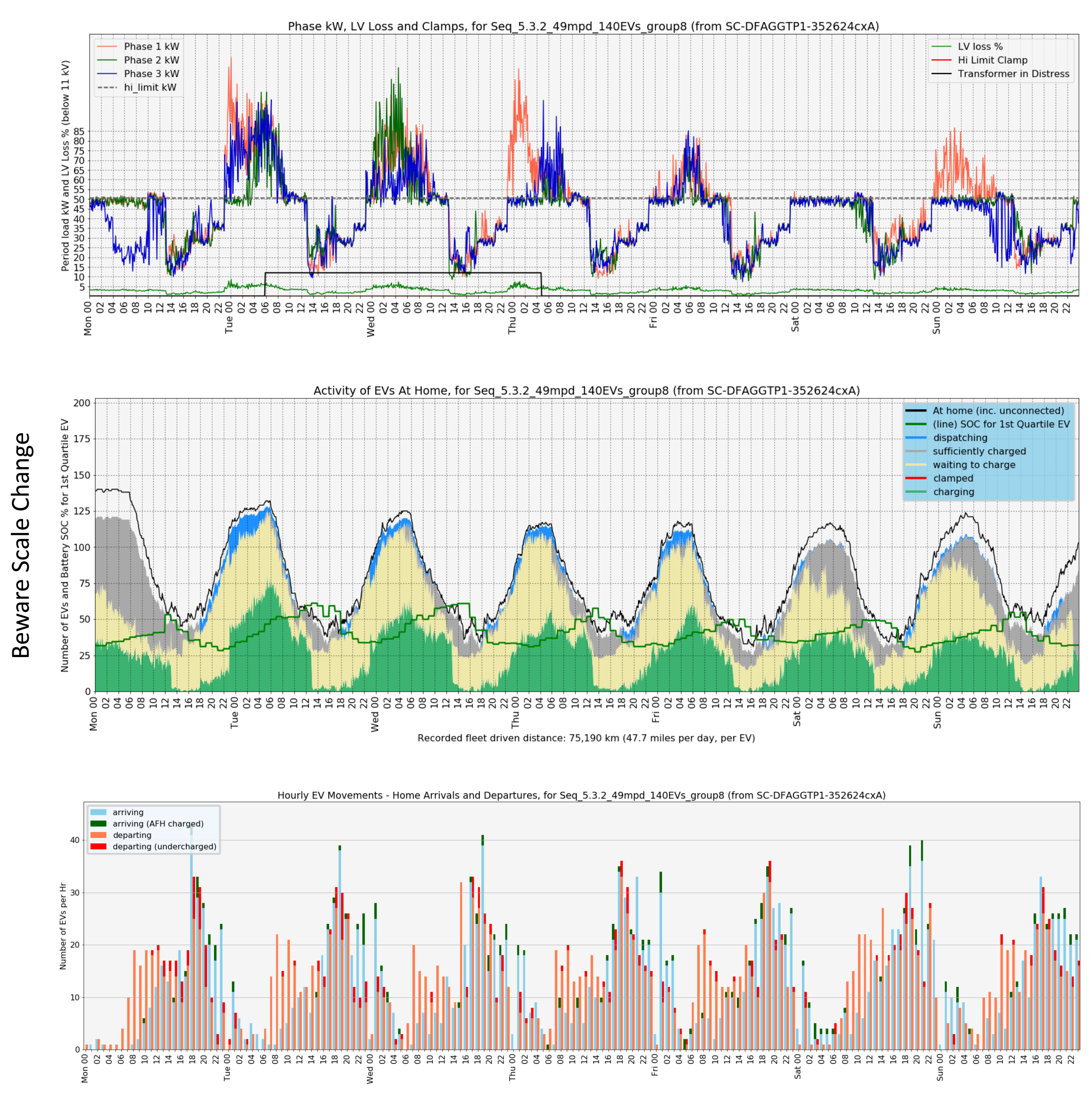
Figure 4-20: Seq_5.3.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- the Feeder plot shows no broaches; the DRFFR signal is apparent and the effect of banning charging in the afternoon is visible vs. 5.2.2 as afternoon load drop
- EV SOC is slightly down by eye vs. 5.2.2, with bursts of V2G blue accompanying the DR period,
- (Arrive/Depart) is by eye identical to the corresponding 5.2.2 plot.

Total EV demand has dropped 102 kWh, V2G use is c. 114 kWh down. AFH charging is up by 75 kWh.

V3-4.9.3.3 Seq_5.3.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 15,251 Home: 10,673 AFH: 4,578 V2G: 1,638

Figure 4-21: Seq_5.3.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) broaching is seen (slightly down from 5.2.2) with the Transformer distress signal in black, apparent in 5.2.2. Here, the signal starts later and is slightly shorter.
- (CICD) Agg ToU command notches can be seen in charging, with SOC slightly down. vs. 5.2.2; V2G blue is very apparent.
- (Arrive/Depart) undercharged departures have risen vs. 5.2.2.

EV energy draw has fallen 1,370 kWh vs. 5.2.2, lowering Home charging. AFH is 340 kWh up. V2G has fallen by 370 kWh, presumably as V2G EVs have less charge to spare.

V3-4.9.4 Data Tables Seq_5.3.2

Data are from MetaMeta spreadsheets for Seq_5.2.2 and Seq_5.3.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 54: Unused kWh (weekly averages) for 5.2.2 vs. 5.3.2

Seq_5.2.2	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,104	16,470	15,214	13,947	12,655	11,342	10,036	8,708
		27mpd	16,986	16,209	14,685	13,130	11,591	10,021	8,390	6,688
		38mpd	16,883	16,004	14,209	12,382	10,586	8,684	6,771	4,650
		49mpd	16,796	15,829	13,834	11,825	9,870	7,742	5,585	3,302
Seq_5.3.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,111	16,486	15,250	13,997	12,729	11,442	10,156	8,848
		27mpd	17,002	16,237	14,740	13,218	11,715	10,189	8,600	6,869
		38mpd	16,904	16,043	14,297	12,515	10,773	8,934	7,064	5,017
		49mpd	16,824	15,878	13,946	12,007	10,129	8,098	6,039	3,913
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	8	17	36	50	73	101	121	140
		27mpd	16	27	56	88	124	167	210	181
		38mpd	21	39	88	133	187	250	294	367
		49mpd	28	49	113	182	259	356	455	610

The tables show that 5.3.2 is consuming less power than 5.2.2, likely due to the effect of the Aggregator limiting charging in the afternoon and evening.

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Table 55: Per EV AFH Uptake kWh (weekly averages) for 5.2.2 vs. 5.3.2

Seq_5.2.2	2. AFH kWh A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	2.9	3.0	3.0	3.1	3.4	3.3	3.3
		27mpd	6.1	7.1	7.0	7.3	7.8	7.9	7.8	7.7
		38mpd	15.9	16.1	16.6	17.2	17.1	17.6	17.4	17.6
		49mpd	33.5	31.2	29.9	29.8	29.6	29.7	30.2	30.3
Seq_5.3.2	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.6	3.2	3.3	3.2	3.4	3.7	3.6	3.6
		27mpd	6.9	7.8	7.7	8.0	8.5	8.6	8.5	8.5
		38mpd	17.1	17.1	17.8	18.3	18.3	19.0	18.8	19.2
		49mpd	35.3	32.6	31.5	31.4	31.4	31.7	32.3	32.7
Difference B - A	C Diff.	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.1	0.3	0.3	0.3	0.3	0.4	0.4	0.4
		27mpd	0.8	0.6	0.6	0.7	0.7	0.8	0.8	0.9
		38mpd	1.2	1.1	1.2	1.1	1.2	1.3	1.4	1.6
		49mpd	1.7	1.4	1.6	1.7	1.8	2.0	2.1	2.4

AFH kWh uptake has risen. Is this accompanied by more AFH visits?

Table 56: Per EV N Connects in Week (averages) for 5.2.2 vs. 5.3.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.2.2	3. EV N AFH A	19mpd	0.11	0.13	0.12	0.12	0.13	0.14	0.14	0.14
		27mpd	0.26	0.28	0.26	0.27	0.30	0.29	0.29	0.29
		38mpd	0.55	0.54	0.55	0.56	0.56	0.58	0.57	0.58
		49mpd	1.04	0.93	0.88	0.87	0.88	0.88	0.90	0.90
Seq_5.3.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.12	0.14	0.14	0.13	0.14	0.16	0.15	0.15
		27mpd	0.31	0.31	0.30	0.30	0.33	0.33	0.33	0.33
		38mpd	0.61	0.60	0.60	0.61	0.62	0.64	0.64	0.65
		49mpd	1.12	1.00	0.95	0.94	0.96	0.97	0.99	1.00
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.005	0.013	0.013	0.014	0.015	0.018	0.017	0.018
		27mpd	0.045	0.034	0.033	0.034	0.035	0.038	0.039	0.044
		38mpd	0.060	0.055	0.056	0.051	0.055	0.060	0.063	0.074
		49mpd	0.081	0.066	0.071	0.072	0.077	0.087	0.091	0.103

There is a c. 10% rise in N AFH visits, per EV per week. This will exacerbate the EV destination chargepoint issues (insufficient in Winter vs. Summer).

Table 57: Severe Undercharging per EV (weekly averages) for 5.2.2 vs. 5.3.2

4. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0110	0.0089	0.0087	0.0068	0.0069	0.0100	0.0101	0.0106
	27mpd	0.0152	0.0130	0.0135	0.0165	0.0182	0.0212	0.0218	0.0240
	38mpd	0.0402	0.0364	0.0368	0.0382	0.0374	0.0429	0.0436	0.0500
	49mpd	0.0546	0.0550	0.0594	0.0558	0.0587	0.0686	0.0762	0.0858

(exceeds limit: < 0.007)

Severe undercharging has rocketed with Aggregator Time of Use

This is the first Set 5 simulation sequence to fail. The author has traced this effect within FPB and it is exemplified by the following diagram, Fig. 6-14 from the main Thesis:

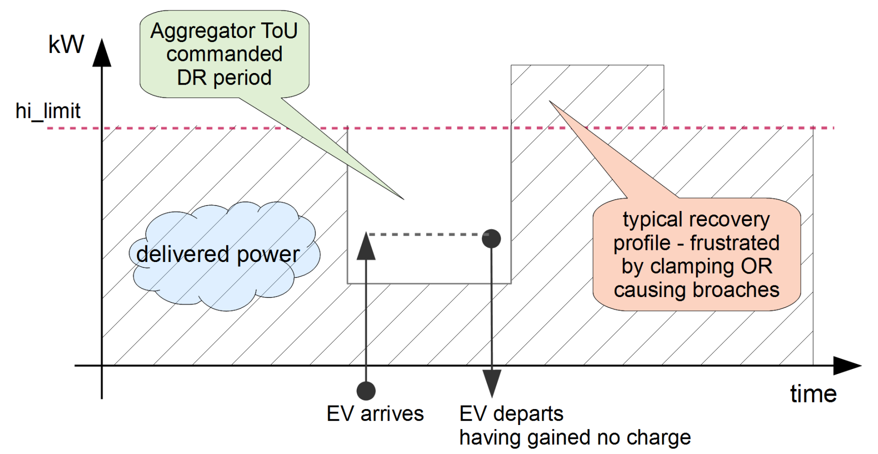


Figure 6-14: Agg ToU / DR: Unfortunate EVs are not charged

ToU commands disadvantage EVs having trip patterns which imply a need to recharge, during the ToU prohibition period. If the EV stays a little longer, there may be increased broaching as the release of the prohibition co-ordinates many EVs to charge together, invalidating the ADMD diversity assumption.

Table 58: DRFFR: Difference in Percent Effective Hours in Week 5.3.2 vs 5.2.2

5. DRFFR PEH metric	N EV	10	20	40	60	80	100	120	140
	19mpd	-1.2%	-0.6%	0.0%	-0.6%	3.5%	1.8%	-2.4%	-6.0%
	27mpd	0.0%	-1.8%	-1.8%	1.8%	0.0%	-1.7%	-4.8%	-7.7%
	38mpd	0.0%	-1.8%	1.8%	1.7%	-2.3%	-0.6%	-6.5%	-13.7%
	49mpd	0.0%	-1.2%	-1.8%	1.2%	-2.3%	-1.8%	-4.7%	-10.8%

The PEH metric has fallen across the board, likely due to lack of response during the Aggregator ToU prohibition periods.

V3-4.9.4.1 Seq_5.3.2 Results Discussion

Sequence 5.3.2 with this form of Aggregator control, applied "in the blind" cannot be recommended, as EV severe undercharging rates become too high.

See also the plots in Figure 4-34 produced for Seq_5.7.2 which places 1 in every 4 EVs under the same Aggregation control.

V3-4.10 Sequence 5.4.2

Sequence	**Simulation ID**	**Description**
Seq_5.4.2	(S_AU)	As 5.2.2 plus 9 Static Batteries (3 per phase).
Baseline	***Description***	
Seq_5.2.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit plus DRB-FFR signal.*	

Static Batteries are added. These are static V2G EVs in addition to the normal EV fleet, placed 3 per phase equidistant along the feeder length.

Each has the standard EV connection of up to 7.2 kW, but large batteries at 150 kWh. A subsidiary question - how deep are these discharged?

Note that the automatically generated plots have no means to distinguish Static Batteries from EVs; these are included in the CICD plot. However the spreadsheets have had a correction applied for the V2G numbers. Most items are based on counts (number of departs etc.) so these do not need correcting.

Also note that simulations have been run with a slightly different tripset.

V3-4.10.1 Broaching

Broaching is improved over 5.2.2, gaining 6 plies. However the parity case was still broaching.

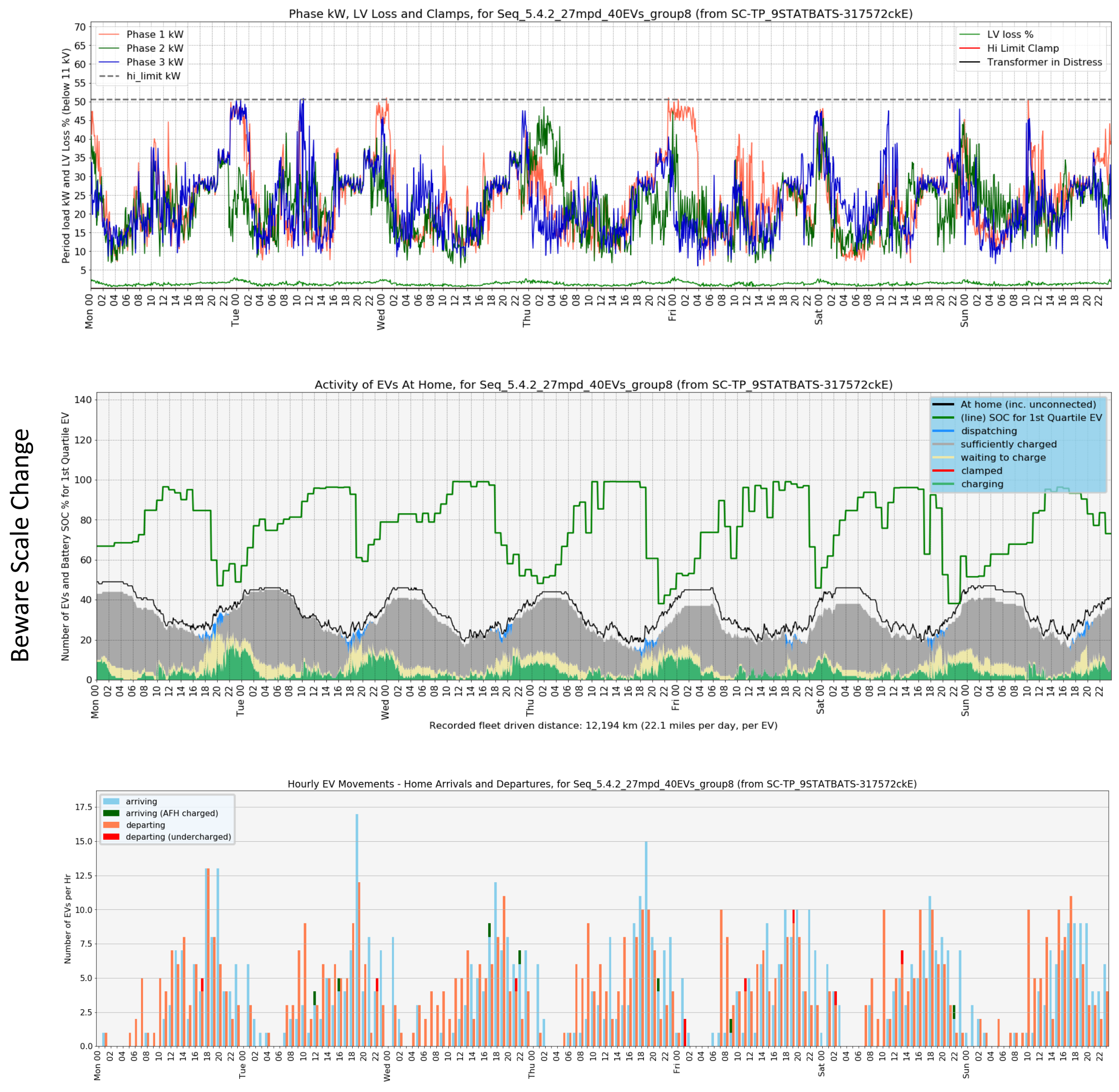
V3-4.10.2 Seq_5.4.2 in Summary

Static batteries proved to be a success, aiding broaching with no noticeable impact on EVs.

See also Seq_6.13.2 which adds Winter PV to the Static Battery case, allowing local storage to utilise sunshine.

V3-4.10.3 Seq_5.4.2: Feeder and EV Plots

V3-4.10.3.1 Seq_5.4.2: 27mpd 40EVs



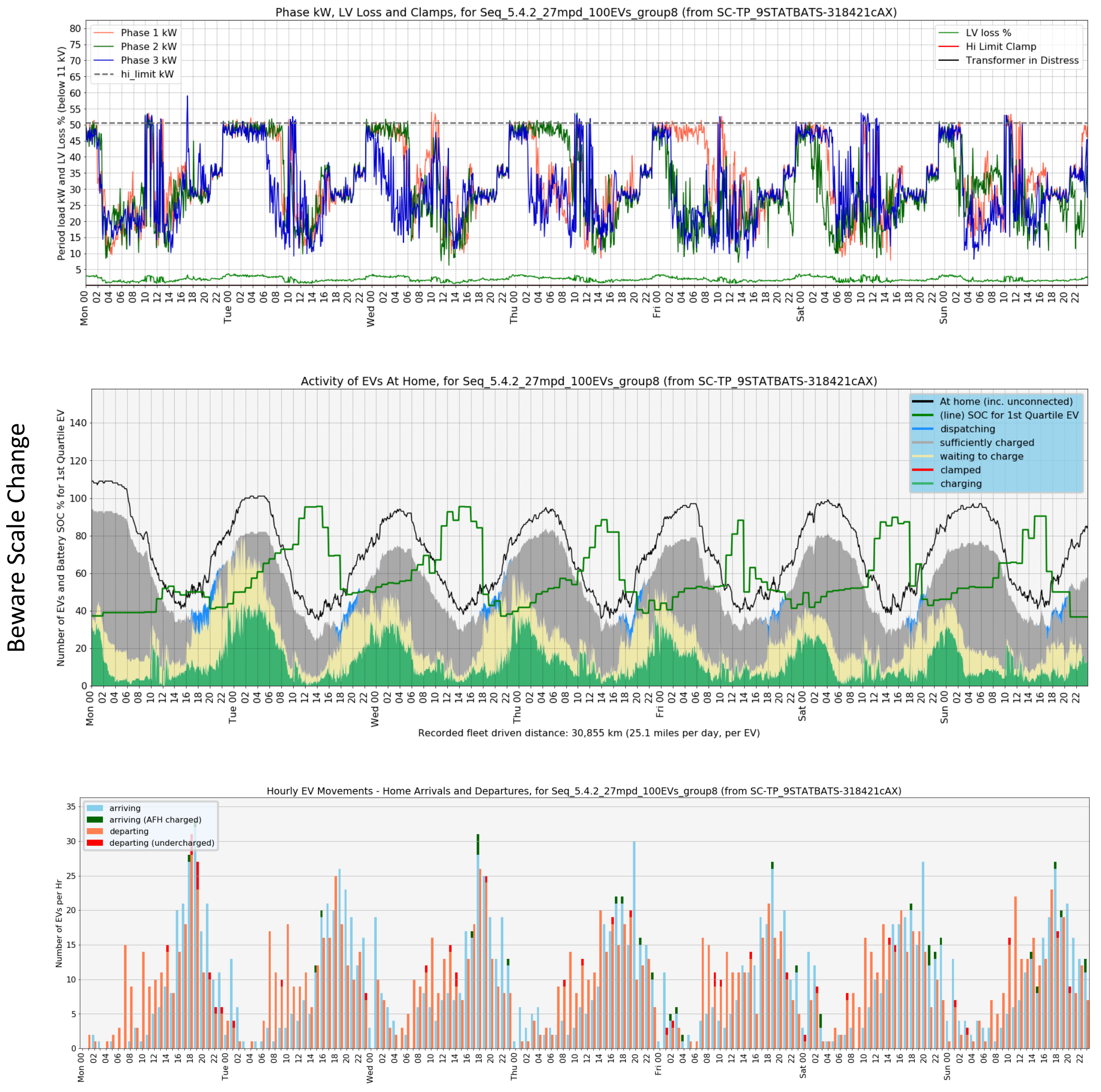
EoW stats: kWh[b] EV total: 2,494 Home: 2,212 AFH: 282 V2G: 179

Figure 4-22: Seq_5.4.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,227

Notes re above plots:

- (Feeder) there are no broaches visible,
- (CICD) EV SOC is by eye higher than 5.2.2, with more time spent at or near 100% - but this will include the Static Battery charge levels
- (Arrive/Depart) very few EVs are departing undercharged or using AFH
- Total kWh consumption is similar, down by 78 kWh, with Home having risen, AFH stays the same. V2G is up by 76 kWh vs. 5.2.2.

V3-4.10.3.2 Seq_5.4.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 6,376 Home: 5,588 AFH: 788 V2G: 472

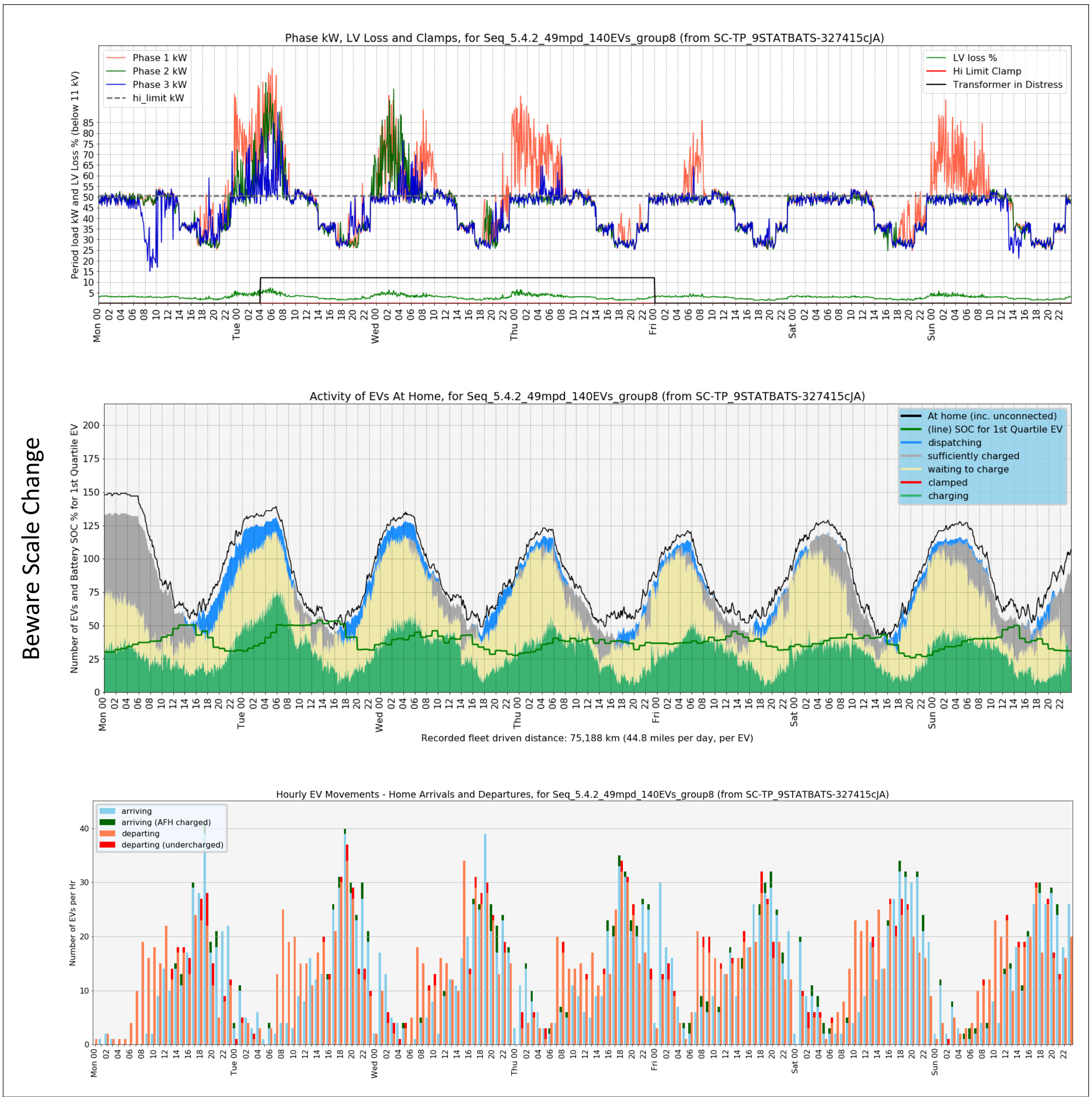
Figure 4-23: Seq_5.4.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,877

Notes re above plots:

- the Feeder plot shows a potential broaches and the DRFFR signal is apparent
- by eye EV SOC is slightly up vs. 5.2.2, with bursts of V2G blue accompanying the DR period,
- (Arrive/Depart) is by eye similar to the corresponding 5.2.2 plot.

Total EV demand has dropped 102 kWh, V2G use is c. 114 kWh down. AFH charging is up by 75 kWh.

V3-4.10.3.3 Seq_5.4.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 17,196 Home: 12,898 AFH: 4,299 V2G: 3,599

Figure 4-24: Seq_5.4.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) broaching is seen with clear emphasis on phase 1 (red). The Transformer distress signal in black is c. 14 hours longer than in 5.2.2.
- (CICD) If anything, EV SOC has fallen slightly; V2G blue is very apparent.
- (Arrive/Depart) is similar to vs. 5.2.2.

EV energy draw has risen 1,550 kWh vs. 5.2.2, with a corresponding amount going into the V2G system. AFH is slightly up by 40 kWh.

V3-4.10.4 Data Tables Seq_5.4.2

Data are from MetaMeta spreadsheets for Seq_5.2.2 and Seq_5.4.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 59: Unused kWh (weekly averages) for 5.2.2 vs. 5.4.2

Seq_5.2.2	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,104	16,470	15,214	13,947	12,655	11,342	10,036	8,708
		27mpd	16,986	16,209	14,685	13,130	11,591	10,021	8,390	6,688
		38mpd	16,883	16,004	14,209	12,382	10,586	8,684	6,771	4,650
		49mpd	16,796	15,829	13,834	11,825	9,870	7,742	5,585	3,302

Seq_5.4.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	16,900	16,265	15,007	13,732	12,436	11,118	9,817	8,485
		27mpd	16,779	16,000	14,470	12,911	11,347	9,770	8,146	6,321
		38mpd	16,673	15,790	13,987	12,144	10,321	8,390	6,340	3,840
		49mpd	16,579	15,611	13,597	11,566	9,575	7,374	4,946	2,501

lime indicates non-broaching plies in 5.4.2

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-204	-205	-207	-216	-219	-223	-219	-223
		27mpd	-206	-209	-215	-219	-244	-252	-244	-367
		38mpd	-211	-214	-222	-238	-265	-294	-431	-810
		49mpd	-217	-218	-236	-258	-295	-368	-638	-802

The tables show that 5.4.2 is consuming more power than 5.2.2, unused headroom has dropped.

.

Table 60: Per EV AFH Uptake kWh (weekly averages) for 5.2.2 vs. 5.4.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.2.2	2. AFH kWh A	19mpd	2.5	2.9	3.0	3.0	3.1	3.4	3.3	3.3
		27mpd	6.1	7.1	7.0	7.3	7.8	7.9	7.8	7.7
		38mpd	15.9	16.1	16.6	17.2	17.1	17.6	17.4	17.6
		49mpd	33.5	31.2	29.9	29.8	29.6	29.7	30.2	30.3
Seq_5.4.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.4	2.9	3.0	2.9	3.1	3.3	3.3	3.3
		27mpd	6.2	7.1	7.1	7.4	7.9	7.9	7.8	7.7
		38mpd	16.0	16.1	16.6	17.3	17.1	17.6	17.5	17.8
		49mpd	33.4	31.1	29.9	29.7	29.6	29.8	30.3	30.7
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.03	-0.08	-0.02	-0.05	0.03	-0.03	0.01	0.02
		27mpd	0.09	0.00	0.02	0.05	0.01	0.01	0.03	0.05
		38mpd	0.05	0.04	0.00	0.12	-0.02	-0.02	0.06	0.29
		49mpd	-0.18	-0.15	-0.02	-0.12	-0.05	0.06	0.14	0.43

AFH kWh uptake is almost identical and likely as much attributable to the alternative trips driven as Static Batteries.

Table 61: Per EV N Connects in Week (averages) for 5.2.2 vs. 5.4.2

Seq_5.2.2	3. EV N AFH A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.11	0.13	0.12	0.12	0.13	0.14	0.14	0.14
		27mpd	0.26	0.28	0.26	0.27	0.30	0.29	0.29	0.29
		38mpd	0.55	0.54	0.55	0.56	0.56	0.58	0.57	0.58
		49mpd	1.04	0.93	0.88	0.87	0.88	0.88	0.90	0.90
Seq_5.4.2	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.27	0.26	0.27	0.30	0.29	0.29	0.29
		38mpd	0.54	0.54	0.55	0.56	0.56	0.58	0.58	0.59
		49mpd	1.03	0.93	0.88	0.87	0.88	0.89	0.91	0.92
Difference B - A	C Diff.	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-0.001	-0.003	-0.001	-0.003	0.001	0.000	0.000	0.001
		27mpd	0.006	-0.001	0.000	0.001	0.000	0.001	0.000	0.002
		38mpd	-0.002	0.003	-0.002	0.002	-0.001	-0.001	0.003	0.015
		49mpd	-0.011	-0.003	0.000	-0.004	-0.003	0.001	0.007	0.022

The number of EV AFH connects in the week is trivially different.

Table 62: Difference in Severe Undercharging per EV (weekly averages) for 5.2.2 vs. 5.4.2

4. Diff. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	-0.0003	-0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
	27mpd	0.0000	-0.0001	0.0000	-0.0004	0.0000	0.0000	-0.0002	-0.0001
	38mpd	0.0002	0.0006	0.0006	-0.0004	0.0007	-0.0003	0.0000	-0.0004
	49mpd	-0.0006	0.0008	0.0003	0.0004	0.0006	-0.0002	-0.0002	0.0003

(exceeds limit: < 0.007)

Severe undercharging is almost unchanged; the highest value seen in 5.4.2 being 0.0054.

Table 63: DRFFR: Difference in Percent Effective Hours in Week 5.4.2 vs 5.2.2

5. Diff. DRFFR PEH metric	N EV	10	20	40	60	80	100	120	140
	19mpd	3.60%	4.20%	6.50%	4.20%	5.90%	4.80%	2.40%	2.90%
	27mpd	4.80%	6.00%	6.50%	4.80%	6.50%	3.00%	1.70%	1.20%
	38mpd	3.60%	4.80%	7.80%	7.70%	4.80%	6.00%	4.20%	7.10%
	49mpd	4.20%	5.40%	5.40%	7.20%	4.20%	8.90%	10.20%	6.50%

The PEH metric has risen across the board. This is likely due to the Static Batteries (mimicking EVs) offering extra daytime control response.

The parity case offers a 73.2% OEH metric, with the span within the 120 and 140 EVs plies being 74% - 95%.

V3-4.10.4.1 Seq_5.4.2 Results Discussion

Sequence 5.4.2 with Static Batteries has been a success in terms of reducing broaches and reducing EV undercharging.

Note that use of Static Batteries allows cost-burdens to be moved from EV owners to the DNO, which may be acceptable assuming the Static Batteries are repurposed ex-EV “second life” units. This suggests that multiple second-life systems used as Static Batteries can replace V2G, e.g. an all-dumb system plus many Static Batteries.

Spot-checks indicated that the Static Batteries were being run down to under 10% SOC in extreme cases, but for the parity case depletion did not reach 50% DOD.

V3-4.11 Sequence 5.5.2

Sequence	Simulation ID	Description
Seq_5.5.2	(S_B8)	As 5.4.2 with 2kW PV per home.
Baseline	***Description***	
Seq_5.4.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network, 49 kW hi_limit, DRB-FFR signal and 9 Static Batteries*	

Static Batteries have PV added, which accept a Winter insolation pattern at a rate corresponding to 2 kW of panels per home.

The hope is that the PV will charge the Static Batteries during the day and supply EVs during the evening / overnight, so reduce the power-flow on LV, evidenced by reduced LV losses and LV throughput kWh.

Note that the hi_limit for this run remains at the standard value of 49 kW per phase.

Also note that the simulation was intended to be run (some early documentation cites) with DR-C (halved-depth DR-B) but was performed using DR-B, as was 5.4.2.

V3-4.11.1 Broaching

Broaching is improved over 5.2.2, gaining 6 plies. However the parity case was still broaching.

V3-4.11.2 Seq_5.5.2 in Summary

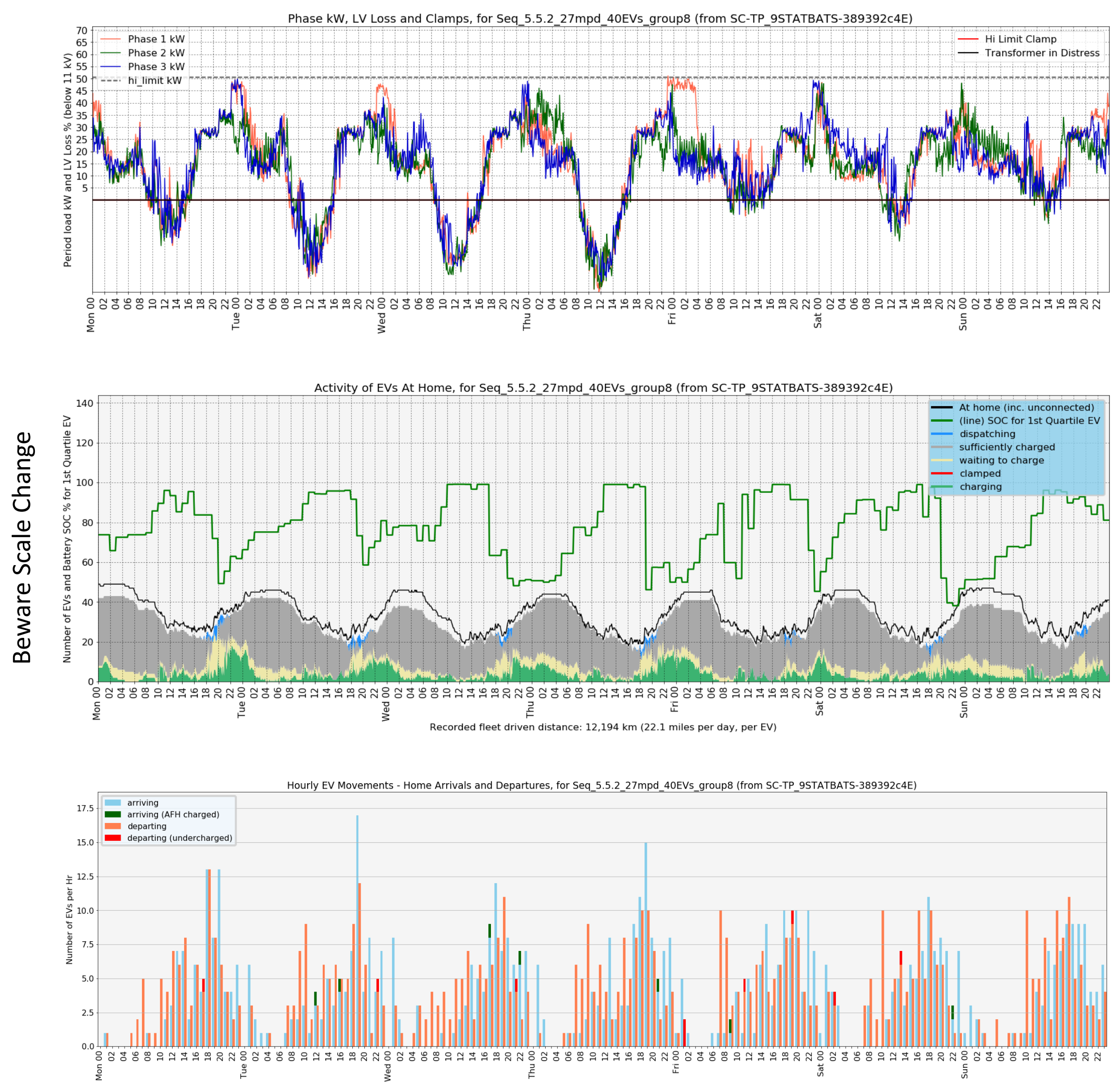
Static batteries paired with Winter PV are a success, slightly reducing broaching and reducing EV undercharging.

Given that PV may be available to many LV systems, it would make sense for DNOs to leverage the installed PV by adding Static Batteries which perform daytime charging.

Note that this is not a complete cure; without clamps Set 5 still experiences broaches i.e. LV network failure.

V3-4.11.3 Seq_5.5.2: Feeder and EV Plots

V3-4.11.3.1 Seq_5.5.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,472 Home: 2,190 AFH: 282 V2G: 158

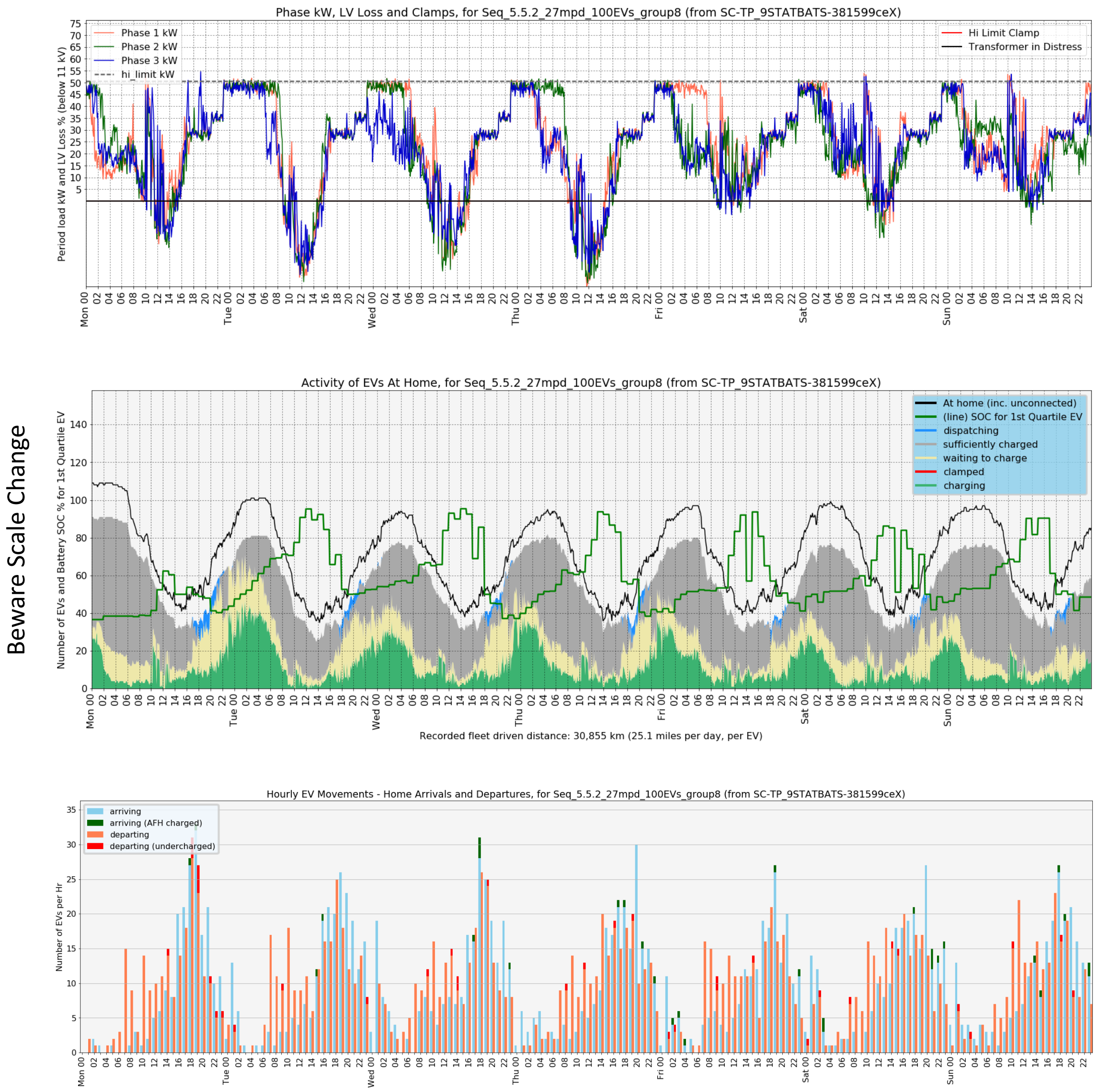
Figure 4-25: Seq_5.5.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,227

Notes re above plots:

- (Feeder) there are no broaches visible, however PVs export power during the day
- (CICD) EV SOC is by eye slightly higher than 5.4.2. This will include the Static Battery charge levels,
- (Arrive/Depart) appears identical to 5.4.2

Total kWh consumption is slightly down; V2G export has dropped by 21 kWh, presumably as some EVs are charging from PV, not Static Batteries / V2G.

V3-4.11.3.2 Seq_5.5.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 6,309 Home: 5,524 AFH: 786 V2G: 411

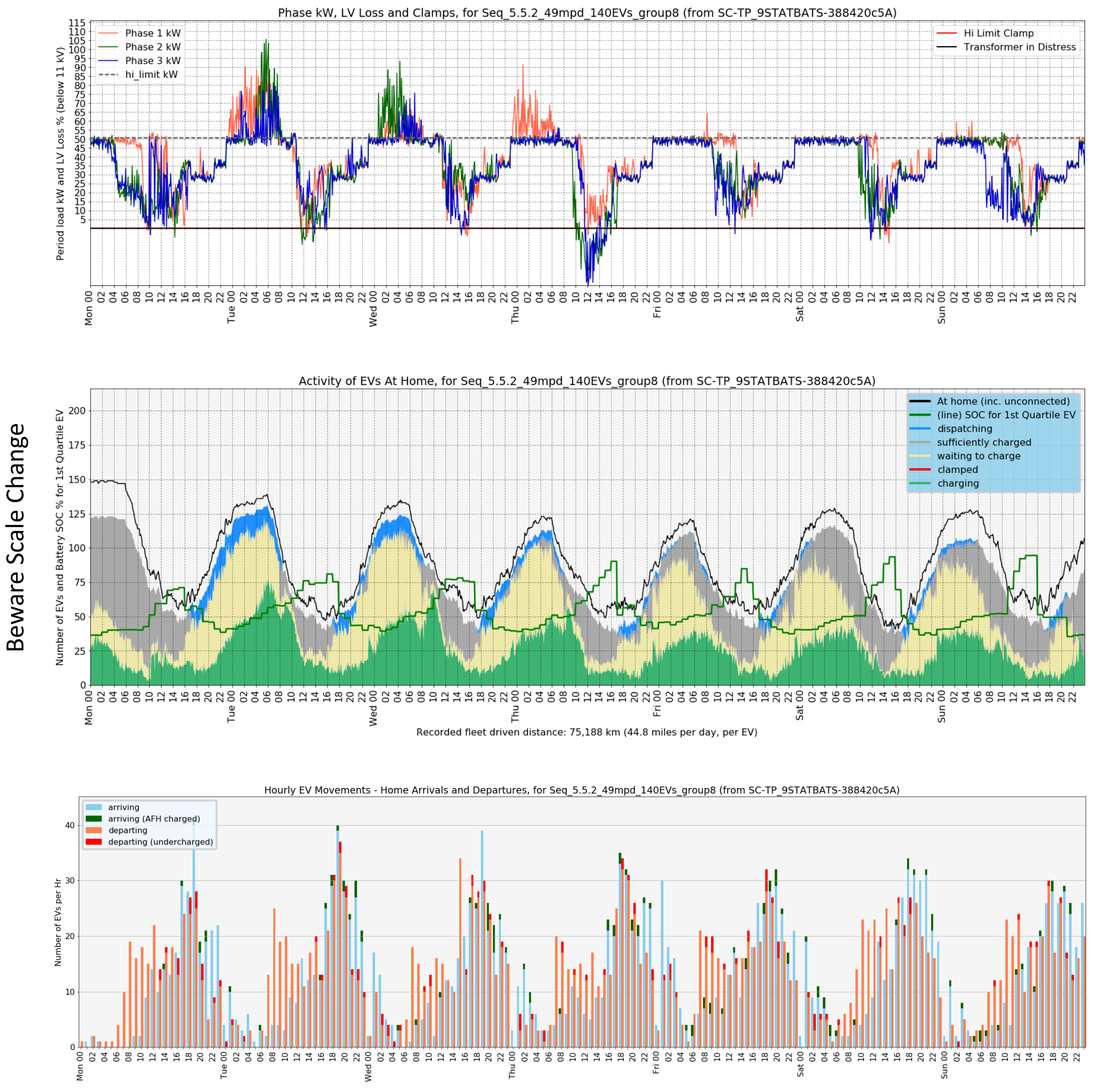
Figure 4-26: Seq_5.5.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,877

Notes re above plots:

- the Feeder plot shows a reduced spike and significant PV export
- by eye EV SOC is near identical to 5.4.2,
- (Arrive/Depart) is by eye identical to the 5.4.2 plot.

Total EV demand has dropped 67 kWh, V2G use is 61 kWh down. AFH charging has seen a small drop.

V3-4.11.3.3 Seq_5.5.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 16,326 Home: 12,112 AFH: 4,214 V2G: 2,718

Figure 4-27: Seq_5.5.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,340

Notes re above plots:

- (Feeder) broaching is seen but diminished vs. 5.4.2, especially from Friday on phase 1 (red). The Transformer distress signal seen in 5.4.2 is now absent.
- (CICD) EV SOC has risen slightly; V2G blue is apparent but down on 5.4.2
- (Arrive/Depart) shows reduced undercharged departing.

EV energy draw has dropped 630 kWh vs. 5.4.2, Home draw 786 kWh down, AFH 85 kWh down and V2G 881 kWh down.

V3-4.11.4 Data Tables Seq_5.5.2

Data are from MetaMeta spreadsheets for Seq_5.4.2 and Seq_5.5.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 64: Unused kWh (weekly averages) for 5.4.2 vs. 5.5.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.4.2	1. Unused kWh A	19mpd	16,900	16,265	15,007	13,732	12,436	11,118	9,817	8,485
		27mpd	16,779	16,000	14,470	12,911	11,347	9,770	8,146	6,321
		38mpd	16,673	15,790	13,987	12,144	10,321	8,390	6,340	3,840
		49mpd	16,579	15,611	13,597	11,566	9,575	7,374	4,946	2,501

		N EV	10	20	40	60	80	100	120	140
Seq_5.5.2	B	19mpd	20,993	20,359	19,109	17,843	16,553	15,251	13,971	12,683
		27mpd	20,874	20,096	18,569	17,020	15,468	13,911	12,330	10,710
		38mpd	20,767	19,889	18,084	16,254	14,452	12,554	10,690	8,576
		49mpd	20,674	19,707	17,702	15,678	13,714	11,588	9,418	7,038

lime indicates non-broaching plies in 5.5.2

		N EV	10	20	40	60	80	100	120	140
Difference B - A	C Diff.	19mpd	4,094	4,094	4,102	4,111	4,117	4,133	4,154	4,198
		27mpd	4,095	4,095	4,099	4,108	4,122	4,141	4,185	4,389
		38mpd	4,095	4,099	4,098	4,110	4,131	4,164	4,350	4,736
		49mpd	4,095	4,096	4,104	4,111	4,139	4,213	4,472	4,537

The parity cell is now free of broaches.

The tables show that PV is injecting c. 4,095 kWh per week and 5.5.2 consumption is down on 5.4.2, likely due to reduced V2G losses. Headroom has risen.

.

Table 65: Per EV AFH Uptake kWh (weekly averages) for 5.4.2 vs. 5.5.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.4.2	2. AFH kWh A	19mpd	2.4	2.9	3.0	2.9	3.1	3.3	3.3	3.3
		27mpd	6.2	7.1	7.1	7.4	7.9	7.9	7.8	7.7
		38mpd	16.0	16.1	16.6	17.3	17.1	17.6	17.5	17.8
		49mpd	33.4	31.1	29.9	29.7	29.6	29.8	30.3	30.7
Seq_5.5.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.4	2.9	3.0	2.9	3.1	3.3	3.3	3.3
		27mpd	6.2	7.1	7.0	7.4	7.8	7.9	7.8	7.7
		38mpd	16.0	16.1	16.6	17.3	17.1	17.6	17.4	17.4
		49mpd	33.4	31.1	29.9	29.6	29.5	29.7	30.1	30.1
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02
		27mpd	0.00	0.00	-0.01	-0.01	-0.01	-0.02	-0.03	-0.07
		38mpd	0.00	0.00	-0.01	0.00	-0.01	-0.05	-0.13	-0.40
		49mpd	0.01	-0.01	-0.01	-0.02	-0.03	-0.09	-0.26	-0.61

AFH kWh uptake is almost identical, with reductions seen in the higher duty regions only.

Table 66: Per EV N Connects in Week (averages) for 5.4.2 vs. 5.5.2

Seq_5.4.2	3. EV N AFH A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.27	0.26	0.27	0.30	0.29	0.29	0.29
		38mpd	0.54	0.54	0.55	0.56	0.56	0.58	0.58	0.59
		49mpd	1.03	0.93	0.88	0.87	0.88	0.89	0.91	0.92
Seq_5.5.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.13
		27mpd	0.27	0.28	0.26	0.27	0.30	0.29	0.29	0.28
		38mpd	0.54	0.54	0.54	0.56	0.56	0.57	0.57	0.57
		49mpd	1.03	0.93	0.88	0.87	0.88	0.88	0.89	0.89
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.001
		27mpd	0.000	0.000	-0.001	-0.001	0.000	-0.001	-0.001	-0.003
		38mpd	0.000	0.000	-0.001	0.000	0.000	-0.002	-0.006	-0.019
		49mpd	0.001	0.000	0.000	-0.001	-0.001	-0.004	-0.012	-0.030

The number of EV AFH connects in the week is trivially different.

Table 67: Difference in Severe Undercharging per EV (weekly averages) for 5.4.2 vs. 5.5.2

4. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	27mpd	0.0000	0.0000	0.0000	0.0000	-0.0002	-0.0001	0.0000	0.0000
	38mpd	0.0000	0.0000	-0.0001	-0.0001	-0.0001	0.0001	-0.0001	-0.0002
	49mpd	-0.0002	0.0000	0.0001	0.0000	0.0000	-0.0001	-0.0001	-0.0002

(exceeds limit: < 0.007)

Severe undercharging has dropped slightly; the highest value seen in 5.5.2 being 0.0053.

Table 68: DRFFR: Difference in Percent Effective Hours in Week 5.4.2 vs 5.5.2

5. DRFFR PEH metric	N EV	10	20	40	60	80	100	120	140
	19mpd	-6.5%	-6.0%	-10.7%	-10.1%	-11.3%	-11.9%	-13.1%	-16.6%
	27mpd	-7.7%	-9.0%	-9.5%	-9.0%	-13.1%	-12.5%	-13.6%	-13.1%
	38mpd	-6.5%	-7.8%	-10.1%	-11.9%	-11.3%	-13.1%	-12.5%	-11.9%
	49mpd	-5.9%	-7.8%	-7.2%	-9.5%	-11.3%	-12.5%	-9.6%	-4.2%

The PEH metric has fallen across the board, implying that responsiveness is a function of how much power is supplied by the LV system. The parity case offers a 60.7% OEH metric, with the span within the 120 and 140 EVs plies being 61% - 93%.

Table 69: Difference in LV Losses 5.4.2 vs 5.5.2

4. Change LV Loss in kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	-42.3	-48.5	-51.2	-61.5	-75.7	-84.9	-96.8	-105.1
	27mpd	-44.0	-46.6	-54.4	-65.0	-79.1	-90.9	-103.4	-117.2
	38mpd	-47.3	-43.7	-55.5	-68.1	-80.6	-95.2	-115.3	-174.2
	49mpd	-49.1	-43.0	-53.4	-66.6	-81.7	-102.0	-136.2	-205.5

These losses are those seen by OpenDSS for transformer and LV cabling, and show that the PV system has reduced losses. The value of these in the parity case is:

$$91\,kWh * £\,0.06 = £\,5.46\;per\;100\;houses\;i.e.\;5\,p\;per\;house\;per\;week \qquad (2)$$

or £54,600 per million DNO supplied homes per Winter week. It could be argued that the Static Batteries have enabled this outcome; without them EVs would be predominantly charging outside of Sunshine hours.

Further simulations are needed to clarify this issue; however this income (or savings) likely do not cover the capital expenditure costs of the Static Batteries.

V3-4.11.4.1 Seq_5.5.2 Results Discussion

Sequence 5.5.2 with Static Batteries and PV has been a success in terms of reducing broaches and reducing EV undercharging, although PEH responsiveness has dropped.

Static Batteries can be a useful tool for a DNO, especially when used with an MCS.

V3-4.12 Sequence 5.6.2

Sequence	**Simulation ID**	**Description**
Seq_5.6.2	(S_BB)	As 5.1.2 with SV1G smart EVs replacing V2G types. EV mix is now 19% dumb, 81% SV1G.
Baseline	***Description***	
Seq_5.1.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.*	

This sequence looks at the effect of removing V2G types, a possible RL scenario if V2G costs are seen as too high. There is no DRFFR.

V3-4.12.1 Broaching

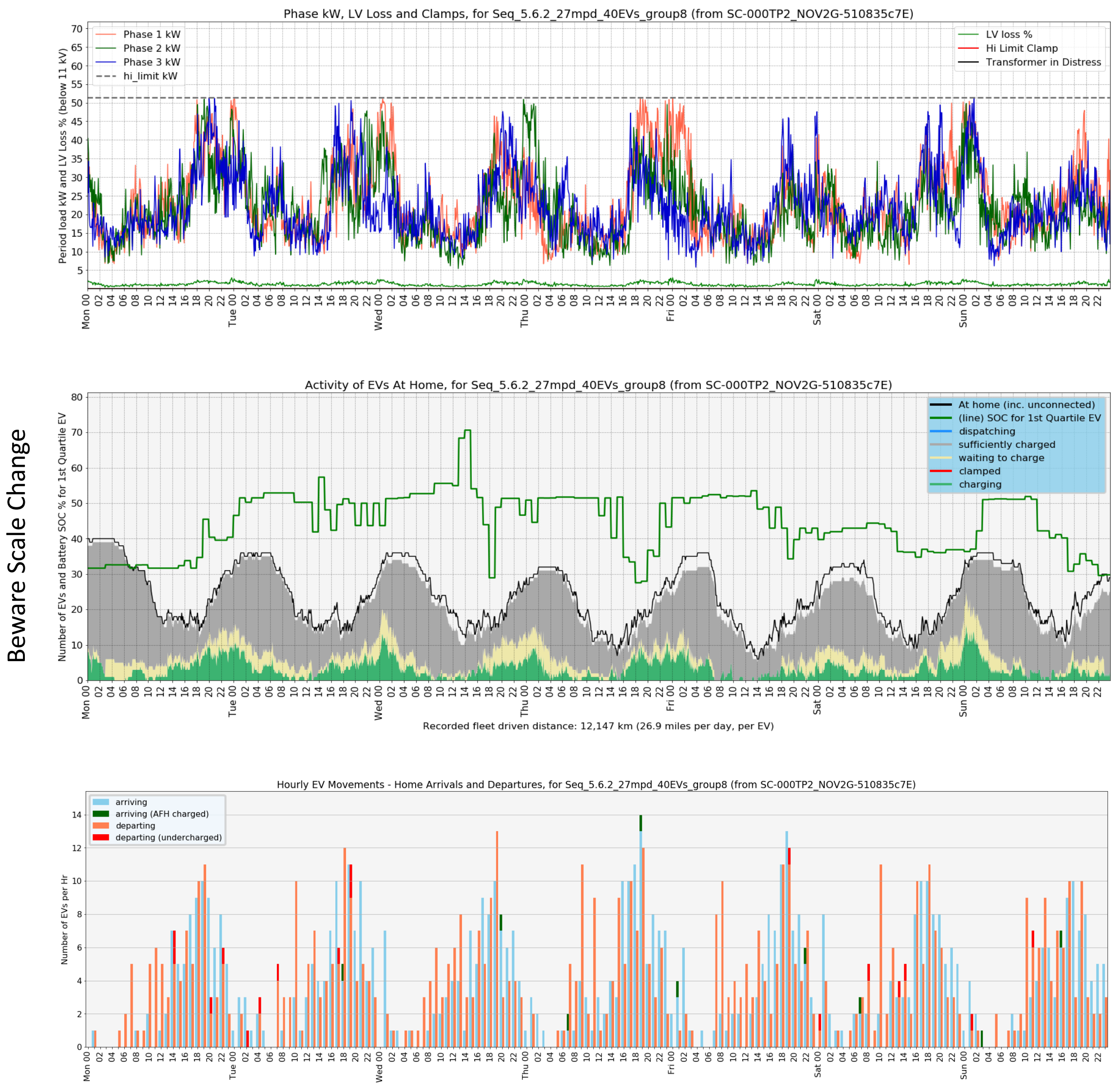
Broaching is notably degraded, with 25 plies now affected vs. 17 in 5.1.2.

V3-4.12.2 Seq_5.6.2 in Summary

This sequence shows the utility (indeed need) for V2G EVs or similar.

V3-4.12.3 Seq_5.6.2: Feeder and EV Plots

V3-4.12.3.1 Seq_5.6.2: 27mpd 40EVs



EoW stats: kWh[b] EV total: 2,328 Home: 2,030 AFH: 298 V2G: 0

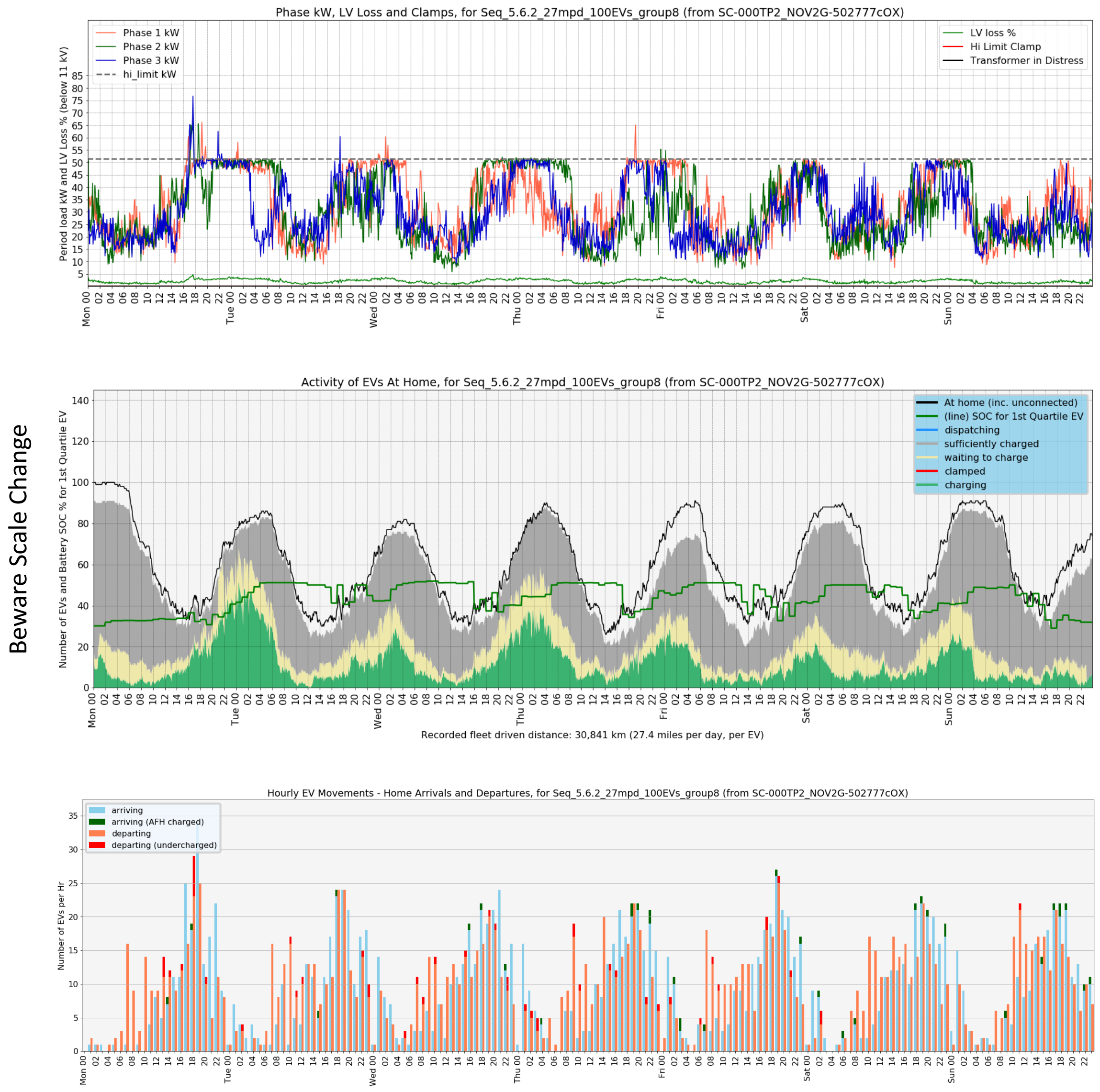
Figure 4-28: Seq_5.6.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no broaches visible.
- (CICD) EV SOC is by eye slightly down on 5.1.2, now c. 50% vs. 60%.,
- (Arrive/Depart) shows more departing undercharged EVs.

Total kWh consumption is slightly down at home by 12 kWh; there is 11 kWh more AFH charging.

V3-4.12.3.2 Seq_5.6.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 5,901 Home: 5,075 AFH: 826 V2G: 0

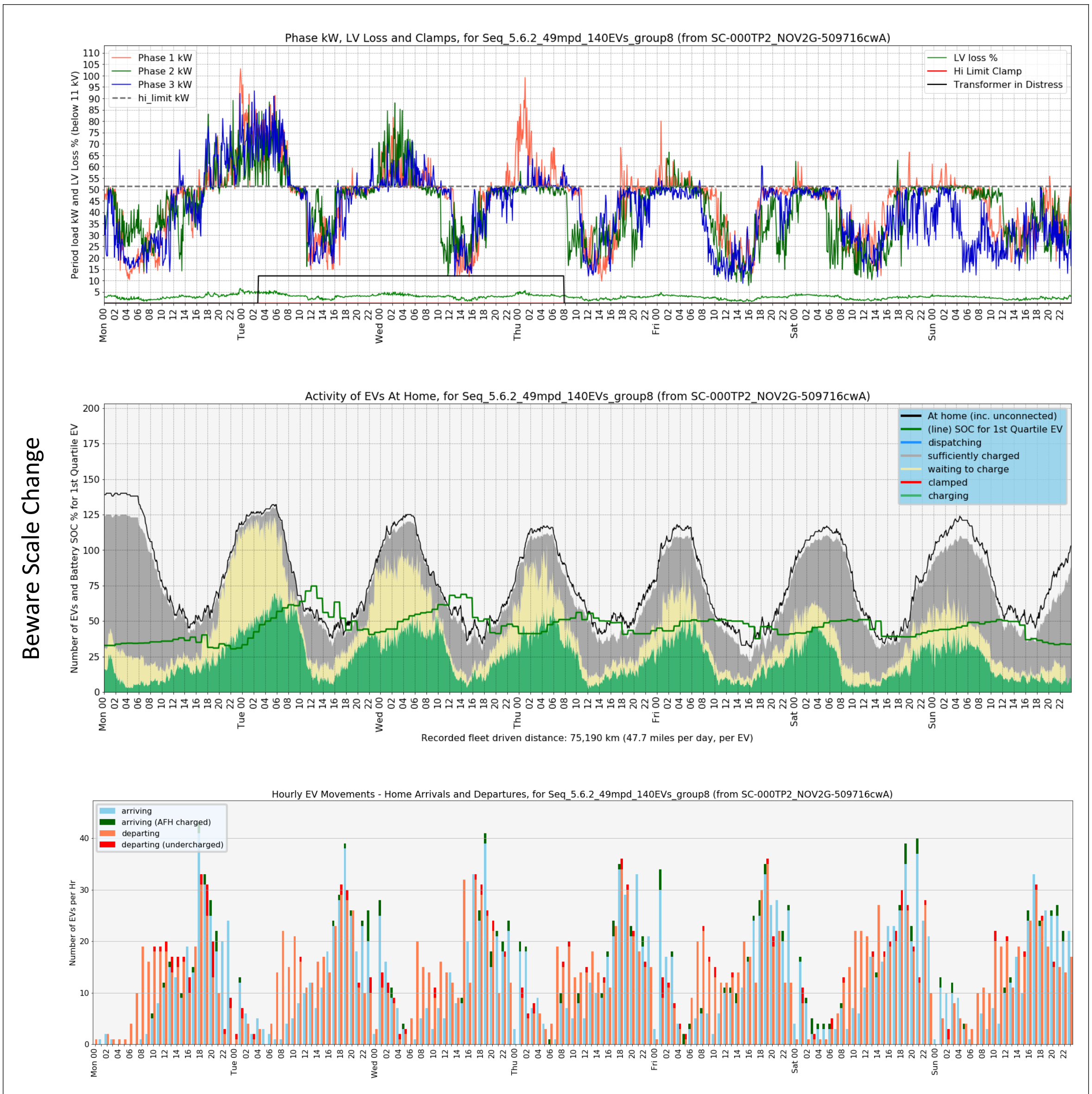
Figure 4-29: Seq_5.6.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,877

Notes re above plots:

- the Feeder plot shows more broaches vs. 5.1.2
- by eye EV SOC is similar with more EVs plugging in vs. 5.1.2,
- (Arrive/Depart) is by eye near identical to the 5.1.2 plot, with occasional more undercharged departs.

Total EV demand is up 19 kWh; Home dropping 8 and AFH charging rising by 27 kWh.

V3-4.12.3.3 Seq_5.6.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,593 Home: 9,234 AFH: 4,360 V2G: 0

Figure 4-30: Seq_5.6.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,328

Notes re above plots:

- (Feeder) broaching is far more noticeable, with the Transformer distress signal seen in 5.1.2 now slightly time shifted.
- (CICD) EV charging has risen, with more EVs being plugged in.
- (Arrive/Depart) again shows slightly elevated undercharging.

EV energy draw has dropped 584 kWh; Home draw is 607 kWh down, AFH 114 kWh up vs. 5.1.2.

V3-4.12.4 Data Tables Seq_5.6.2

Data are from MetaMeta spreadsheets for Seq_5.1.2 and Seq_5.6.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 70: Unused kWh (weekly averages) for 5.1.2 vs. 5.6.2

Seq_5.1.2	1. Unused kWh A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091

Seq_5.6.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,125	16,490	15,227	13,941	12,654	11,345	10,059	8,693
		27mpd	17,008	16,236	14,718	13,181	11,664	10,102	8,512	6,850
		38mpd	16,916	16,050	14,289	12,506	10,747	8,887	7,108	5,223
		49mpd	16,834	15,893	13,949	12,006	10,110	8,074	6,152	4,103

lime indicates non-broaching plies in 5.6.2

Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	7	1	-19	-45	-65	-104	-146	-251
		27mpd	8	1	-13	-33	-63	-117	-178	-267
		38mpd	15	13	8	-8	-49	-90	-120	-116
		49mpd	18	25	24	9	-26	-47	-26	12

Further plies lost in 5.6.2 are darker red. Overall, the network is more loaded by 5.6.2 as well as experiencing noticably more broaches.

Table 71: Per EV AFH Uptake kWh (weekly averages) for 5.1.2 vs. 5.6.2

Seq_5.1.2	2. AFH kWh A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3
Seq_5.6.2	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.6	3.2	3.3	3.2	3.3	3.5	3.5	3.5
		27mpd	6.5	7.5	7.5	7.8	8.3	8.3	8.1	8.0
		38mpd	17.2	17.1	17.5	18.1	17.9	18.4	18.2	18.2
		49mpd	35.3	32.9	31.3	31.1	30.8	30.8	31.3	31.1
Difference B - A	C Diff.	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2
		27mpd	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		38mpd	1.0	0.8	0.7	0.7	0.6	0.6	0.6	0.6
		49mpd	1.4	1.3	1.0	0.9	0.8	0.8	0.9	0.8

AFH kWh uptake has risen about 1 part in 30.

Table 72: Per EV N Connects in Week (averages) for 5.1.2 vs. 5.6.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	3. EV N AFH A	19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91
Seq_5.6.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.12	0.14	0.14	0.13	0.14	0.15	0.15	0.15
		27mpd	0.28	0.30	0.28	0.30	0.32	0.31	0.31	0.30
		38mpd	0.61	0.59	0.59	0.60	0.60	0.62	0.61	0.61
		49mpd	1.14	1.02	0.95	0.94	0.95	0.94	0.96	0.95
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.007	0.011	0.010	0.009	0.007	0.007	0.008	0.008
		27mpd	0.015	0.016	0.012	0.014	0.012	0.013	0.013	0.013
		38mpd	0.051	0.042	0.036	0.032	0.027	0.028	0.030	0.029
		49mpd	0.074	0.066	0.048	0.044	0.040	0.039	0.043	0.039

The number of EV AFH connects in the week is up by a few percent.

Table 73: Difference in Severe Undercharging per EV (weekly averages) for 5.1.2 vs. 5.6.2

4. Sevr. UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
	27mpd	0.0000	0.0002	0.0001	0.0002	0.0001	0.0001	0.0002	0.0002
	38mpd	0.0002	0.0003	0.0009	0.0005	0.0004	0.0006	0.0004	0.0003
	49mpd	0.0008	0.0005	0.0008	0.0007	0.0007	0.0008	0.0009	0.0008

(exceeds limit: < 0.007)

Severe undercharging has risen c. 10%; the highest value seen in 5.6.2 being 0.0059.

V3-4.12.4.1 Seq_5.6.2 Results Discussion

Sequence 5.6.2 has seen degradation all around, showing the loss of V2G benefits. Clearly this might have been compensated for by Static Batteries.

V3-4.13 Sequence 5.7.2

Sequence	**Simulation ID**	**Description**
Seq_5.7.2	(S_A0)	Agg-B (daily ToU rules) reduced from 100% EV control to 1 in 4 EVs. There is no DRFFR signal.
Baseline	***Description***	
Seq_5.1.2	*Winter, MCS control with 19% dumb EVs, 48% SV1G and 33% V2G EVs. Typical network with 49 kW hi_limit.*	

This attempts to provide Aggregator ToU control, for 1 in 4 EVs and no DRFFR.

See also the 100% controlled EV case, 5.3.2.

The Aggregator Time of Use (ToU) signals are as follows:

- from 1pm: idle only (no charging or dispatch)
- from 6pm: charging only allowed if SOC < 33%
- from 11pm: unrestricted operation.

V3-4.13.1 Broaching

The broaching results are mixed with somewhat unusual results; the author thinks happenstance is involved. What is seen is that one medium-duty ply now broaches, but two extreme duty plies become clear. The exact mechanism behind this is not apparent.

V3-4.13.2 Seq_5.7.2 in Summary

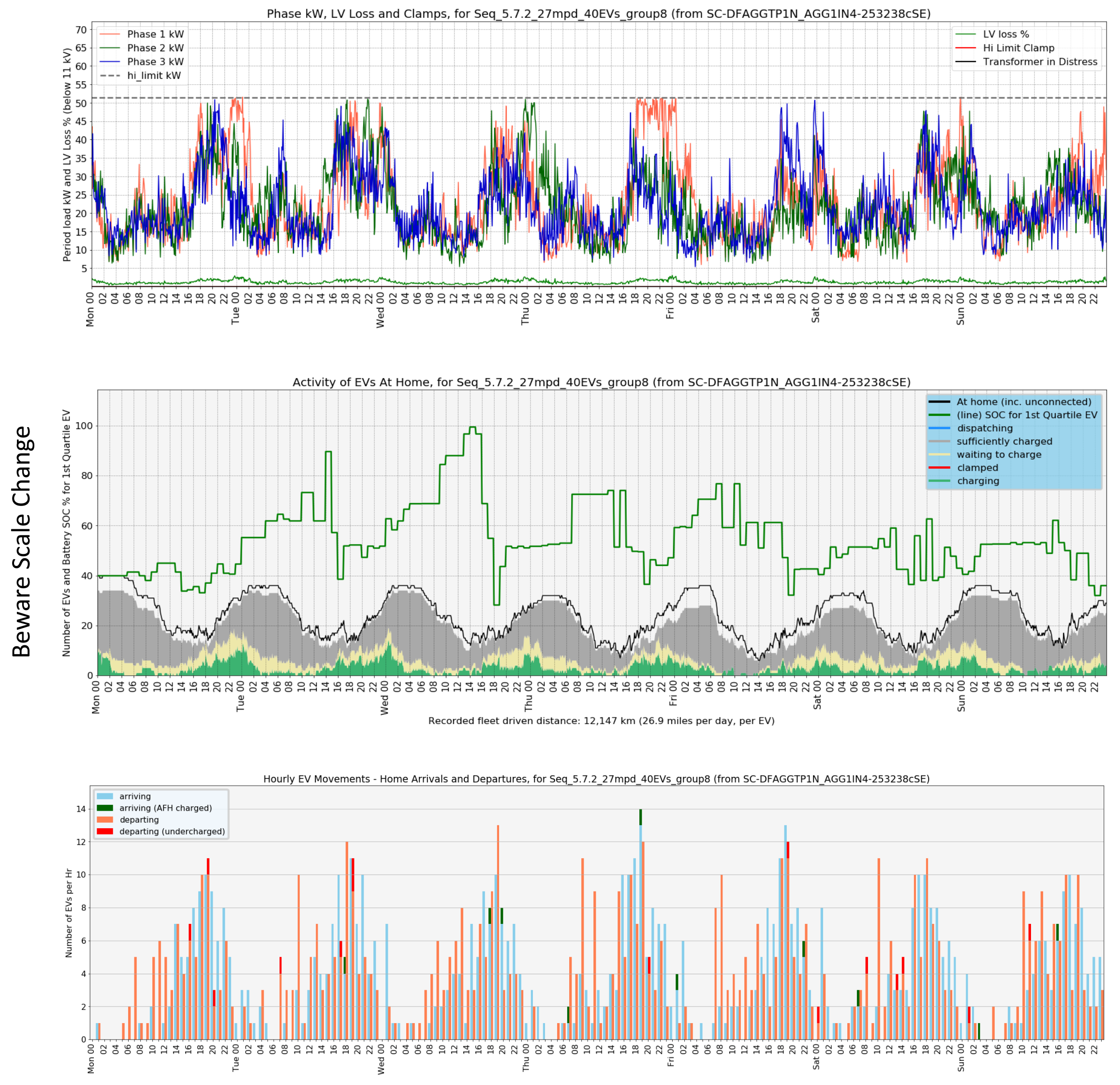
The plots shown in the last section indicate that there is no discernable benefit to Aggregator control of 1 in 4 EVs, in so far as outcomes are near invisible. The author suggests that the MCS control is substituting EV charging i.e.:

- Aggregator turns EVs **A,** and **B** off / cannot charge
- the MCS, seeing released capacity, turns EVs **X and Y** to charge

giving no net change. See also plots of this in Figure 4-34.

V3-4.13.3 Seq_5.7.2: Feeder and EV Plots

V3-4.13.3.1 Seq_5.7.2: 27mpd 40EVs



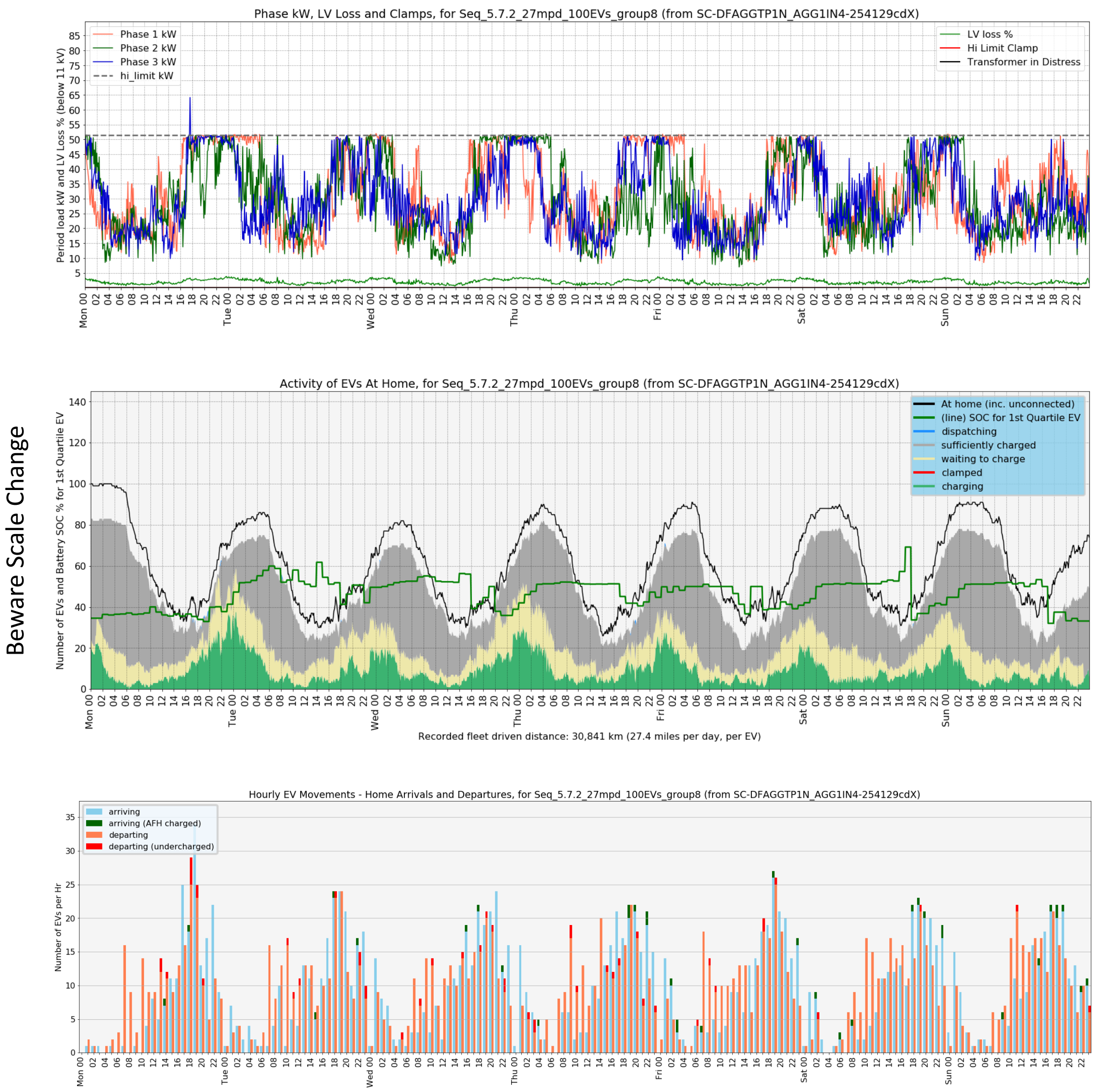
EoW stats: kWh[b] EV total: 2,305 Home: 2,012 AFH: 293 V2G: 0

Figure 4-31: Seq_5.7.2 27mpd 40 EVs group 8 plots. Av. weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there are no broaches visible,
- (CICD) EV SOC appear slightly reduced by eye vs. 5.1.2
- (Arrive/Depart) very few EVs are departing undercharged. AFH appears slightly reduced; otherwise the plot is identical to 5.2.2
- Total kWh consumption is the same, with Home dropping 6 kWh and AFH rising 6 kWh vs. 5.1.2.

V3-4.13.3.2 Seq_5.7.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 5,885 Home: 5,070 AFH: 814 V2G: 9

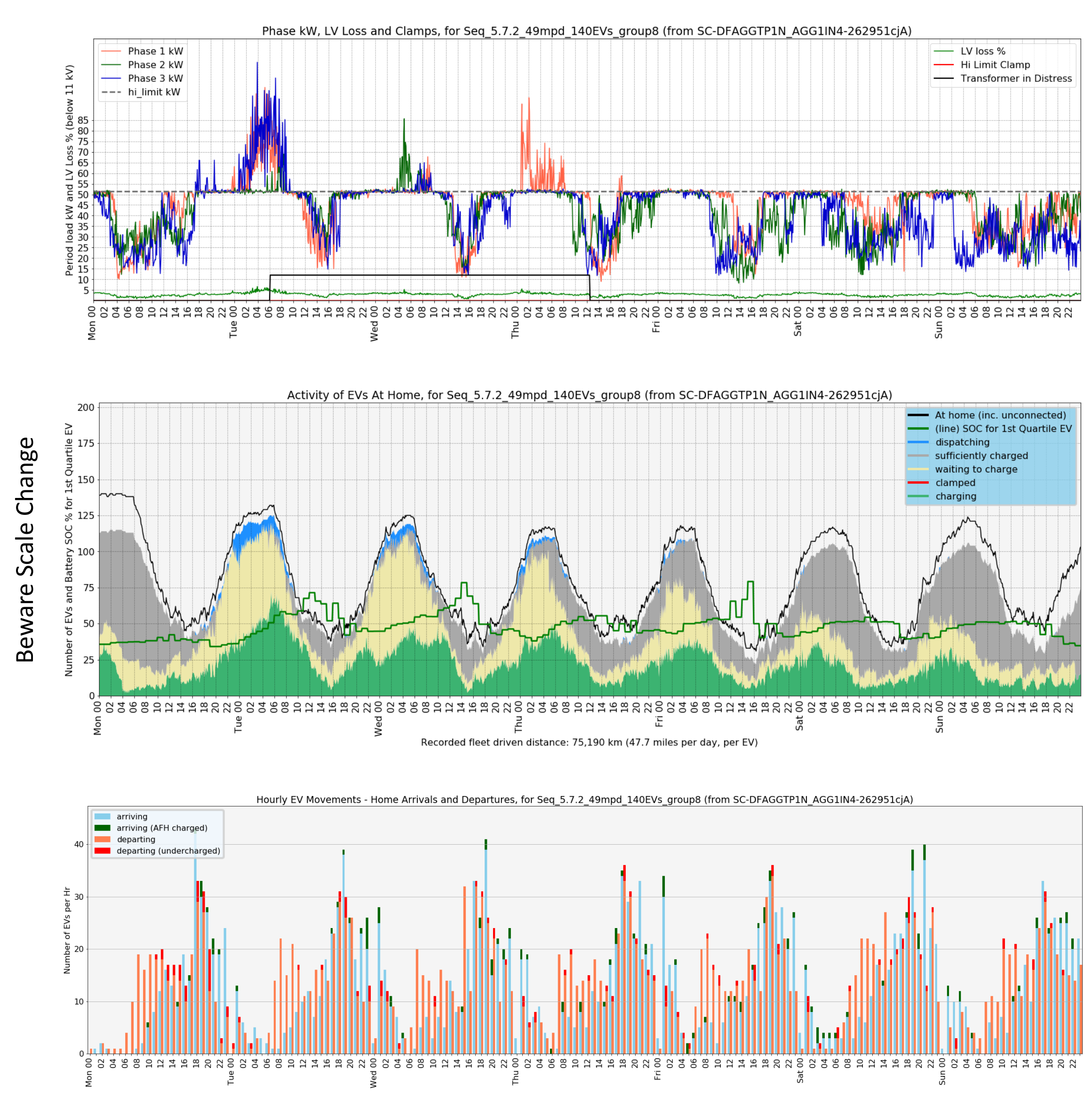
Figure 4-32: Seq_5.7.2 27mpd 100 EVs group 8 plots. Av. weekly fleet km: 30,876

Notes re above plots:

- the Feeder plot shows a less severe broach vs. 5.1.2
- EV SOC is trivially varied vs. 5.1.2
- (Arrive/Depart) is by eye identical to the corresponding 5.1.2 plot.

Total EV demand has move by only 3 kWh. Home is down 13 kWh, and AFH up 15 kWh.

V3-4.13.3.3 Seq_5.7.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,181 Home: 9,872 AFH: 4,309 V2G: 597

Figure 4-33: Seq_5.7.2 49mpd 140 EVs group 8 plots. Av. weekly fleet km: 77,327

Notes re above plots:

- (Feeder) broaching is now more severe than 5.1.2, with an identical transformer distress flag in black,
- (CICD) the plot is near indistinguishable with that of 5.1.2
- (Arrive/Depart) very rare increase undercharged departures vs. 5.1.2.

EV energy draw is up by 104 kWh, with Home up 41 kWh and AFH 63 kWh. V2G has risen by 27 kWh, implying V2G is standing in for charging during Agg ToU periods which prohibit charging.

V3-4.13.4 Data Tables Seq_5.7.2

Data are from MetaMeta spreadsheets for Seq_5.1.2 and Seq_5.7.2. The parity case (UK average mpd with 1:1 household EV penetration) is yellow, with broaches in red.

Table 74: Unused kWh (weekly averages) for 5.1.2 vs. 5.7.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	1. Unused kWh A	19mpd	17,118	16,489	15,246	13,986	12,719	11,449	10,205	8,944
		27mpd	17,001	16,235	14,731	13,213	11,726	10,220	8,691	7,117
		38mpd	16,901	16,036	14,281	12,515	10,796	8,978	7,229	5,339
		49mpd	16,816	15,868	13,925	11,997	10,136	8,120	6,178	4,091
Seq_5.7.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,118	16,493	15,252	13,993	12,727	11,457	10,213	8,949
		27mpd	17,002	16,237	14,742	13,226	11,741	10,240	8,708	7,130
		38mpd	16,904	16,044	14,294	12,537	10,820	9,007	7,257	5,349
		49mpd	16,817	15,878	13,944	12,022	10,166	8,154	6,198	4,069
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	1	4	5	7	7	8	8	5
		27mpd	1	2	11	13	15	20	18	13
		38mpd	2	8	13	23	24	29	28	11
		49mpd	1	10	19	25	30	34	20	-23

The tables show that 5.7.2 is consuming trivially less power than 5.1.2; the author immediately suspects that there is no greater network benefit to 1 in 4 Aggregator ToU control.

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Table 75: Per EV AFH Uptake kWh (weekly averages) for 5.1.2 vs. 5.7.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	2. AFH kWh A	19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
		27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
		38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.5	17.6
		49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.4	30.3
Seq_5.7.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	3.1	3.2	3.1	3.2	3.5	3.4	3.4
		27mpd	6.2	7.4	7.3	7.6	8.1	8.1	8.0	7.9
		38mpd	16.3	16.5	17.1	17.7	17.6	18.1	17.8	17.9
		49mpd	33.9	31.9	30.6	30.4	30.3	30.4	30.8	30.8
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.02	0.11	0.10	0.08	0.08	0.09	0.09	0.09
		27mpd	0.06	0.12	0.15	0.12	0.13	0.15	0.15	0.16
		38mpd	0.12	0.27	0.28	0.26	0.25	0.26	0.28	0.30
		49mpd	0.03	0.33	0.33	0.29	0.33	0.40	0.41	0.45

AFH kWh uptake has slightly risen. Is this accompanied by more AFH visits?

Table 76: Per EV N Connects in Week (averages) for 5.1.2 vs. 5.7.2

		N EV	10	20	40	60	80	100	120	140
Seq_5.1.2	3. EV N AFH A	19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.58
		49mpd	1.06	0.95	0.90	0.90	0.91	0.90	0.92	0.91
Seq_5.7.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.12	0.13	0.13	0.13	0.14	0.15	0.14	0.14
		27mpd	0.27	0.29	0.28	0.29	0.31	0.31	0.31	0.30
		38mpd	0.57	0.57	0.57	0.58	0.59	0.60	0.60	0.60
		49mpd	1.07	0.97	0.92	0.91	0.92	0.92	0.94	0.93
Difference B - A	C Diff.	N EV	10	20	40	60	80	100	120	140
		19mpd	0.002	0.006	0.006	0.005	0.005	0.005	0.005	0.005
		27mpd	0.004	0.008	0.009	0.007	0.008	0.008	0.009	0.009
		38mpd	0.008	0.016	0.013	0.013	0.013	0.014	0.015	0.015
		49mpd	0.002	0.018	0.016	0.014	0.016	0.019	0.020	0.020

There is a c. 2% rise in N AFH visits, per EV per week.

Table 77: Severe Undercharging per EV (weekly averages) for 5.1.2 vs. 5.7.2

	N EV	10	20	40	60	80	100	120	140
4. Sevr. UnChg	19mpd	0.0000	0.0022	0.0035	0.0022	0.0022	0.0022	0.0022	0.0025
	27mpd	0.0004	0.0039	0.0048	0.0042	0.0046	0.0048	0.0049	0.0051
	38mpd	0.0036	0.0119	0.0105	0.0096	0.0094	0.0090	0.0090	0.0102
	49mpd	0.0038	0.0203	0.0204	0.0145	0.0180	0.0179	0.0197	0.0205

(exceeds limit: < 0.007)

Severe undercharging is now present in 14 plies, whereas in 5.1.2 there were none.

The net feeder load for Aggregator Time of Use control is shown in Figure 4-34.

This compares total network load vs. rolling averaged load for the parity case; each curve is an average of the ply's 500 simulations, which is smoothed by applying a 1 hour rolling average i.e. for all periods from $pd = 10$ and up, the plots show values:

$$v_n = 0.1 * \sum_{n=pd-10}^{n=pd} load_n \tag{3}$$

In Figure 4-34, loads are compared to 5.1.2 results, which has no Aggregator ToU:

a) 5.3.2: all EVs experience Aggregator ToU,

b) 5.7.2: only 1 in 4 EVs experience Aggregator ToU control.

To reduce visual clutter, only Monday - Friday rolling averages are plotted.

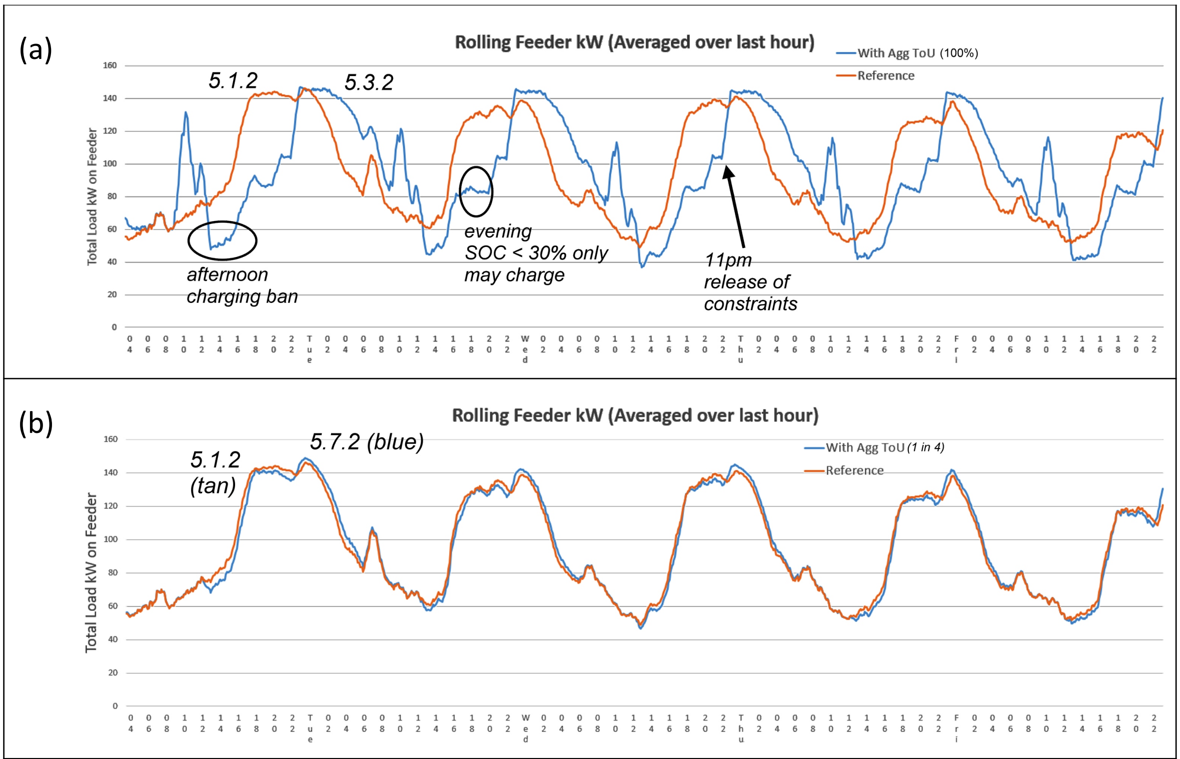

Figure 4-34: Agg. Time of Use Impact (a) All EVs have ToU Control, (b) 1 in 4

In (a), Aggregator control gives a clear effect - deferring a charging peak, plus causing significant EV disruption. Yet for (b), with 1 in 4 EVs under Aggregator control, there is negligible network load effect, plus the method provokes EV undercharging.

ToU commands disadvantage EVs having trip patterns which imply a need to recharge during the ToU prohibition period. If the EV stays a little longer, there may be increased broaching as the release of the prohibition signals many EVs to charge together, invalidating the network ADMD diversity assumption.

V3-4.13.4.1 Seq_5.7.2 Results Discussion

Sequence 5.7.2 with this form of Aggregator control, applied “in the blind” to 1 in 4 EVs is not recommended, for the effect is negligible as well as causing EV severe undercharging.

V3-4.14 Sequence 5 in Summary

MCS, V2G and Static Batteries are effective but not a cure-all; clamps remain necessary to stop occasional broaching. DRFFR services continue to be effective with the proviso that Ofgem may dislike use of a form of network protection to offer Balancing Services.

Sequence 5.1.3 has shown that bringing network capability to 2 kW ADMD per house is useful. Many DNOs may find that specific networks are near such a level; this implies a scrutiny of local network for points of weakness - and reinforcing those - would help.

External Aggregator control is again found disruptive, as both undercharging and broaches are provoked.

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Note there is a complete Bibliography in the main Thesis.

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