UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

Transport Research Group

Volume 2: Results Analysis for

Sequence Sets 0, 1 and 2

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 2 Chapter 1: Introduction to Volume 1

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.

V2-1.1 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.

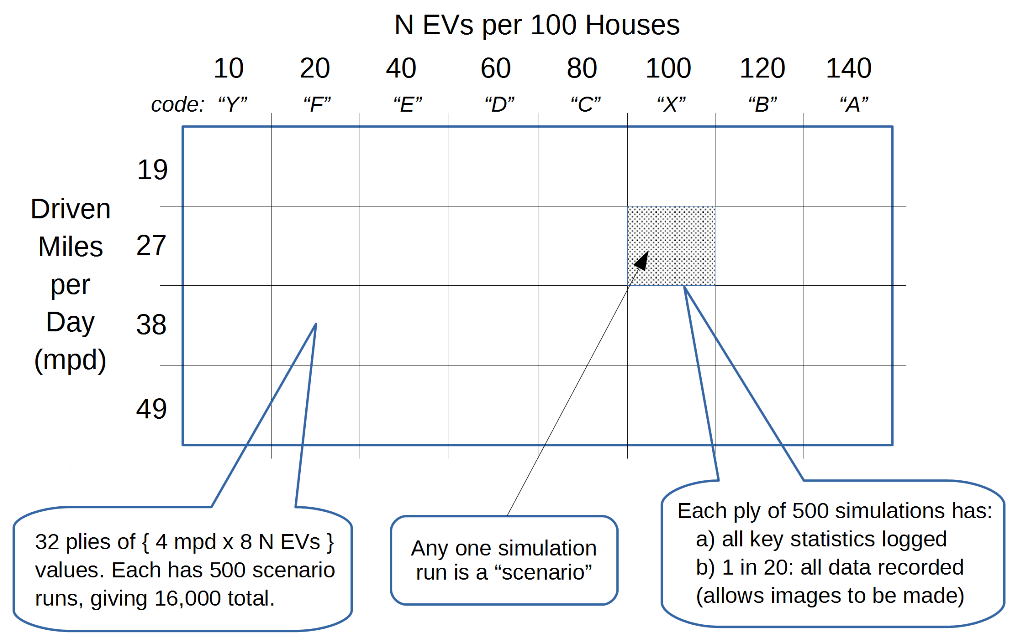

Figure 1-1: Allocation of 16,000 simulations in a Sequence

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.

V2-1.2 The Data Repository Files

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

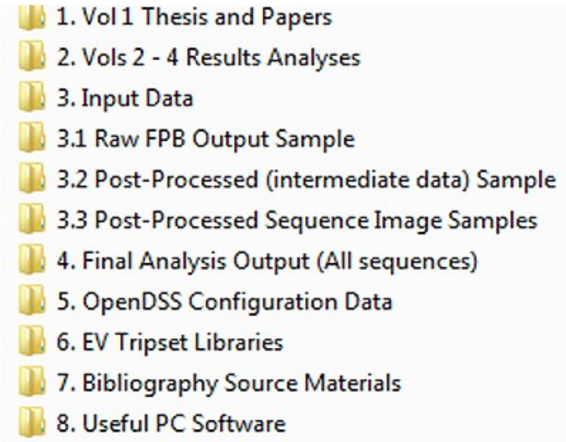

Figure 1-2: Results Data Repository Structure

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.

V2-1.3 Common Terms

Table 1-1: 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)		
$\text{kWh}^{\mathbf{b}}$	“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, <u>across all phases</u> }. 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		

V2-1.4 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).

V2-1.5 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$^{\mathbf{b}}$ 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.

V2-1.6 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):

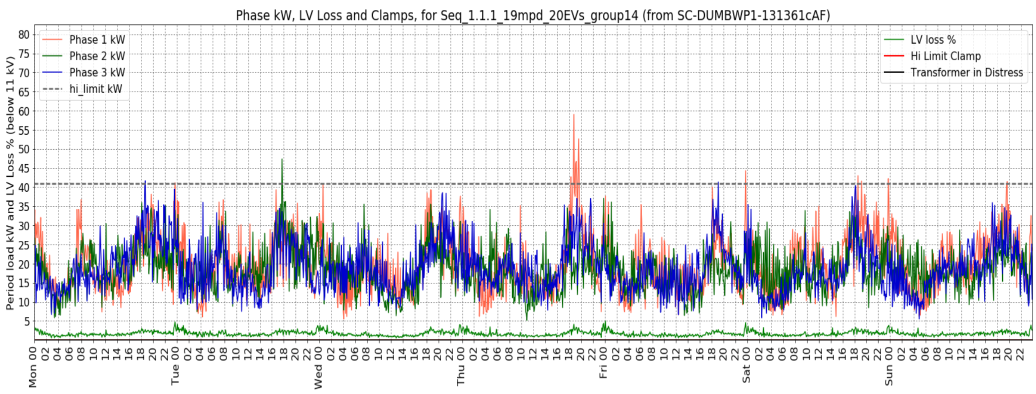

Figure 1-3: Seq_1.1.1 19mpd 20 EVs - passed, no broaches found

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

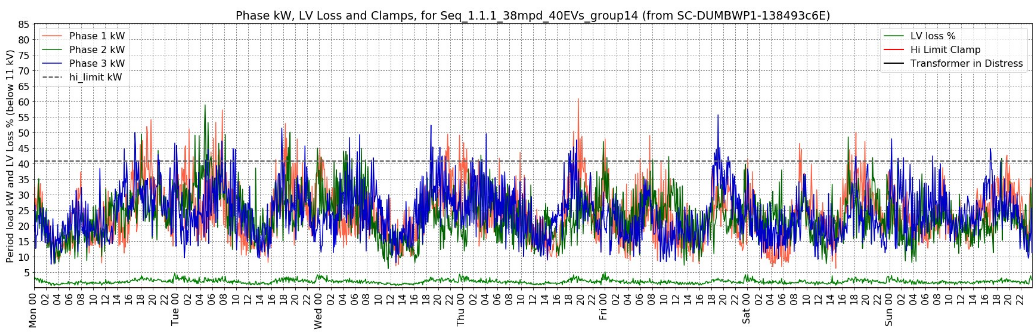

Figure 1-4: Seq_1.1.1 38mpd 40 EVs - failed with broaches

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.

V2-1.7 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.

V2-1.8 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.

V2-1.9 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).

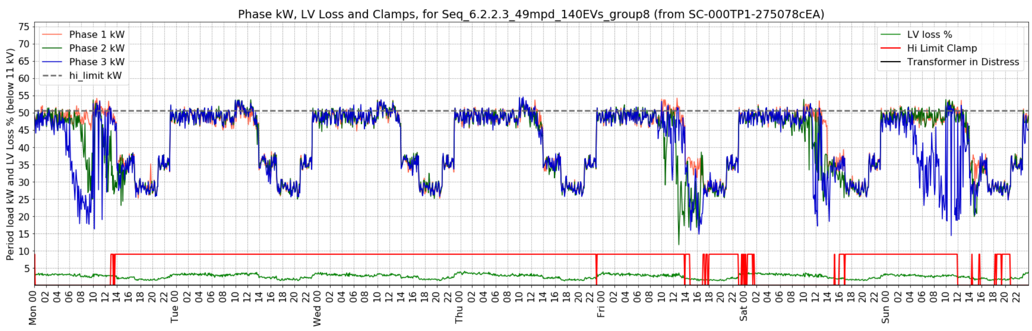

Figure 1-5: Sample of a Feeder plot

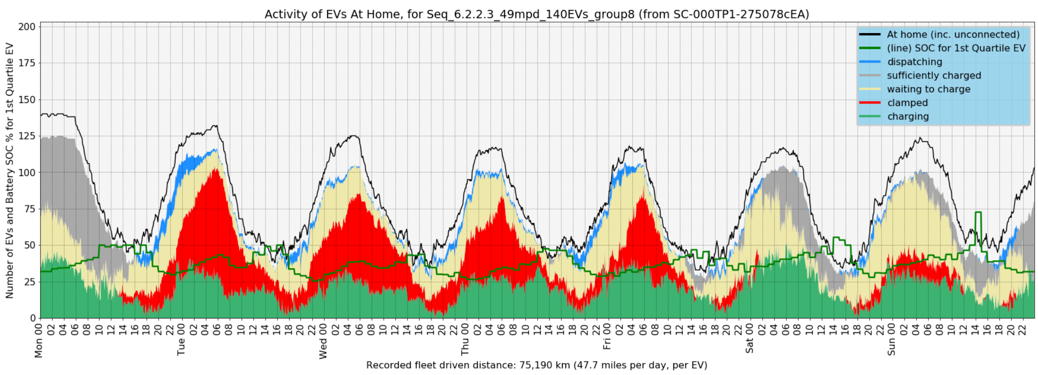

Figure 1-6: Sample of a CICD plot

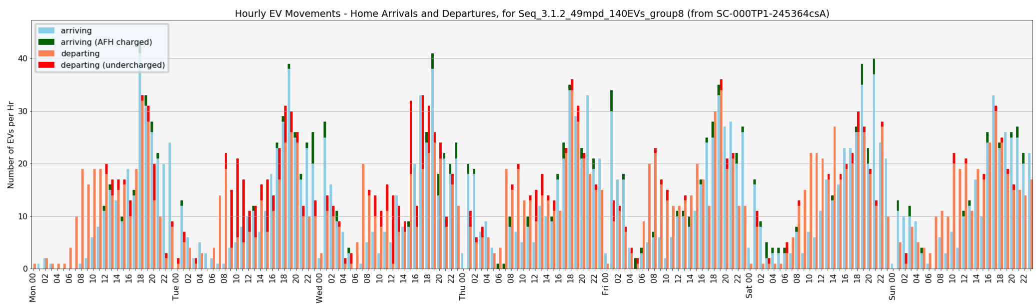

Figure 1-7: Sample of an Arrive / Depart plot

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 2 Chapter 2: Seq. Set 0: Residential Loads

The loads are: Winter, Alt_Winter (an alternative week) and Summer, chosen as:

- The Standard Winter Week contains household loads from the coldest week of 2013 (Monday 11th March 2013)
- Alt_Winter is the following week (Monday 18th March 2013)
- Summer is household load for the hottest week of 2013 (Monday 15th July 2013).

Data is per house from Bracknell, England from SSE's NTVV dataset. The dataset used is:

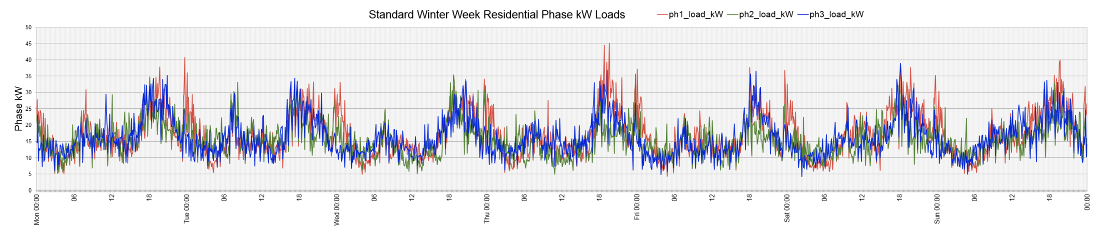


Figure 2-1: Seq_0 Standard Residential Winter Week

Alternative Winter Week Residential Loads (from Monday 18th March 2013)

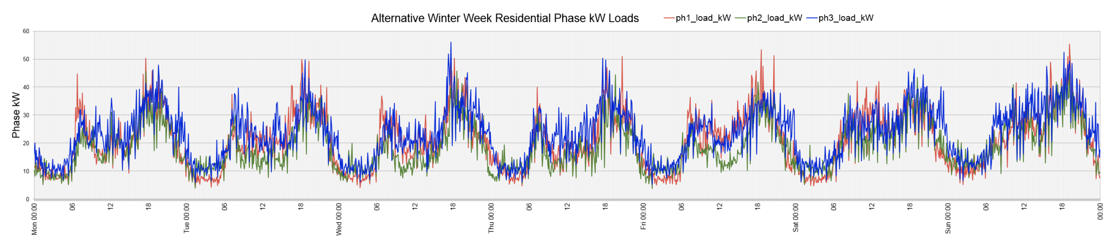


Figure 2-2: Seq_0 Alternative Residential Winter Week

By eye it can be seen that this was electrically a more demanding week vs. the prior week. This highlights that the "worst possible week" is unknown.

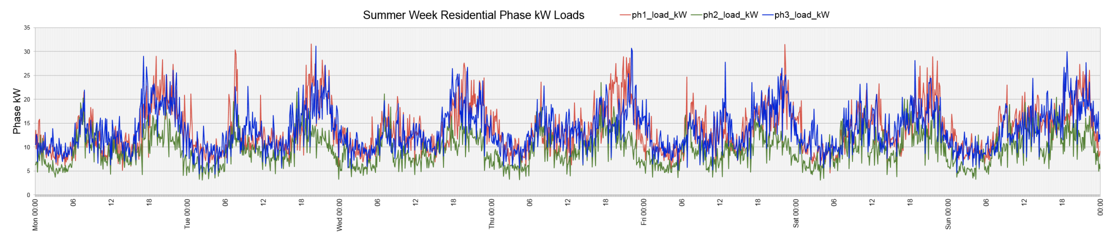


Figure 2-3: Seq_0 Standard Residential Summer Week

Summer Week Residential Loads are for the hottest week in 2013 (from 15th July 2013). Note kW scale is 0-35 kW vs. 0-60 kW. It is unlikely that AC was in use. Phase 2 (green) is consistently low.

Vol 2 Chapter 3: Seq. Set 1 (1.1.1, 1.1.2, 1.1.3)

V2-3.1 Introduction to Set 1

Sequences cover Weak (x.x.1), Typical (x.x.2) and Strong (x.x.3) networks respectively. For each network type, 16,000 simulations were run in 4 mpd x 8 N EV groups (500 per ply). Of the 500 simulations per ply, plots are available for 25, called groups 1 ... 25.

V2-3.1.1 Description of Sequence Set 1

Purpose: To investigate the impact of dumb EVs left to their own devices, without a Managed Charging System, and to form baselines for the 3 network types as they experience rising EV numbers. Finally to familiarise the reader with the plots used.

Outcomes:

Table 3-1: *The ability of networks to support EVs falls as mpd and N EVs increases*

	EV mpd	Seq_1.1.1 (Weak)	Seq_1.1.2 (Typical)	Seq_1.1.3 (Strong)	
	19	20 EVs	40 EVs	80 EVs	
	27	10 EVs	20 EVs	80 EVs	
	38	cannot support 10 EVs	20 EVs	60 EVs	
	49	10 EVs	20 EVs	40 EVs	

.

Table 3-2: *Undervolts detected from N EV:*

	EV mpd	Seq_1.1.1 (Weak)	Seq_1.1.2 (Typical)	Seq_1.1.3 (Strong)	
	19	fails at 80 EVs	did not fail	did not fail	
	27	fails at 80 EVs	fails at 140 EVs	did not fail	
	38	fails at 80 EVs	fails at 140 EVs	did not fail	
	49	fails at 60 EVs	fails at 120 EVs	did not fail	

Observations:

a) in general, there is significant unused kWh capacity which EVs do not access. The problem is: no control over coincidence of simultaneous charging. A means is needed to diversity charging in time, to stop simultaneous loads => overload

b) a contributor to this issue: EVs are being parked at home but not plugged-in; this means they do not charge even when network capacity is spare. Conversely, when they do connect they need more charge, so charge for longer - lowering diversity

c) happenstance is involved when EVs are not managed

d) the test network suffered under-voltage fails far later than other stress conditions; this is purely a consequence of topology.

Concerning Seq_1.1.1. 500 runs of 10 EVs driving 49 mpd were insufficient to cause a broach, yet a broach was found at 38 mpd with lower network load. Hence: "No problems seen in 500 runs" does not mean that problems will not occur in the 501st run.

V2-3.1.2 EV Types and General Settings

a) **"old dumb" EVs** which charge to 100% as fast as possible are, by default, **not modelled** as EVs are assumed mature. The old types impose more network load.

b) EVs: 100% "modern dumb" performing 2 forms of BLP (see **Dubarry, M. (2017)** and **Dubarry, M., & Devie, A. (2018)**):

   i. apply battery cooling strategies e.g. stagger charging over time parked

   ii. minimised time outside mid-band SOC to reduce ageing effects

c) implemented by:

   i. cool down on arrival (don't charge)

   ii. charge in stages to a SOC in mid-band range

   iii. add final charge just before departure

d) EVs are characterised by parameters which mimic current SMMT marques (in the proportion SMMT report as sales)

e) the residential load data (from 2013) is scaled from 1.5 kW to 1.3 kW ADMD per home as LED lighting is assumed in use (load data is for incandescent lighting)

f) DR/FFR mechanisms are OFF

g) clamping mechanisms are OFF

h) the scenario is set in Winter with an average temperature of +1°C. This:

   i. slightly increases the transformer hi_limit and

   ii. reduces EV battery capacity by c. 40% (Li-ion batteries assumed)

   iii. adds auxiliary loads to EVs (e.g. cabin heating)

i) simulates 1 logical week from Monday 00:00, and

j) at Midnight Sunday / Monday 00:00 hrs. all EVs are at home

k) the simulator performs 2 “repetitions” per run to resolve battery SOC:

   1) set each battery SOC to 50% and perform a 1-week conditioning simulation

   2) repeat simulation resetting all parameters except SOC; i.e. SOC values from the first repetition are retained (this broadly stabilises SOC to an “in use” value)

l) simulations are set “post 2021” so use a low-loss Amorphous core transformer.

V2-3.2 Sequence 1.1.1 - the Weak Network

Sequence	Simulation ID	Description
Seq_1.1.1	***(S_82)***	***Weak network, Winter, all dumb EVs***

Data below are from MetaMeta spreadsheets (online) for Seq_1.1.1. Figure 3-1 shows:

a) Feeder load,

b) CICD (middle - note scale changes between corresponding CICD plots). This plot relates what EVs are doing whilst parked at home, i.e. if they are:

   - Home (black), Clamped (red), Idle (grey), Charging (green), Dispatching (blue),
   - a green line indicates fleet charge state: the 25th percentile EV SOC.

c) Arrive / Depart (bottom) presents EV movements, with Depart (pink) and Arrive (sky blue). Tip colours indicate: Red, departing undercharged and: Green have taken on charge Away from Home / AFH.

Note re CICD counts EV activity, not kW. Of 800 image sets (25 sets per ply), 3 are shown.

V2-3.2.1 Seq_1.1.1 Summary

Table 3-3: 1.1.1 Observed Broaches in Week

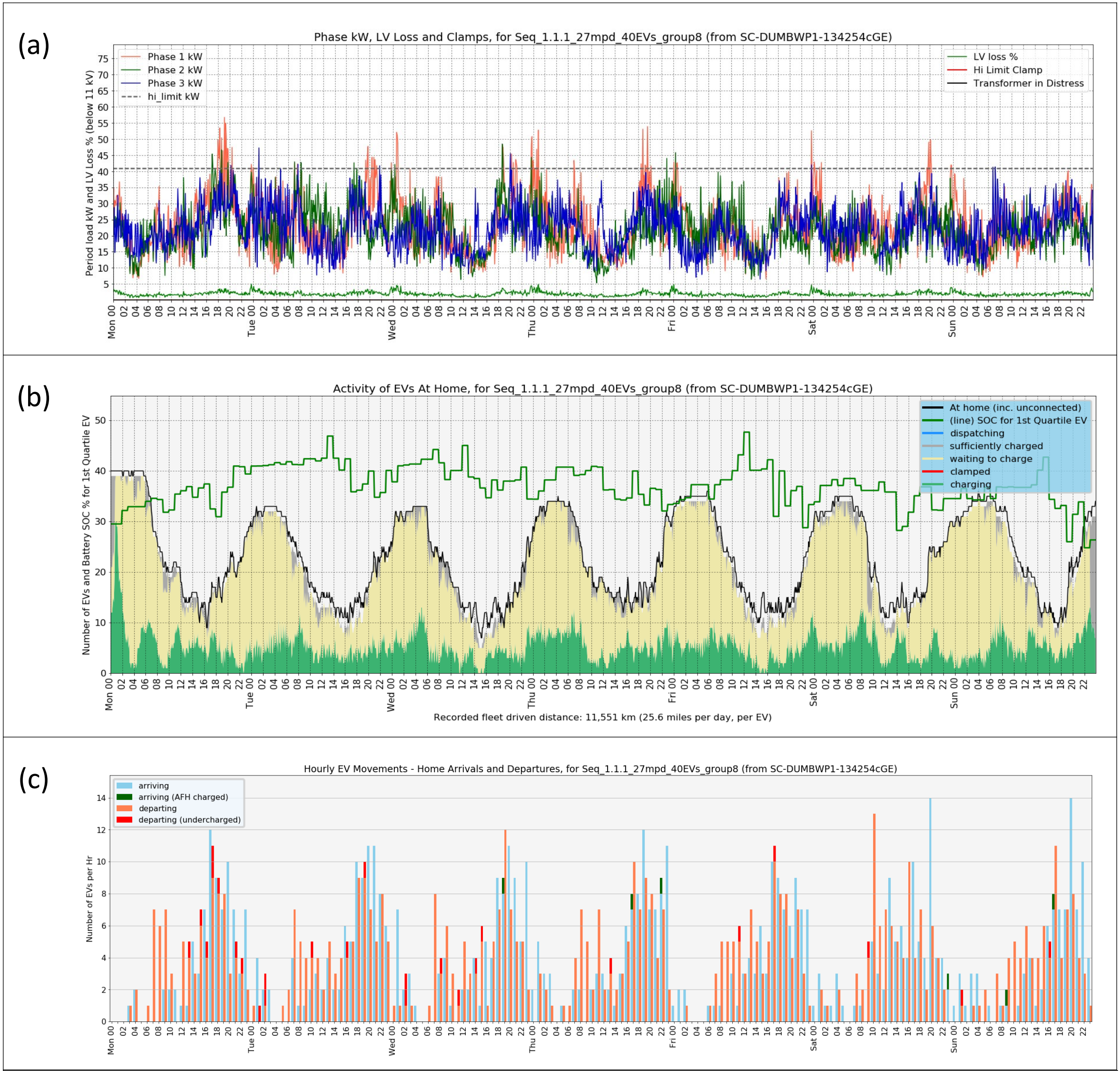
O Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	74	282	359	449	498	500
	27mpd	0	4	150	339	444	498	500	500
	38mpd	2	20	300	404	497	500	500	500
	49mpd	0	33	339	433	498	500	500	500

Note 49mpd had no broaches whereas 38mpd did; happenstances can occur.

For a Weak 1.2 kW network no more than 3 EVs per phase are tolerable, if they do not exceed average miles per day. Clear ply cells are acceptable; Seq_1.1.1 only has 3.

V2-3.2.2 Seq_1.1.1: Feeder and EV Plots

V2-3.2.2.1 Seq_1.1.1: 27mpd 40EVs



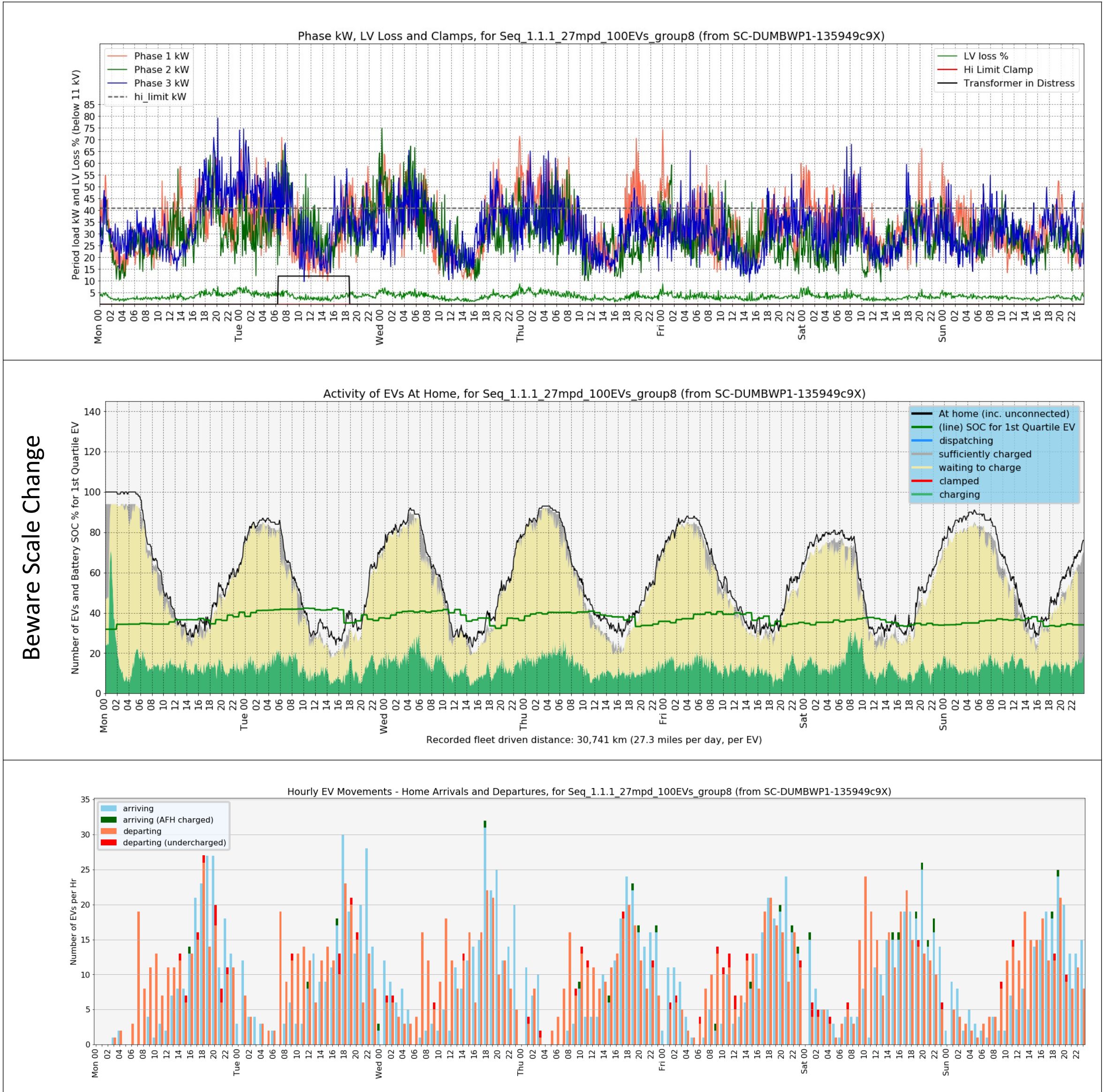
EoW stats: kWh[b]	EV total: 2,339	Home: 2,036	AFH: 303	V2G: 0

Figure 3-1: Seq_1.1.1 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,271

Notes re above plots:

- (Feeder) the hi_limit has no impact, even though shown. Losses are c. 2 - 5%.
- (CICD) there is little sign of grey (EVs finished charging); most are waiting as their tranches are yet to complete. 25th percentile SOC is generally 30 - 40% band.
- (Arrive/Depart) occasional departs undercharged with occasional use of AFH.

V2-3.2.2.2 Seq_1.1.1: 27mpd 100EVs



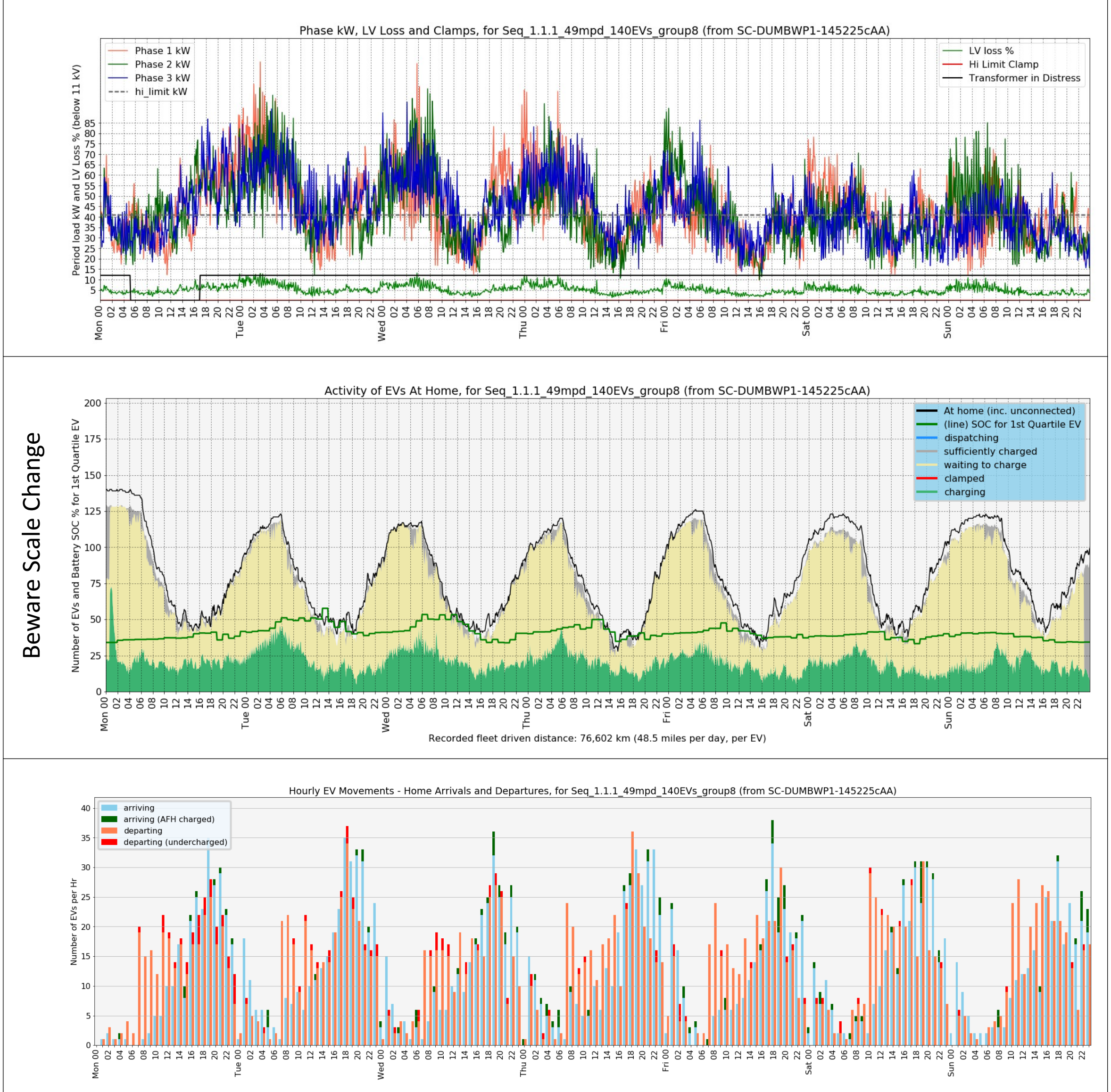
EoW stats: kWh[b] EV total: 5,929 Home: 5,116 AFH: 813 V2G: 0

Figure 3-2: Seq_1.1.1 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,995

Notes re above plots:

- (Feeder) there are serious broaches every day, especially overnight. The transformer flags "overstressed" for 12 hours on Tuesday
- (CICD; NB vertical scale change) EV SOC appears very similar to the prior CICD plot,
- (Arrive/Depart) occasional departs undercharged and use of AFH.

V2-3.2.2.3 Seq_1.1.1: 49mpd 140EVs



EoW stats: kWh**b** EV total: 13,560 Home: 9,245 AFH: 4,316 V2G: 0

Figure 3-3: Seq_1.1.1 49mpd 140EVs group 8 plots. Weekly fleet km: 77,007

Notes re above plots:

- (Feeder) midweek afternoons are without broaches, which are endemic at all other times. The transformer is almost continually overstressed.
- (CICD) EV SOCs remain similar to "as before"; with unrestricted charging they can do as they want; however
- (Arrive/Depart) there is a noticeable rise in departs undercharged and use of AFH. NB undercharging can only arise from insufficient power delivery due to low voltage. The MetaMeta summary for 49mpd shows network undervolts for these simulations.

V2-3.2.3 Data Tables Seq_1.1.1

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 3-4: 1.1.1 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	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

Each cell is the average over 500 simulation runs, varied only in EV trip timing. Red indicates network broaches detected.

Table 3-5: 1.1.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	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	16.9	16.5	17.4	18.0	17.9	18.2	18.1	18.1
	49mpd	34.3	32.3	30.8	30.8	30.7	30.5	31.0	30.8

AFH uptake appears to be a function of distance driven.

Table 3-6: 1.1.1 Per EV AFH N events (count of away connects, weekly averages)

3. EV N AFH	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

These count times the driver was obliged to charge Away from Home. The values here are reasonable; the connects made in the week are set by the distance travelled.

Table 3-7: 1.1.1 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	1.3	1.2	1.2	1.2	1.3	1.3	1.3
	27mpd	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	38mpd	2.3	2.4	2.4	2.4	2.3	2.3	2.3	2.4
	49mpd	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 3-8: 1.1.1 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	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

(limit: < 0.007)

A severe undercharge is an EV departing knowing the trip cannot be completed e.g. “pushed home”, including “pushed out of driveway”. These are known to cause upset and blowback, especially as they tend to be prompted by potentially regular network conditions, hence unfortunately may effect the same drivers repeatedly.

A “50:50 chanced of 1 severe undercharge per EV, per decade” was calculated (for 10 Winter weeks pa) and found probability was 0.007; this is taken as a limiting value beyond which driver distress might be incurred. Red highlights unacceptable values.

Table 3-9: 1.1.1 LV Losses kWh (weekly averages)

6. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	158.2	170.5	216.6	286.3	374.5	489.9	616.2	746.2
	27mpd	160.2	174.9	233.4	318.2	427.8	**574.2**	740.5	913.3
	38mpd	161.7	178.3	245.5	347.5	480.3	662.9	862.3	1,095.3
	49mpd	163.1	181.1	254.4	366.2	517.7	726.4	958.2	1,212.0

LV losses are measured from substation transformer 11 kV terminals to customer meter. There is no stated intent for losses post 2021, although they should be improved over prior years (due to use of low-loss transformers). A traditional LV loss design goal was 4%, here 806 kWh assuming the system is delivering rated power, and a 3% loss is 605 kWh. Losses over a 3% are arbitrarily deemed unacceptable and in Table 3-9 are shown coloured red. **Note** that the MetaMeta sheet for all results (sheet “CompareMetas”) includes a range of losses calculations including pro-rata loss % for the delivered power, kWh losses, V2G losses and combined losses.

Returning to the issue of the 49mpd 10 N EV (fail to) broach mentioned in V2-3.2.1; there is nothing in the above data tables that indicate 49mpd should have any favours over 38mpd; that is, there is no clear driver of happenstance other than randomness.

Table 3-10: 1.1.1 Averaged Hours of Under-volts (weekly averages)

7. Hrs Under volts in Week	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
	27mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4
	38mpd	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.8
	49mpd	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.1

Acceptable limit: 0

The network shows evidence of under-volts for the more extreme ranges. Broaching (Table 3-3) was seen from 20 EVs.

Note that this is probably due to the nature of the network layout used; a real-world network is likely to suffer more severe under-volting.

V2-3.3 Sequence 1.1.2 - the Typical Network

Sequence	Simulation ID	Description
Seq_1.1.2	***(S_83)***	***Typical network, Winter, all dumb EVs***

This is identical to Seq_1.1.1 except the network has a built capability of 1.5 kW per house. This means that changes have been made to:

- OpenDSS transformer and cable specifications
- hi and lo_limit values, here effecting the broaching analysis only.

V2-3.3.1 Seq_1.1.2 Summary

Clear ply cells are acceptable. For a Typical 1.5 kW built ADMD then no more than 7 EVs per phase are tolerable, or 13 EVs per phase if daily driven distances are short.

Table 3-11: 1.1.2 Observed Broaches in Week

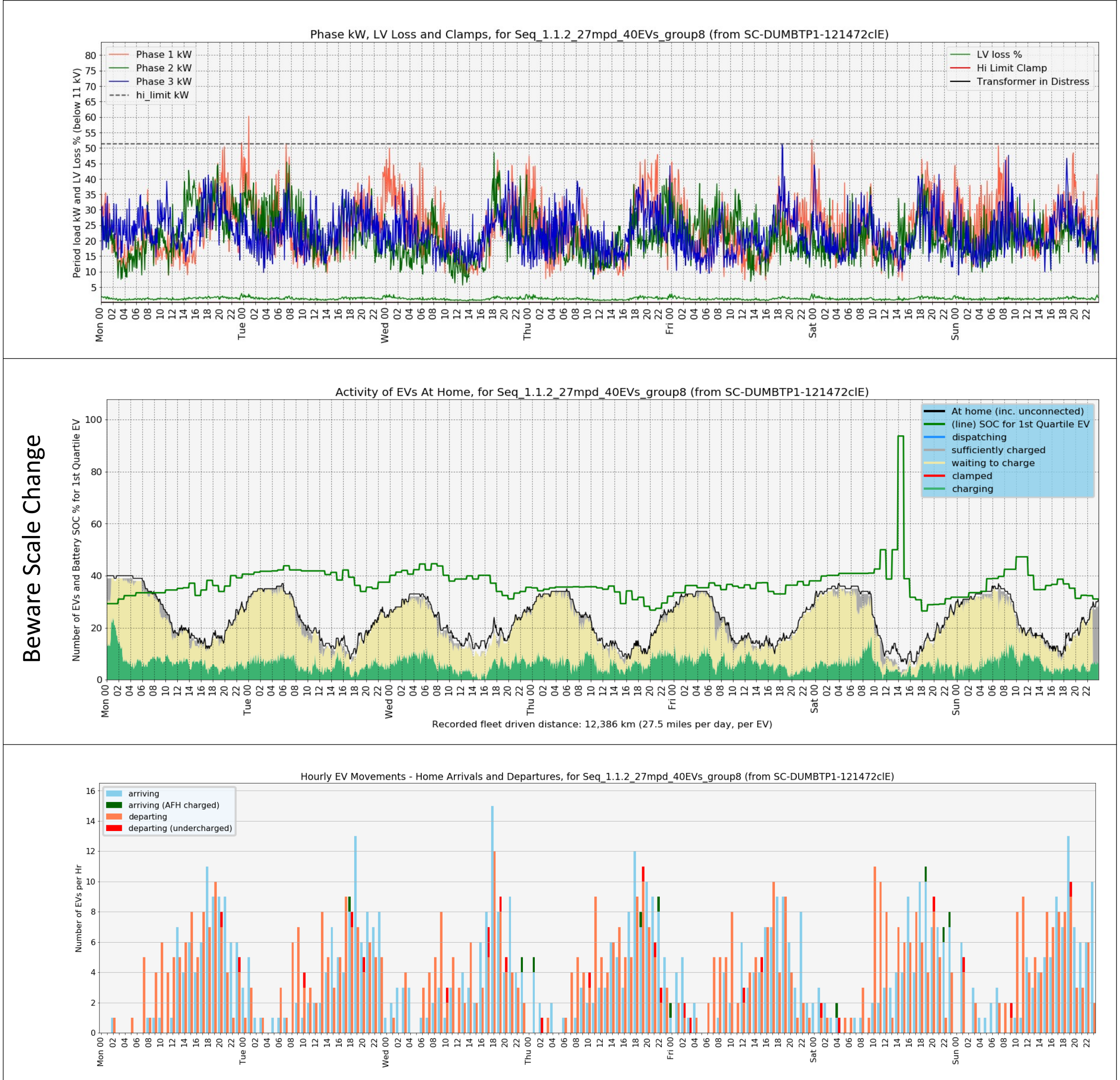
O Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	11	60	249	349	333
	27mpd	0	0	2	53	203	383	358	344
	38mpd	0	0	7	125	357	371	352	380
	49mpd	0	0	10	188	383	360	392	439

Seq_1.1.2 has 9 acceptable plies; cf. 1.1.1 which has 3.

Under-volts are all under a minute per week for the extreme (140 N EV) cases only.

V2-3.3.2 Seq_1.1.2: Feeder and EV Plots

V2-3.3.2.1 Seq_1.1.2: 27mpd 40EVs



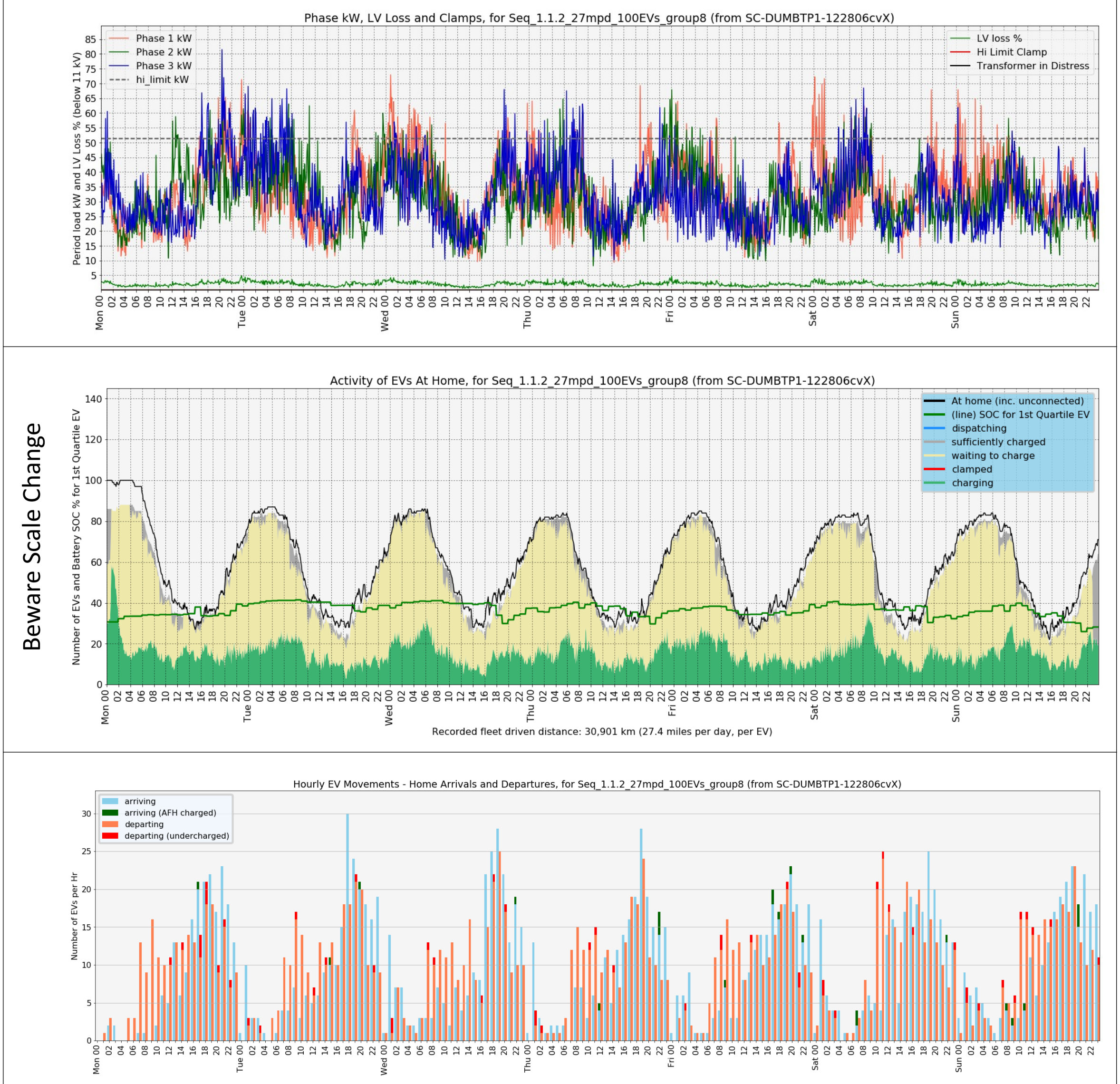
EoW stats: kWh[b] EV total: 2,346 Home: 2,035 AFH: 311 V2G: 0

Figure 3-4: Seq_1.1.2 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,315

Notes re above plots:

- (Feeder) the hi_limit has no impact, even though shown. Losses are in 1 - 3% range.
- (CICD) there is little sign of grey (EVs finished charging). 25th percentile SOC is generally 30 - 40% band. The spike Friday afternoon is likely due to there only being 1 EV from which to take a sample, and it happened to have a high SOC.
- (Arrive/Depart) there are rare departs undercharged and little use of AFH.

V2-3.3.2.2 Seq_1.1.2: 27mpd 100EVs



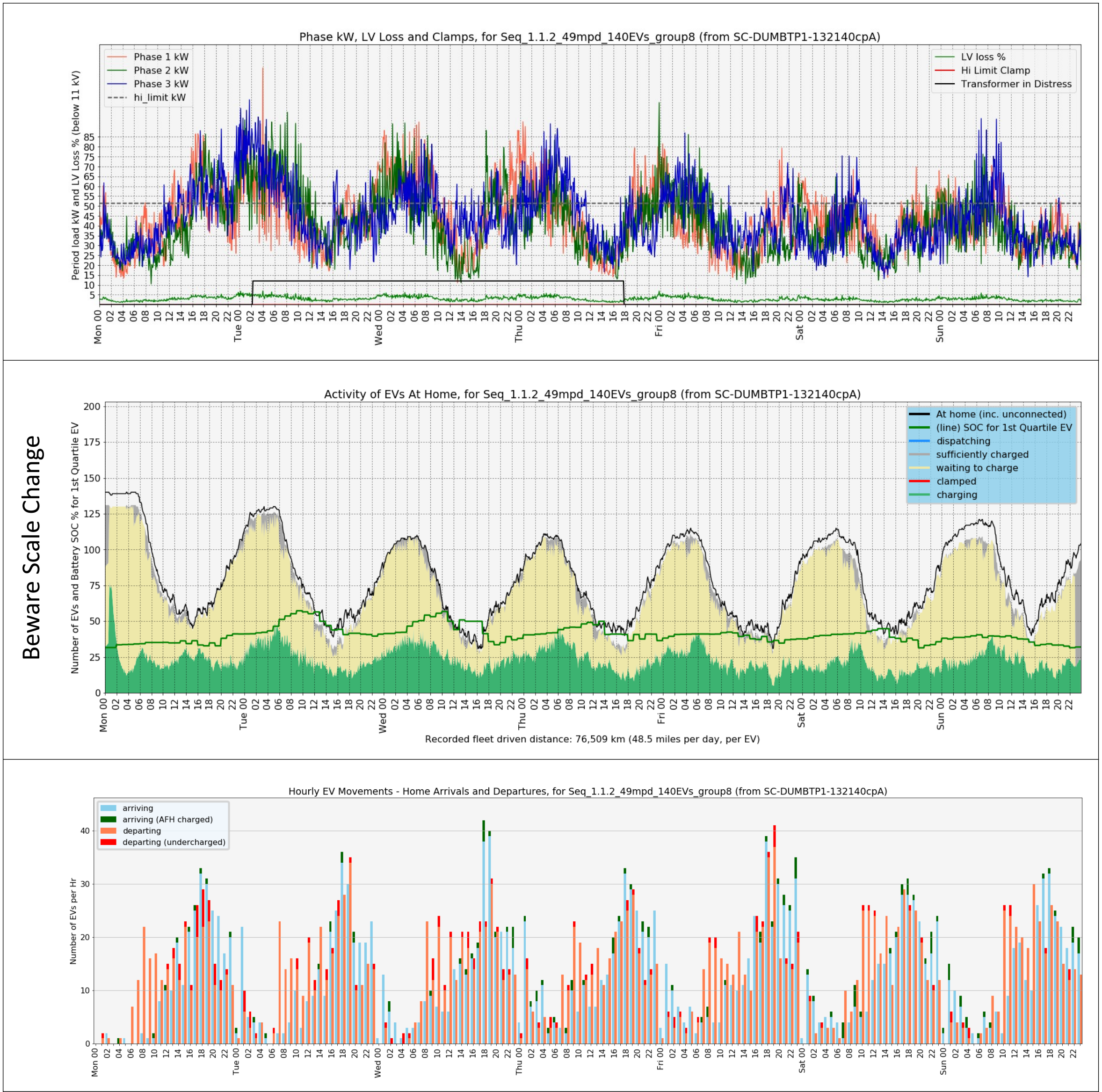
EoW stats: kWh[b] EV total: 5,927 Home: 5,097 AFH: 830 V2G: 0

Figure 3-5: Seq_1.1.2 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,988

Notes re above plots:

- (Feeder) there are broaches near every day, especially overnight. The transformer though is not flagging “overstressed”.
- (CICD) EV SOC appears very similar to the prior CICD plot,
- (Arrive/Depart) occasional departs undercharged and use of AFH.

V2-3.3.2.3 Seq_1.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,592 Home: 9,221 AFH: 4,371 V2G: 0

Figure 3-6: Seq_1.1.2 49mpd 140EVs group 8 plots. Weekly fleet km: 77,227

Notes re above plots:

- (Feeder) broaches are endemic. The transformer is overstressed for several days;
- (CICD) EV SOCs remain similar to "as before"; with unrestricted charging they can do as they want; however
- (Arrive/Depart) there is a noticeable rise in departs undercharged and use of AFH.

V2-3.3.3 Data Tables Seq_1.1.2

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 3-12: 1.1.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	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

Each cell is the average over 500 simulation runs, varied only in EV trip timing. Red indicates network broaches detected.

Table 3-13: 1.1.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	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	8.0	7.8	8.0	8.4	8.3	8.3	8.1
	38mpd	17.6	17.3	17.9	18.5	18.2	18.5	18.5	18.5
	49mpd	35.5	33.0	31.5	31.3	31.1	30.8	31.2	31.2

AFH uptake appears to be a function of distance driven.

Table 3-14: 1.1.2 Per EV AFH N events (count of away connects, weekly averages)

3. EV N AFH	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

These show the counts of the driver charging Away from Home. The values here are reasonable; the connects made in the week are set by the distance travelled.

Table 3-15: 1.1.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	27mpd	1.8	1.9	1.9	1.9	1.8	1.8	1.8	1.8
	38mpd	2.3	2.4	2.5	2.4	2.4	2.4	2.4	2.4
	49mpd	2.9	2.9	2.9	2.9	2.8	2.8	2.9	2.9

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 3-16: 1.1.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0004	0.0003	0.0001	0.0003	0.0002	0.0004	0.0003	0.0004
	27mpd	0.0004	0.0006	0.0008	0.0010	0.0012	0.0010	0.0009	0.0010
	38mpd	0.0004	0.0024	0.0022	0.0027	0.0030	0.0031	0.0030	0.0030
	49mpd	0.0046	0.0039	0.0044	0.0046	0.0052	0.0055	0.0058	0.0059

(limit: < 0.007)

A severe undercharge is an EV departing knowing the trip cannot be completed e.g. “pushed home”, including “pushed out of driveway”. Red highlights unacceptable values.

Table 3-17: 1.1.2 LV Losses kWh (weekly averages)

6. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	96.7	111.2	141.3	182.4	233.1	302.1	371.4	447.2
	27mpd	97.9	116.7	147.6	201.3	265.0	351.8	443.1	541.7
	38mpd	98.9	118.8	160.3	220.2	300.9	403.5	513.4	642.3
	49mpd	99.8	120.6	168.9	236.8	321.8	444.8	570.8	716.8

A 3% loss on this network equates to 756 kWh per week. There are no losses over that level. **Note** that an under-volts of c. 40 seconds in the week occurred for 38 and 49mpd, 140 N EV. The under-volts table is omitted as it is otherwise blank.

V2-3.4 Seq_1.1.2.1. - Typical Network (No Residential Load)

Sequence	**Simulation ID**	**Description**
Seq_1.1.2.1	***(S_BR)***	***Typical network, Winter, all dumb EVs, no household loads***

This sequence was used to generate EV ADMD coincidence plots (see Thesis results) and otherwise is perhaps only relevant to car-park operators. Feeder plots only have been generated.

V2-3.4.1 Seq_1.1.2.1 Summary

Table 3-18: 1.1.2.1 Observed Broaches in Week

O Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	0	0	0	1	17
	27mpd	0	0	0	0	1	2	33	169
	38mpd	0	0	0	0	0	52	240	331
	49mpd	0	0	0	0	14	149	343	387

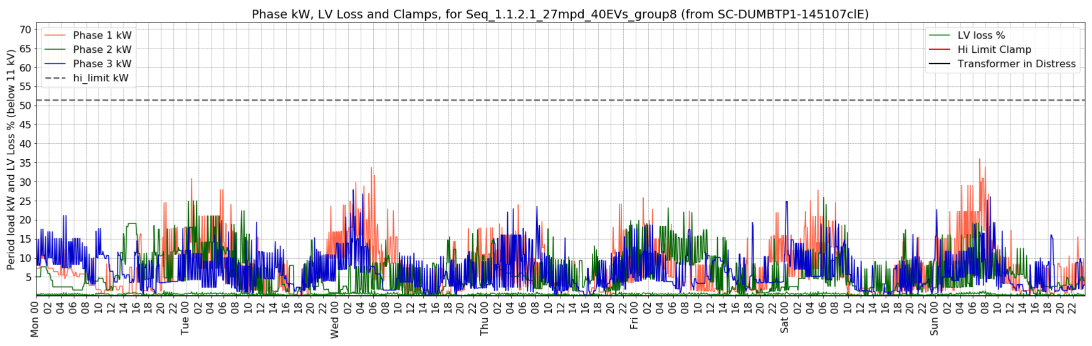
Clear ply cells are acceptable. This result of 19 usable plys (vs. Seq_1.1.2's 9) shows the impact of removing residential loads.

In the following tables, the EV results are identical to Seq_1.1.2. This is due to there being on constraints, so the EVs can charge as they will in both situations.

No under-volts were detected.

V2-3.4.2 Seq_1.1.2.1: Feeder and EV Plots

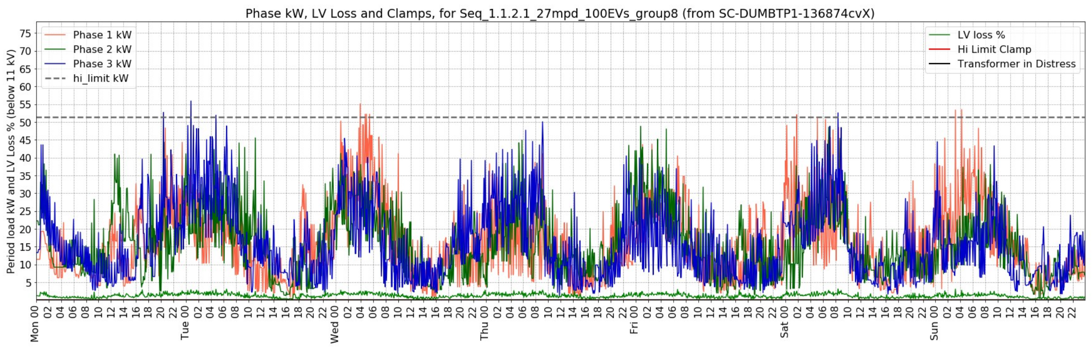
V2-3.4.2.1 Seq_1.1.2.1: 27mpd 40EVs



EoW stats: kWh[b]	EV total: 2,346	Home: 2,035	AFH: 311	V2G: 0

Figure 3-7: Seq_1.1.2.1 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,315

V2-3.4.2.2 Seq_1.1.2.1: 27mpd 100EVs



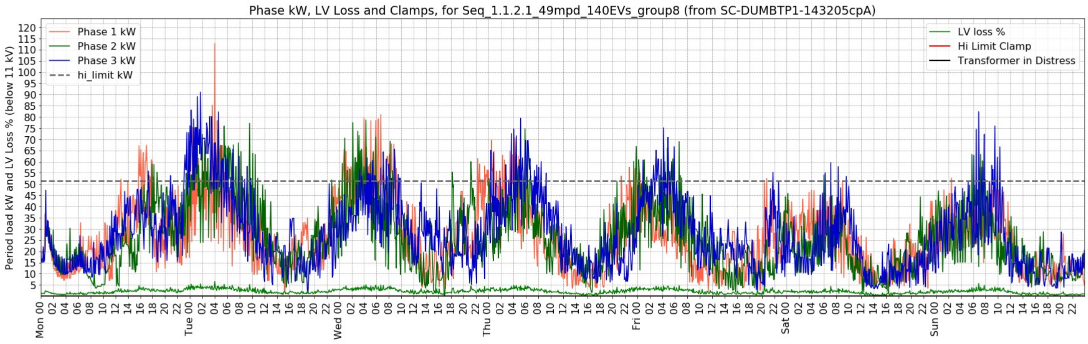
EoW stats: kWh[b]	EV total: 5,927	Home: 5,097	AFH: 830	V2G: 0

Figure 3-8: Seq_1.1.2.1 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,988

Notes re above plot:

- Feeder there are indications broaches are possible, with 2 found in 500 simulated weeks.

V2-3.4.2.3 Seq_1.1.2.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,592 Home: 9,221 AFH: 4,371 V2G: 0

Figure 3-9: Seq_1.1.2.1 49mpd 140EVs group 8 plots. Weekly fleet km: 77,227

Notes re above plot:

- Feeder 343 broaches of 500 weeks were found.

V2-3.4.3 Data Tables Seq_1.1.2.1

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 3-19: 1.1.2.1 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	25,269	24,574	23,194	21,806	20,449	19,075	17,773	16,401
	27mpd	25,158	24,335	22,711	21,090	19,535	17,957	16,424	14,827
	38mpd	25,075	24,165	22,308	20,470	18,710	16,878	15,187	13,342
	49mpd	24,990	24,010	22,002	20,031	18,162	16,154	14,326	12,342

Each cell is the average over 500 simulation runs, varied only in EV trip timing. Red indicates network broaches detected.

Table 3-20: 1.1.2.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	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	8.0	7.8	8.0	8.4	8.3	8.3	8.1
	38mpd	17.6	17.3	17.9	18.5	18.2	18.5	18.5	18.5
	49mpd	35.5	33.0	31.5	31.3	31.1	30.8	31.2	31.2

This table is identical to the table for Seq_1.1.2. AFH uptake appears to be a function of distance driven.

Table 3-21: 1.1.2.1 Per EV AFH N events (count of away connects, weekly averages)

3. EV N AFH	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

These show the counts of the driver charging Away from Home and is identical to Seq_1.1.2's Table 3-14.

Table 3-22: 1.1.2.1 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	27mpd	1.8	1.9	1.9	1.9	1.8	1.8	1.8	1.8
	38mpd	2.3	2.4	2.5	2.4	2.4	2.4	2.4	2.4
	49mpd	2.9	2.9	2.9	2.9	2.8	2.8	2.9	2.9

This table is also identical to the corresponding table (Table 3-15) for Seq_1.1.2.

Table 3-23: 1.1.2.1 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0004	0.0003	0.0001	0.0003	0.0002	0.0004	0.0003	0.0004
	27mpd	0.0004	0.0006	0.0008	0.0010	0.0012	0.0010	0.0009	0.0010
	38mpd	0.0004	0.0024	0.0022	0.0027	0.0030	0.0031	0.0030	0.0030
	49mpd	0.0046	0.0039	0.0044	0.0046	0.0052	0.0055	0.0058	0.0059

(limit: < 0.007)

This table is identical to the table for Seq_1.1.2.

Table 3-24: 1.1.2.1 LV Losses kWh (weekly averages)

6. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	3.0	11.1	26.6	50.0	85.5	123.3	166.9
	27mpd	1.4	4.6	15.9	36.6	68.1	113.5	166.1	229.5
	38mpd	1.6	5.2	20.2	46.3	85.8	145.9	214.4	298.0
	49mpd	1.8	5.6	23.3	53.8	99.1	172.4	252.0	351.0

The losses shown above are the kWh solely attributable to the presence of EVs on the LV system.

V2-3.5 Seq_1.1.2.2 - Typical Network (Summer)

Sequence	Simulation ID	Description
Seq_1.1.2.2	*(S_AF)*	***Typical network, Summer, all dumb EVs***

This is identical to Seq_1.1.2 except the simulations are performed in Summer, meaning Summer residential loads and ambient temp of 18°C. The network has a built capability of 1.5 kW per house.

V2-3.5.1 Seq_1.1.2.2 Summary

Clear cells are acceptable; lime green have no problems in Summer but fail in Winter i.e. 17 plies are acceptable in Summer vs. 9 in Winter.

Table 3-25: 1.1.2.2 Overall Usable EV Bands

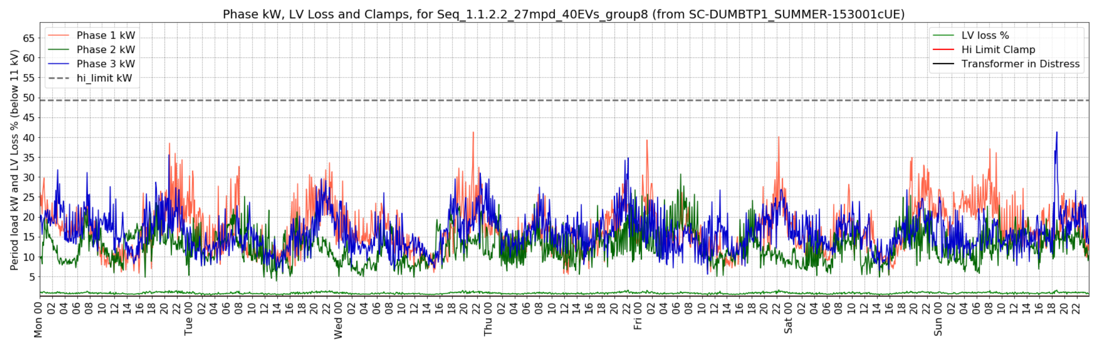
O Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								
	49mpd								

This implies that it is possible for EV populations to be at a point (lime cells) which has no network stress in Summer, yet experience problems in a hard Winter.

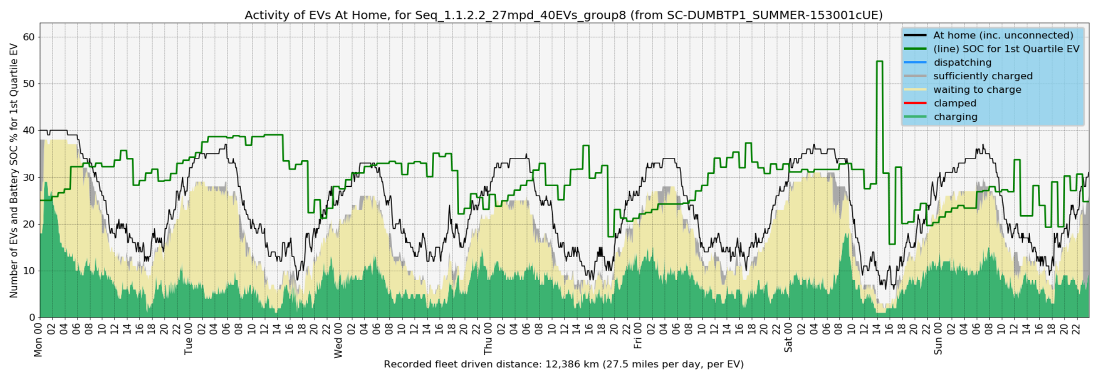
This may be affected by UK car sales which SMMT data (https://www.smmt.co.uk/vehicle-data/) suggests are low over Winter but have two yearly peaks: following 1st March and 1st September. From this, it may be expected that DNOs face bursts of substation failures due to an uptick of EV numbers, new vehicles, charging at home during later March which were not present in February.

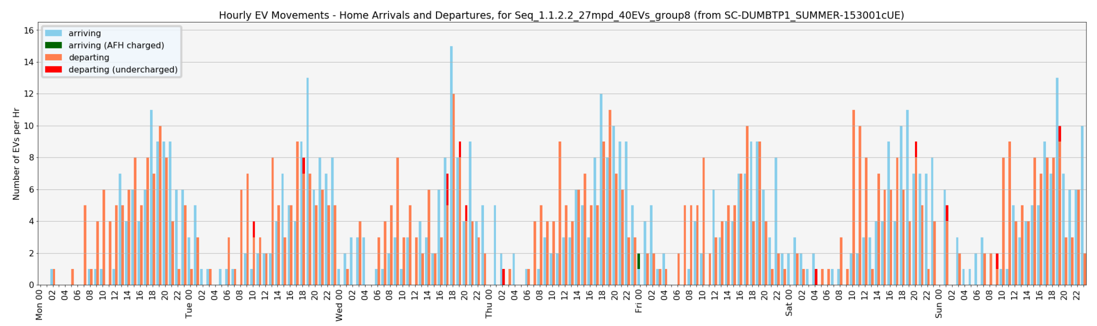
V2-3.5.2 Seq_1.1.2.2: Feeder and EV Plots

V2-3.5.2.1 Seq_1.1.2.2: 27mpd 40EVs



Beware Scale Change





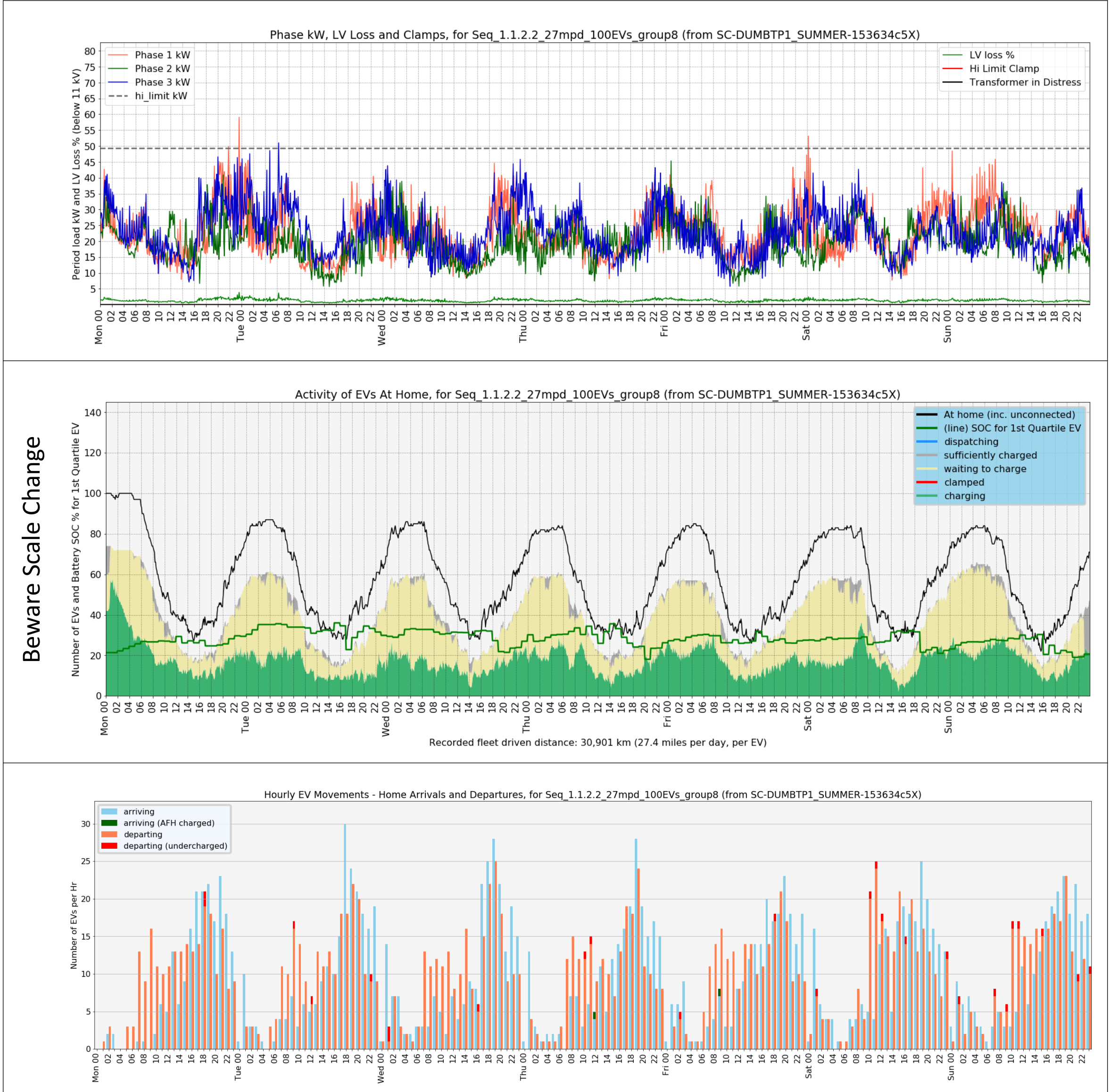
EoW stats: kWh[b]	EV total: 1,410	Home: 1,360	AFH: 50	V2G: 0

Figure 3-10: Seq_1.1.2.2 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,315

Notes re above plots:

- (Feeder) the hi_limit has no impact, even though shown. Losses are c. 1%.
- (CICD) there is little sign of grey (EVs finished charging) but many EVs are not being plugged-in (clear gap below black total count of EVs at home). 25th percentile SOC is generally c. 20 - 30%+ region.
- (Arrive/Depart) there are very rare departs undercharged and use of AFH.

V2-3.5.2.2 Seq_1.1.2.2: 27mpd 100EVs



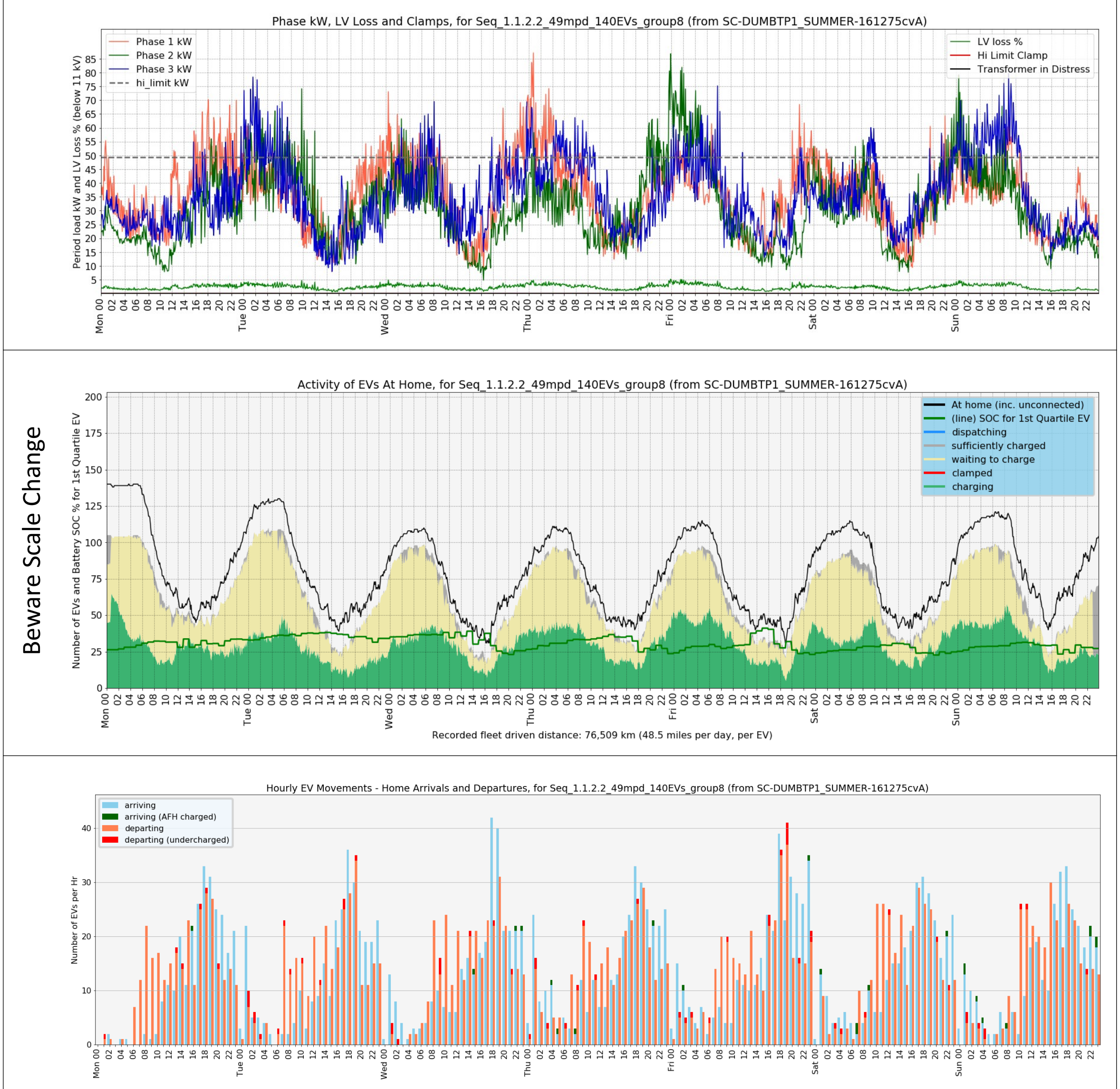
EoW stats: kWh[b] EV total: 3,605 Home: 3,467 AFH: 138 V2G: 0

Figure 3-11: Seq_1.1.2.2 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,988

Notes re above plots:

- (Feeder) there appears potential for broaches overnight.
- (CICD) EV SOC appears very similar to the prior CICD plot,
- (Arrive/Depart) rare departs undercharged and use of AFH.

V2-3.5.2.3 Seq_1.1.2.2: 49mpd 140EVs



EoW stats: kWh[b]	EV total: 9,457	Home: 8,118	AFH: 1,339	V2G: 0

Figure 3-12: Seq_1.1.2.2 49mpd 140EVs group 8 plots. Weekly fleet km: 77,276

Notes re above plots:

- (Feeder) broaches are regular overnight;
- (CICD) EV SOCs remain similar; with unrestricted charging they can do as they want; however
- (Arrive/Depart) there is a rise in departs undercharged and use of AFH.

V2-3.5.3 Data Tables Seq_1.1.2.2

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 3-26: 1.1.2.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,196	18,752	17,913	17,035	16,186	15,341	14,483	13,730
	27mpd	19,059	18,433	17,277	16,080	14,944	**13,806**	12,645	11,582
	38mpd	18,923	18,168	16,645	15,104	13,676	12,161	10,728	9,259
	49mpd	18,753	17,864	16,071	14,294	12,590	10,815	9,101	7,363

Light green shows plies which failed in Winter, now without broaches in Summer. Red indicates broaches detected. Again, there is significant potential spare kWh not being consumed.

The Summer AFH kWh charging is shown compared to Winter, a three-table group of differences:

Table 3-27: 1.1.2.2 Winter vs Summer per EV AFH kWh Uptake (weekly averages)

Seq_1.1.2	**2.** A EV AFH kWh	**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	8.0	7.8	8.0	8.4	8.3	8.3	8.1
		38mpd	17.6	17.3	17.9	18.5	18.2	18.5	18.5	18.5
		49mpd	35.5	33.0	31.5	31.3	31.1	30.8	31.2	31.2
Seq_1.1.2.2	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.2	0.3	0.5	0.5	0.4	0.4	0.4	0.4
		27mpd	0.8	1.0	1.2	1.4	1.5	1.4	1.3	1.4
		38mpd	4.0	3.9	4.2	4.6	4.6	4.7	4.6	4.6
		49mpd	10.4	9.8	9.5	9.6	9.4	9.3	9.5	9.5
Difference B - A	**C Diff.**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-2.58	-2.86	-2.83	-2.86	-3.01	-3.19	-3.16	-3.11
		27mpd	-6.15	-7.04	-6.5	-6.7	-6.9	-6.9	-6.93	-6.71
		38mpd	-13.61	-13.39	-13.64	-13.86	-13.64	-13.81	-13.85	-13.84
		49mpd	-25.16	-23.24	-21.98	-21.72	-21.73	-21.45	-21.75	-21.64

Average AFH charging Winter Seq_1.1.2 (top, A) vs. Summer Seq_1.1.2.2 (middle, B)

Summer Away from Home (AFH) charging is less frequent than in Winter. The cause was investigated and found to consist of two parts: EVs consume more overall in Winter (fleet consumption for the parity case being 5.9 MWh vs. Summer's 3.6 MWh, a c. 39% range loss), plus EV batteries suffer significant cold thermal shrinkage. Longer distance trips which need most of the battery's capacity (i.e. near full) can succeed in Summer but not in Winter, as battery capacity drops with temperature. The resulting loss of range means that EVs with further to drive cannot take on sufficient charge at home, thus must charge Away from Home more often.

Battery capacity drop is a function of battery chemistry and EV design interventions (internal battery heaters). The EVs used in these simulations have no battery heater; if those were added then Winter load would increase (due to a heater of say 0.5 kW in every EV plus taken on more charge) raising Winter broaching; AFH may though reduce.

Table 3-28: 1.1.2.2 Winter vs Summer per EV AFH (mean of weekly away connects)

Seq_1.1.2	3. A Winter EV N AFH	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_1.1.2.2	B Summer EV N AFH	N EV	10	20	40	60	80	100	120	140
		19mpd	0.006	0.008	0.014	0.012	0.012	0.011	0.011	0.013
		27mpd	0.027	0.031	0.033	0.036	0.042	0.039	0.038	0.038
		38mpd	0.105	0.108	0.104	0.114	0.112	0.113	0.114	0.113
		49mpd	0.244	0.221	0.213	0.216	0.218	0.218	0.219	0.218
Ratio A / B	C Ratio Winter to Summer	N EV	10	20	40	60	80	100	120	140
		19mpd	22.31	17.55	9.73	11.83	11.98	13.74	13.36	11.78
		27mpd	11.01	10.31	8.99	8.33	7.72	8.11	8.22	8.14
		38mpd	5.89	5.60	5.79	5.37	5.44	5.43	5.42	5.48
		49mpd	4.66	4.59	4.47	4.37	4.38	4.32	4.37	4.35

Average AFH connections Winter Seq_1.1.2 (top, A) vs. Summer Seq_1.1.2.2 (middle, B)

The table above shows the ratio of use of public charge points, for Winter vs. Summer.

These imply either that charge points are hardly used in Summer, or are far more often used in Winter. Provision to the Winter level is needed if EV drivers are not to be stranded.

This results impact provision estimates and the economics of public charging points - given that EV batteries remain affected by capacity loss with reduced temperature.

For example, a planner expecting a city population to visit a mall might install 1 EVSE per 100 parking spaces, adequate for Summer (Table 3-28 B, 19mpd row shows about 0.6% of EVs need charging). However if a housing development was built say 10 miles away and the mall attracted many visitors from the development, each undertaking a minimum 20 mile trip - then a Winter EVSE provision for table A, 27mpd might be more apt. But this suggest 30% of EVs charge, not 1%.

How many charge points to install? 10 per 1,000 mall car parking spaces - or 300? If this is miscalculated the mall may find EV drivers stay away in cold periods, impacting turnover.

There is a clear difference between city and rural charge-point needs - but at the destination, not the home location.

Table 3-29: 1.1.2.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	27mpd	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	38mpd	1.1	1.1	1.2	1.2	1.1	1.2	1.2	1.2
	49mpd	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 3-30: 1.1.2.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0002	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0002
	27mpd	0.0006	0.0003	0.0007	0.0005	0.0005	0.0006	0.0004	0.0005
	38mpd	0.0008	0.0007	0.0009	0.0015	0.0015	0.0021	0.0019	0.0018
	49mpd	0.0044	0.0046	0.0057	0.0051	0.0057	0.0054	0.0045	0.0049

(limit: < 0.007)

A severe undercharge is an EV departing knowing the trip cannot be completed. Red highlights unacceptable values.

Table 3-31: 1.1.2.2 LV Losses kWh (weekly averages)

6. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	39.5	42.6	55.4	70.5	91.3	116.6	145.8	171.9
	27mpd	40.4	44.8	61.7	87.9	119.5	161.5	208.7	252.3
	38mpd	41.4	47.7	73.1	109.4	153.1	216.5	282.7	358.9
	49mpd	42.6	52.1	83.1	127.3	187.6	270.9	361.3	463.4

A 3% loss on this network is 620 kWh, thus Summer losses are down vs. Winter. Given the reduction of charging, this is not surprising.

V2-3.6 Sequence 1.1.3 - the Strong Network

Sequence	Simulation ID	Description
Seq_1.1.3	***(S_83)***	***Strong network, Winter, all dumb EVs***

This is identical to Seq_1.1.1 except the network is given a built capability of 2 kW per house. This means that changes have been made to:

- OpenDSS transformer and cable specifications
- hi and lo_limit values, which effects the broaching analysis only.

V2-3.6.1 Seq_1.1.3 Summary

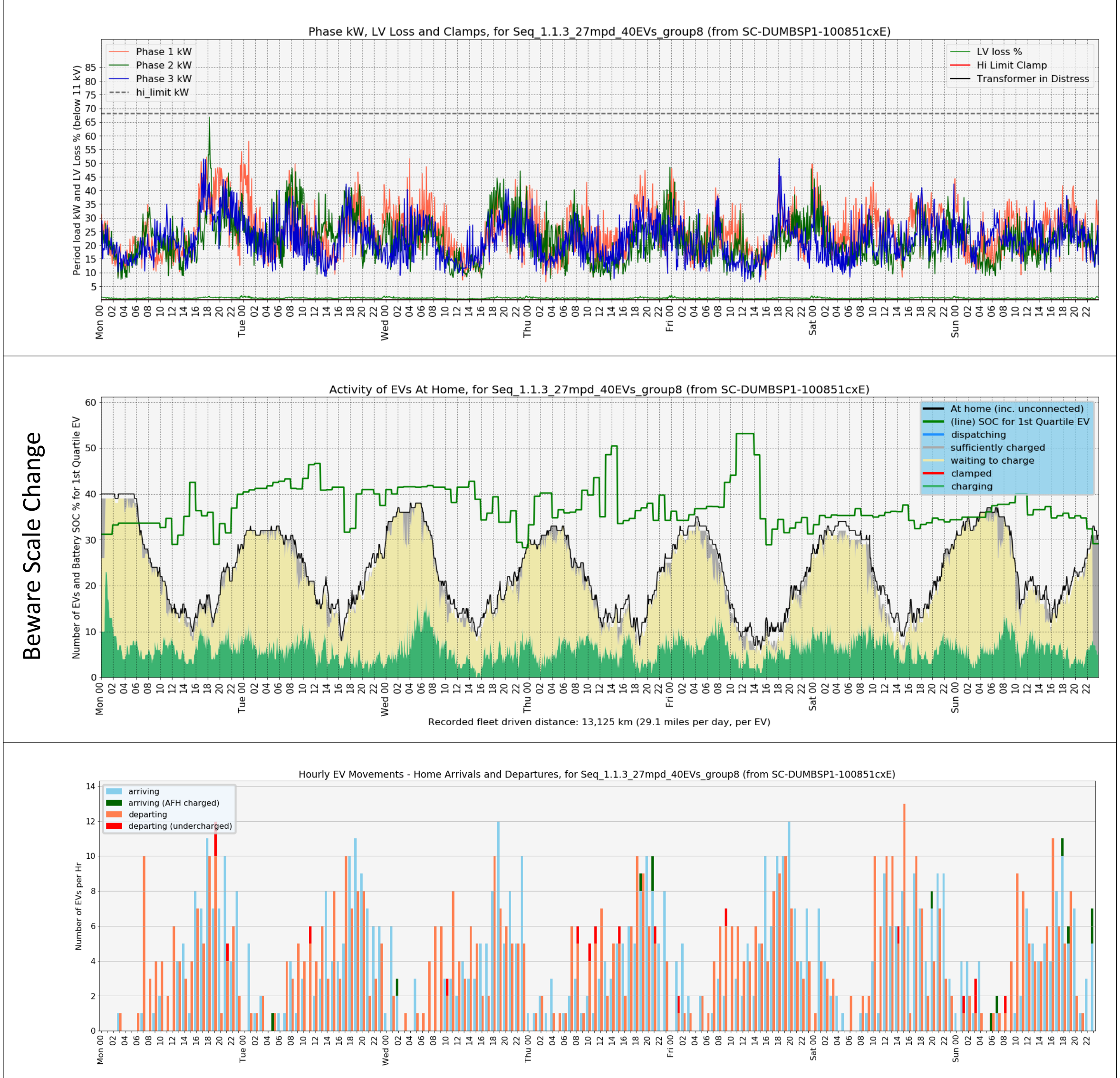
The 17 clear ply cells shown are acceptable; an improvement over the Typical network's 11 plies. However no network can cope with the parity case, indeed for locations with long typical driven distances only c. 13 EVs per phase can be coped with in Winter.

Table 3-32: 1.1.3 Overall Usable EV Bands

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

V2-3.6.2 Seq_1.1.3: Feeder and EV Plots

V2-3.6.2.1 Seq_1.1.3: 27mpd 40EVs



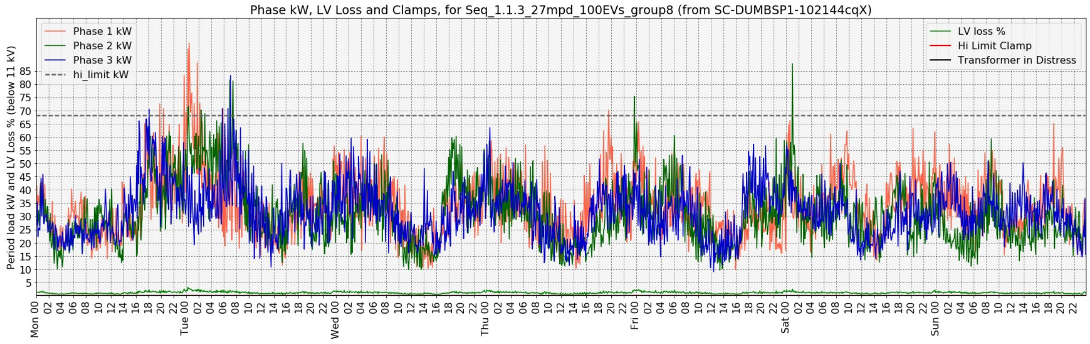
EoW stats: kWh[b] EV total: 2,335 Home: 2,026 AFH: 308 V2G: 0

Figure 3-13: Seq_1.1.3 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,268

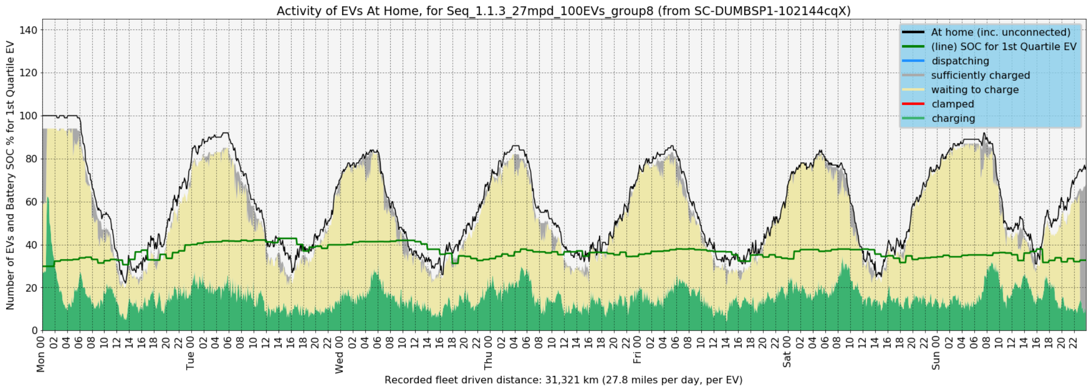
Notes re above plots:

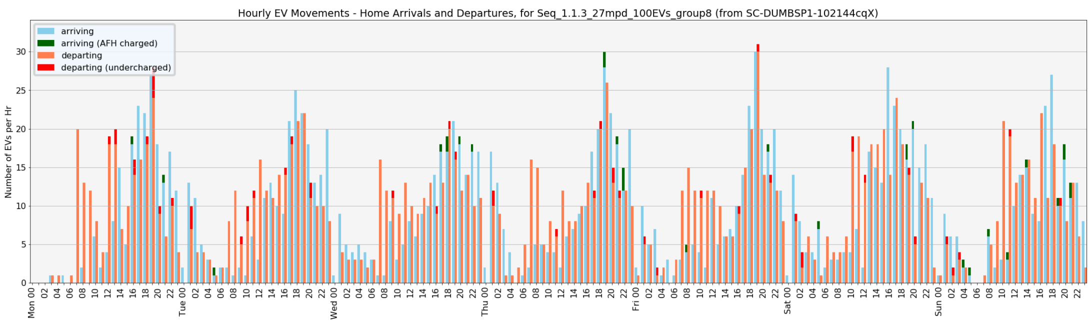
- (Feeder) the hi_limit has no impact, even though shown. Losses are around 1%.
- (CICD) 25th percentile SOC is generally 30 - 40%+ band.
- (Arrive/Depart) there are rare departs undercharged and use of AFH.

V2-3.6.2.2 Seq_1.1.3: 27mpd 100EVs



Beware Scale Change





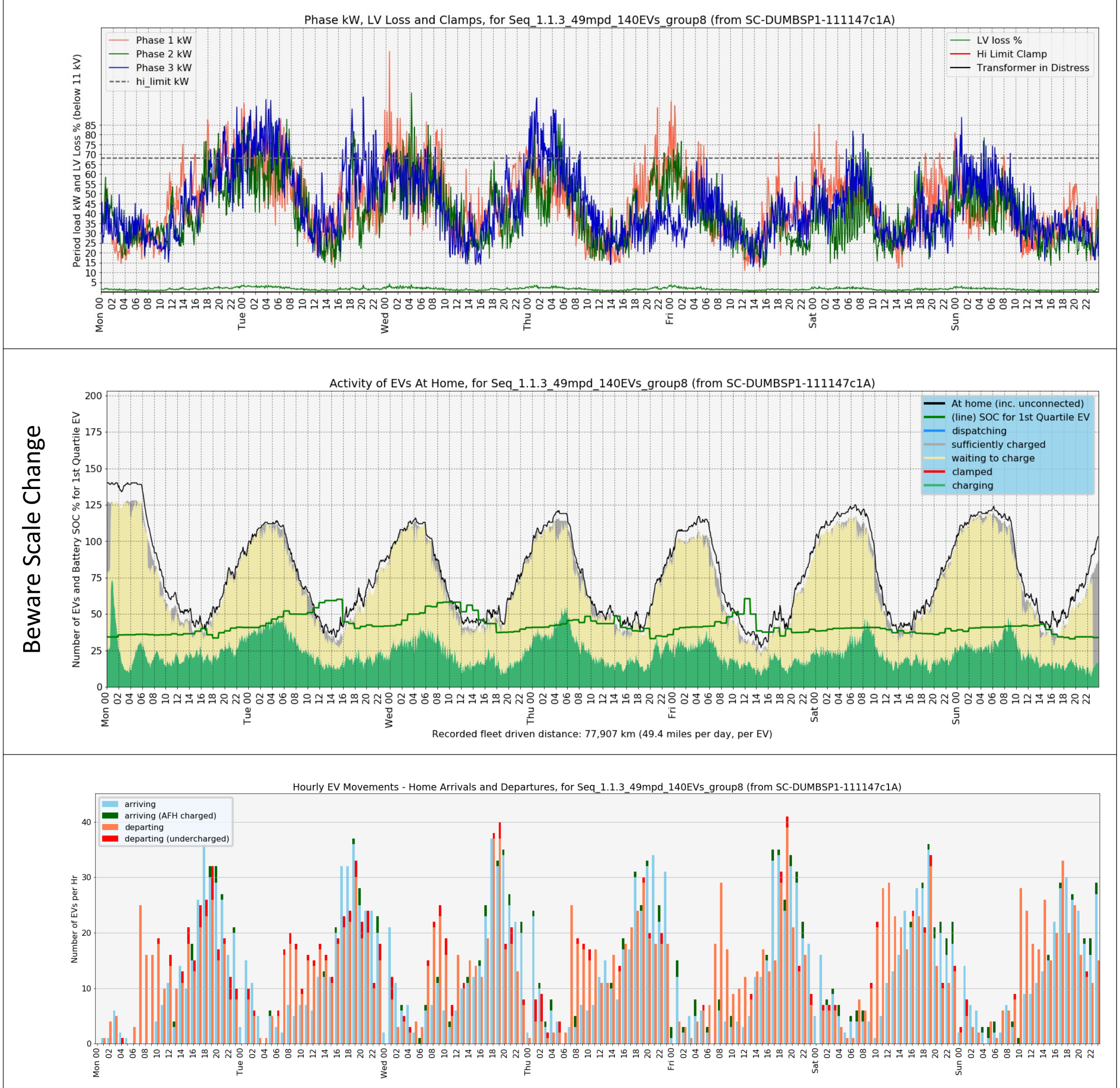
EoW stats: kWh[b] EV total: 5,912 Home: 5,073 AFH: 839 V2G: 0

Figure 3-14: Seq_1.1.3 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,923

Notes re above plots:

- (Feeder) there are occasional broaches early in the week.
- (CICD) EV SOC appears very similar to the prior CICD plot,
- (Arrive/Depart) occasional departs undercharged and use of AFH.

V2-3.6.2.3 Seq_1.1.3: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,613 Home: 9,233 AFH: 4,381 V2G: 0

Figure 3-15: Seq_1.1.3 49mpd 140EVs group 8 plots. Weekly fleet km: 77,339

Notes re above plots:

- (Feeder) broaches are daily;
- (CICD) EV SOCs remain similar to “as before”; with unrestricted charging they can do as they want; however
- (Arrive/Depart) there is a noticeable rise in departs undercharged and use of AFH.

V2-3.6.3 Data Tables Seq_1.1.3

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 3-33: 1.1.3 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	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

Each cell is the average of 500 simulations, each with varied EV trip timing. Red indicates network broaches detected.

Table 3-34: 1.1.3 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.8	3.2	3.4	3.3	3.4	3.6	3.5	3.5
	27mpd	6.8	7.8	7.7	8.1	8.4	8.4	8.3	8.1
	38mpd	17.8	17.5	17.8	18.4	18.1	18.5	18.4	18.4
	49mpd	36.0	33.4	31.5	31.3	31.0	31.0	31.4	31.3

AFH uptake appears to be a function of distance driven.

Table 3-35: 1.1.3 Per EV AFH N events (count of away connects, weekly averages)

3. EV N AFH	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	0.15
	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

These show the counts of the driver charging Away from Home. The values here are reasonable; the connects made in the week are set by the distance travelled.

Table 3-36: 1.1.3 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	27mpd	1.8	1.9	1.9	1.8	1.8	1.8	1.8	1.8
	38mpd	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	49mpd	2.9	2.9	2.9	2.9	2.8	2.8	2.9	2.9

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 3-37: 1.1.3 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0002	0.0001	0.0000	0.0002	0.0005	0.0004	0.0001	0.0002
	27mpd	0.0002	0.0007	0.0010	0.0013	0.0009	0.0010	0.0009	0.0009
	38mpd	0.0006	0.0021	0.0028	0.0032	0.0027	0.0032	0.0031	0.0033
	49mpd	0.0040	0.0036	0.0042	0.0054	0.0048	0.0062	0.0064	0.0061

(limit: < 0.007)

A severe undercharge is an EV departing knowing the trip cannot be completed e.g. “pushed home”, including “pushed out of driveway”. Red highlights unacceptable values.

Table 3-38: 1.1.3 LV Losses kWh (weekly averages)

6. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	52.7	56.9	76.1	98.0	122.4	164.7	202.6	245.8
	27mpd	53.4	58.3	79.4	103.6	144.5	189.0	239.5	290.5
	38mpd	53.9	59.4	82.2	114.6	154.6	217.6	279.1	348.6
	49mpd	54.4	60.3	84.4	126.3	173.7	236.2	311.1	388.6

A 3% loss on this network is 450 kWh. A traditional LV loss design goal was 4%, 600 kWh. There are no losses over that level.

V2-3.7 Other Sequence Set 1 Works

To construct the network capability heatmap presented in the Thesis, clones of 1.1.3 were run with improved network ratings: Sequence 1.1.5 at 2.5 kW ADMD, and Sequence 1.1.6 at 3 kW. Sequence 7.15.4 was already run using NPG's suggested 3.7 kW rating.

It is not proposed to include breakdowns of results, as:

- they are outside scope, and
- they bring nothing new other than raised kW ratings.

Further, a reduced Sequence run (only 250 not 500 per ply) was performed, to view the impact of removing BLPs. Seq_1.1.2.6 has BLPs OFF). This mimics present EVs in a 2050 context causing broaches to occur from N EV 20, not 40 i.e. the only clear N EV was 10.

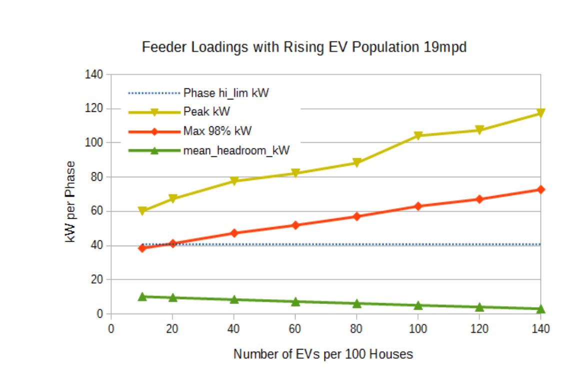
This implies that DNO networks are effected by EV charging policy.

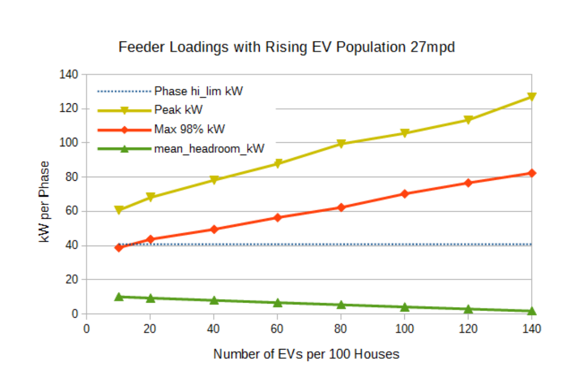
The MetaMeta zip results are included for interested readers.

V2-3.8 Other Sequence Set 1 Charts

V2-3.8.1 Feeder Loadings

Incremental delivered load increases broadly in line with the EV population increase. Losses drop; the reason being that Typical and Strong network assets are more capable i.e. have more conductor unit area, which lowers resistivity thus reducing losses.





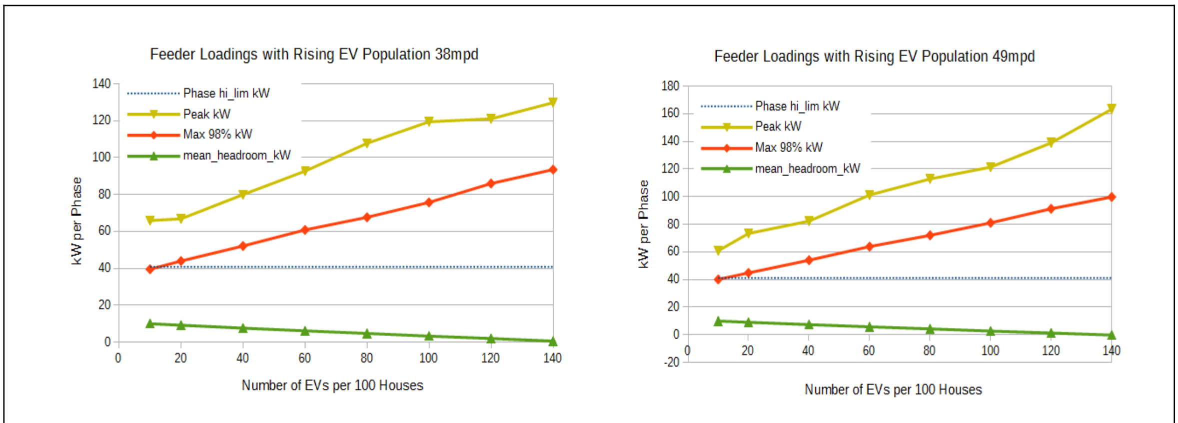


Figure 3-16: Seq_1.1.1 Feeder Load by mpd *Beware changes in scale*

V2-3.8.2 Broaching (Cable and Transformer Fusing) Events

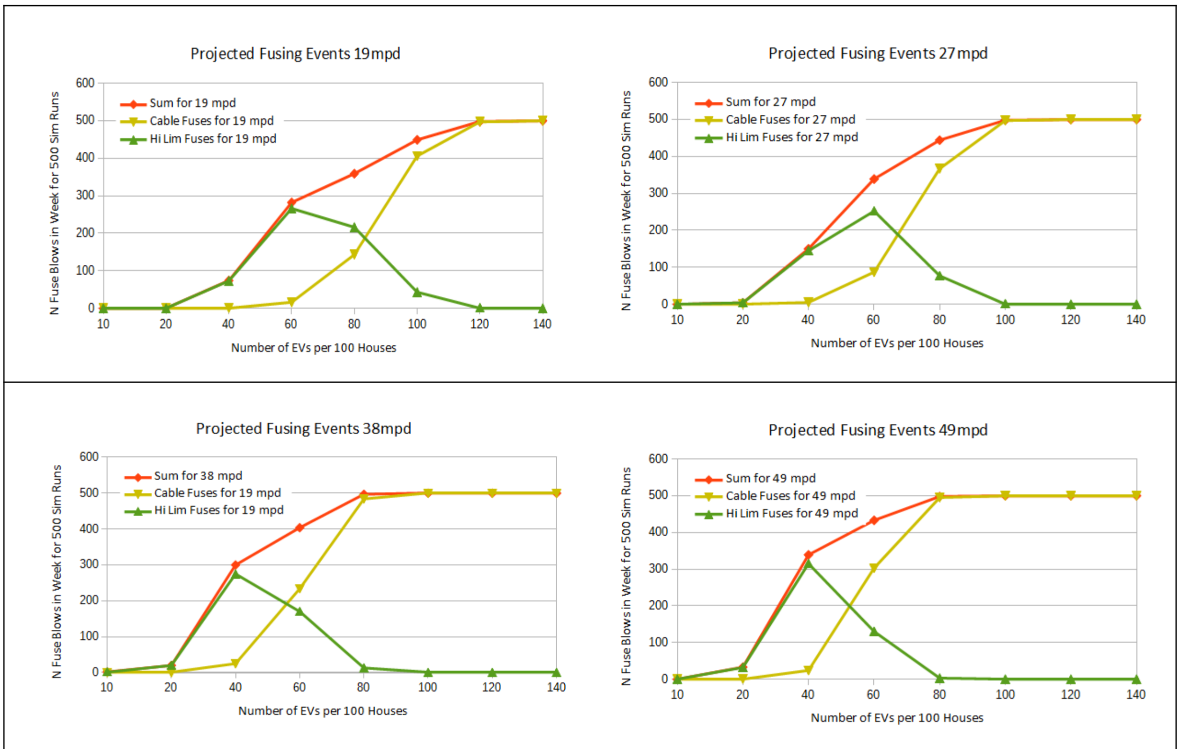


Figure 3-17: Seq_1.1.1 Broaching (fusing) Events by mpd

Note there are a maximum of 500 broaches; detection stops when a broach is seen.

V2-3.8.3 EV Distances Driven and Number of Home Plugins

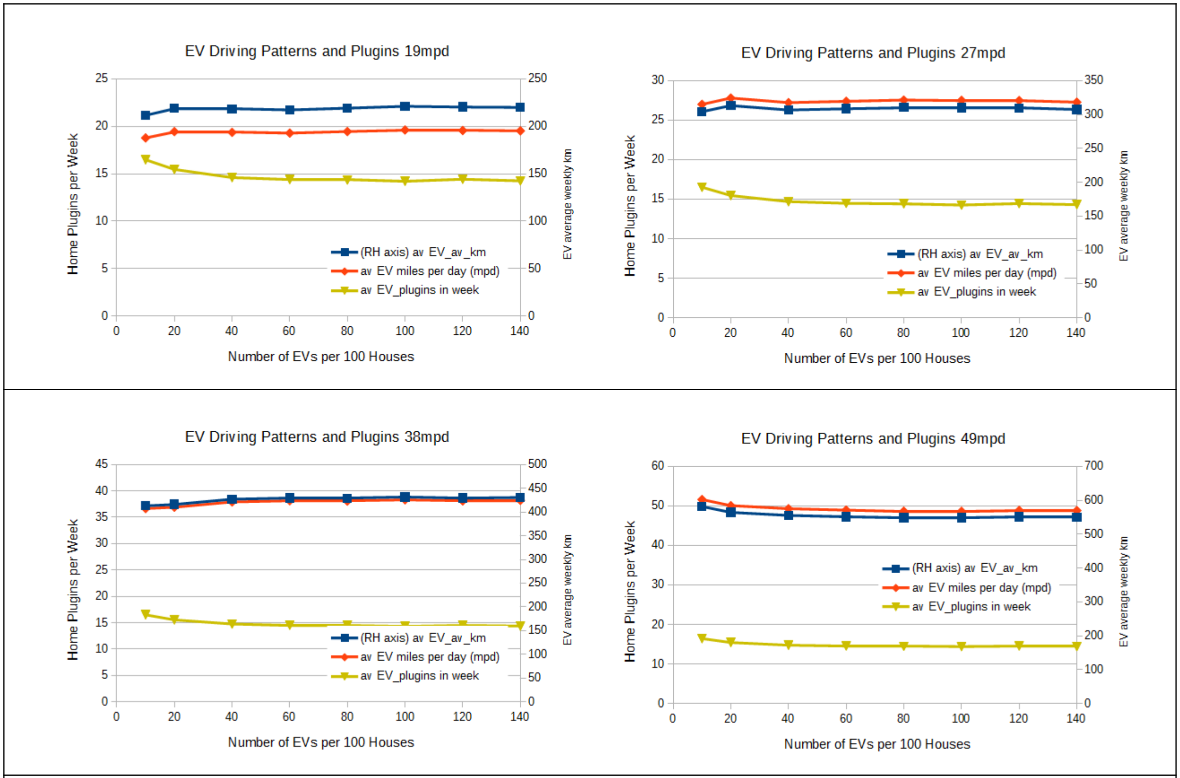


Figure 3-18: Seq_1.1.1 EV Distance Driven and Number of Home Plugins in Week

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V2-3.8.4 EV Undercharging Events

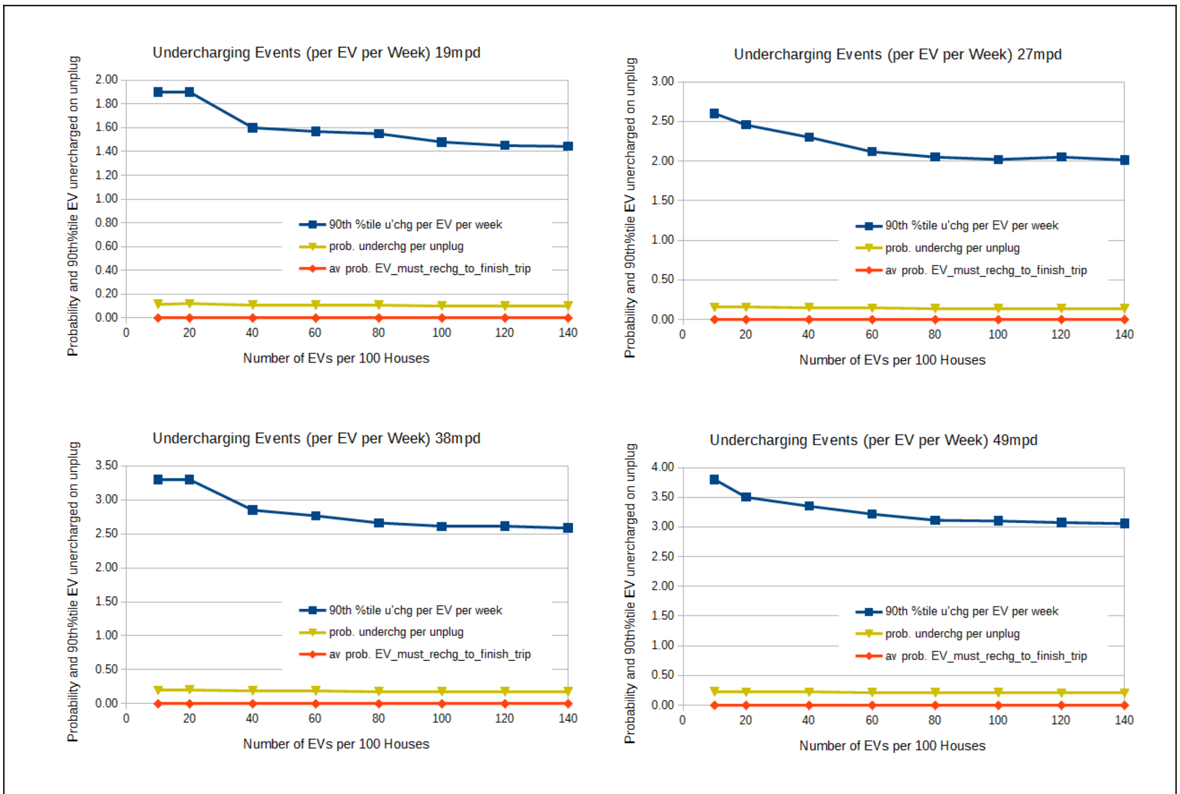


Figure 3-19: Seq_1.1.1 Weekly Number Undercharges and Probability on Unplug

Undercharging is now encountered. Any scheme to manage the addition of EVs to a feeder must ration power, with potential for undercharging. What then is undercharging?

An undercharge is defined as when the EV cannot accumulate enough charge it thinks it needs for known duties, up to the end of the next day. There is a modest margin built in; trivial undercharges of a few % are not counted.

A more severe undercharge is when the EV sets out with less power than needed to complete the present trip (including "so low it had to be pushed out of the drive").

Note that the modest undercharge still enables the EV to make a trip and get home i.e. to have more home charging opportunities.

Also note that driver irresponsibility can provoke undercharging; if they repeatedly perform short stops or forego plugging in, the EV will become undercharged.

Persistent undercharging may indicate a struggling system (inadequate power supply).

V2-3.8.5 EV End of Week Results: Seq_1.1.1, Seq_1.1.2, Seq_1.1.3

End of Week (EoW) results are shown. These figures are taken from output logs, reporting in retrospect (i.e. what the simulator did, rather than what it was told to do). For example, EV class counts are found by scanning EVs and asking "what are you?".

Table 3-39: EV outcome data for Seq_1.1.N

Parameter	**Baseline**	**Seq_1.1.1**	**Seq_1.1.2**	**Seq_1.1.3**	
		SC-DUMBWP1-131361cAF	**SC-DUMBTP1-118521ckE**	**SC-DUMBSP1-97068cTC**	
	No EVs	**19mpd 20 EVs**	**19mpd 40 EVs**	**19mpd 80 EVs**	
N dumb		20	40	80	
N SV1G		0	0	0	
N V2G		0	0	0	
EoW fleet km driven		4,680.07	9,279.09	16,373.84	km
Average EV mpd		20.8	20.6	18.2	mpd
EoW fleet stored kWh		260.1	466.3	1005.7	kWh
prior EoW fleet kWh		260.1	466.2	1005.1	kWh

Parameter	Baseline	Seq_1.1.1	Seq_1.1.2	Seq_1.1.3	
EoW home_chg kWh		875.4	1,686	3,161.5	kWh
EoW AFH_kWh		27.5	153	190.8	kWh
EoW home_disp_kWh		0	0	0	kWh
EV used kWh		903	1839	3,353	kWh
kWh in week per EV		45.1	46	41.9	
Unutilised kWh in week		10,848.4	14,800.8	20,748	kWh
Notional spare capacity for further EVs		240	322	495	#

V2-3.8.6 EV End of Week Histograms

There are six sets of End of Week (EoW) results for EVs, present in the Meta zip files. All histograms are plotted using data from a 500 simulation mpd x N EV cell.

V2-3.8.6.1 EoW EV mpd Histogram

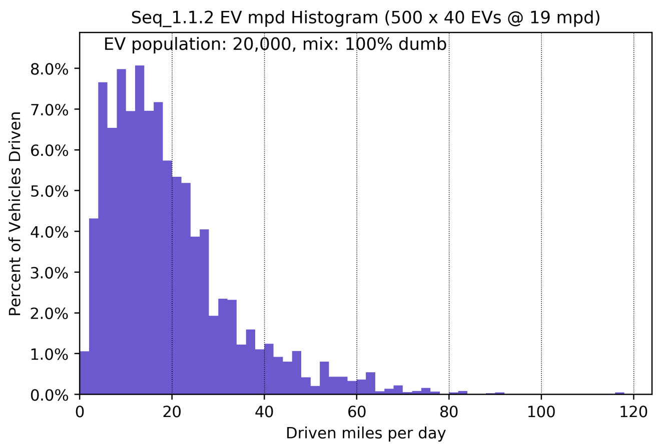


Figure 3-20: Seq_1.1.1 EoW EV mpd Histogram

These distributions show a mean in the mid-teens mpd with some vehicles driving much further. Probabilities are generated via python's "random.random" normal distribution generator. This sets EV driven distances, determining charging demands.

V2-3.8.6.2 EoW EV Home Charged kWh Histogram

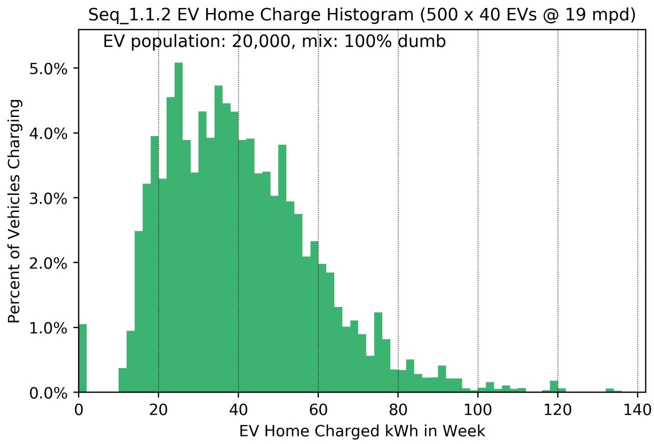


Figure 3-21: Seq_1.1.1 EoW EV Home Charged kWh Histogram

The histograms display the distribution of total accepted charge, taken at home.

V2-3.8.6.3 EoW EV AFH Charging Histogram

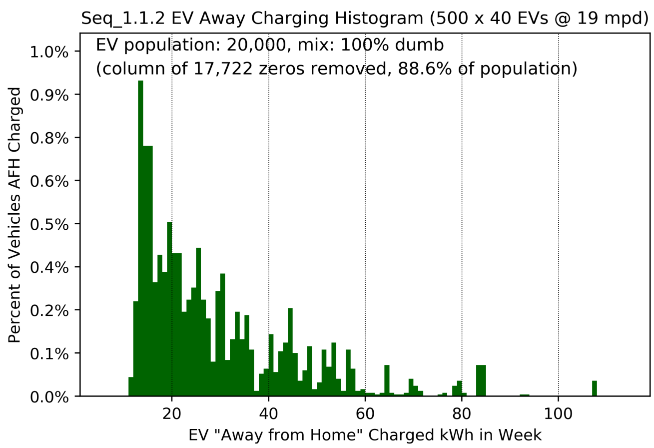


Figure 3-22: Seq_1.1.1 EoW EV AFH Charging Histogram

EVs also take on charge away from home e.g. workplace charging points. The probability of this is determined by modelling the driver's perceived needs - if arrival SOC is < needed, they will always plugin - but if SOC > needed, there is a probabilistic chance of plugin.

Note that all plugins here are supposed manual; automated plugins via inductive charging pads are possible. For clarity, Figure 3-22 also has removed a tall column of zeros.

V2-3.8.6.4 EoW EV SOC Histogram

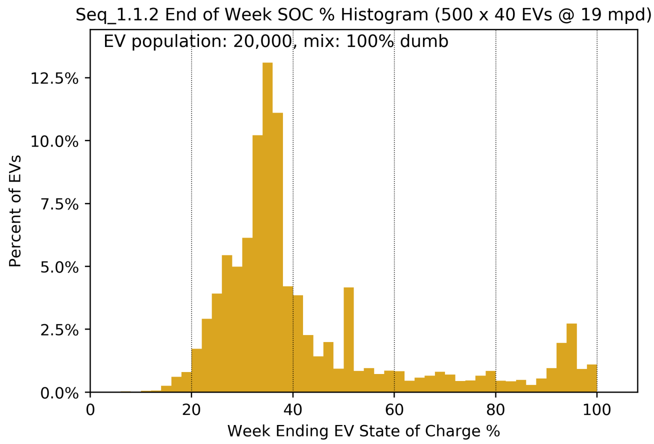


Figure 3-23: Seq_1.1.1 EoW EV SOC Histogram

The SOC plots are again similar and show the majority of EVs (which, being the same class, follow the same battery algorithms) are in the lower-mid SOC range, with some (likely expecting longer trips) are near 100% SOC. Note that EV trips include an 8th day, so EVs can determine the next-day's use profile.

V2-3.8.6.5 EoW EV Home Plugin Counts Histogram

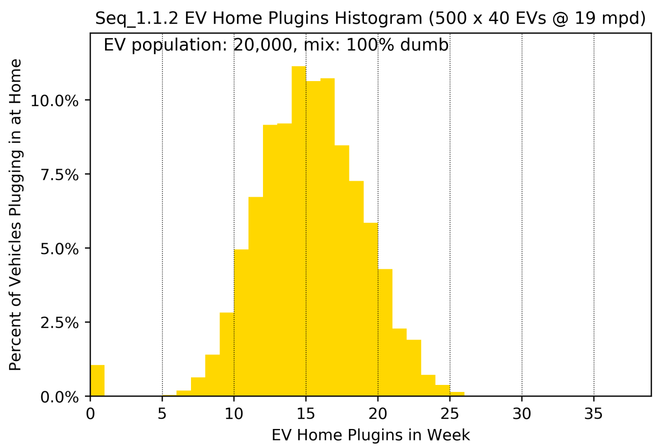


Figure 3-24: Seq_1.1.1 EoW EV Home Plugin Counts Histogram

Home plugin frequency is surprisingly high. This was found driven by reduction of the EV battery capacity due to low ambient temperature. In winter, when EV loads are higher, the battery can store less hence EVs are plugged in more often. This is a learning point:

- the use of EV chargers, especially public, will rise in winter for top-ups
- provision of sufficient public chargers is needed in the built society.

V2-3.8.6.6 EoW V2G EV Dispatch kWh Histogram

A similar histogram plotted for V2G dispatch of kWh; for sequences without V2G EVs this will be empty (NB V2G values are negative). Here is an example for V2G EVs:

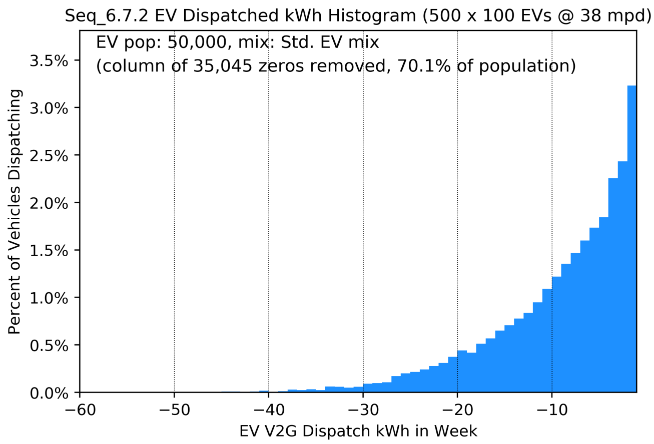


Figure 3-25: Seq_1.1.1 EoW V2G EV kWh Dispatched Histogram

V2-3.9 Observations on Sequence 1

V2-3.9.1 General Observations

Observations points include:

- no significant simulator errors are observed
- results are similar to others: curves in My Electric Avenue **(EA Technology Ltd., & Roberts, 2016)** and expressed thermal limits **(WPD, 2018)**
- the modelled networks **cannot support levels of EVs as common as cars**
- the modelled networks are likely less prone to voltage issues vs. some in real-life i.e. these views are **optimistic in that they are best-case and likely understate** network experiencing significant voltage degradation issues
- driven mpd makes a difference => geographic location of the LV system at hand will be significant
- in Winter vs. Summer:
    - EVs consume more kWh than anticipated
    - EVs plug in more often when arriving home
    - EVs need access to significantly more AFH charging opportunities,
- data generated includes AFH kWh and plugin counts, allowing assessment of the need for public charging points

- overall, the author considers the simulator to be slightly optimistic, due to:
  - lack of local homoeostasis (discussed in V2-3.9.3 below) and
  - likely improvements to low temperature battery performance
  - both of which may increase Winter demand by c. 10% i.e. a RL experienced net demand uplift of c. 15% - 20% is plausible.

V2-3.9.2 Results Observations

a) The fleet driven distance is a little high, other than the 80 EV case; this is a little low. The cause of this is a mechanism which checks trip timings for plausibility; as trips lengthen then there may be an implausible (negative) home turn-around time created. The following trip is struck, so that remaining scheduled trips can complete. The impact of this is that EVs may make slightly different trips, with slightly different total distances.

b) The Unutilised kWh suggests that there is plenty of kWh available to add more EVs. How many can access the charge at home is another question. It seems reasonable that more EVs might be supported, but adding more causes broaches.

   Some form of Managed Charging, able to diversify (prohibit simultaneity) EV charging may be able to access this energy without causing broaches.

c) Batteries are more hindered by cold than expected. If this is corrected by EV manufacturers, home kWh taken in Winter will increase per EV by some tens of percent (the modelled C loss being about 40%).

d) A “simulation sensibility” check is possible: calculate EV kWh consumed per km, and compare with the expected (pre-defined) consumption rate. This is performed for Seq_1.1.1, which has EoW fleet kWh for the prior Repetition 1 shown.

   These winter simulations are at 1°C. The FPB has penalised these trips by 177 kWh (about 0.75 kWh per EV use) to account for cabin heating. This reduces driving energy use to 726 kWh, giving a net consumption rate of 0.155 kWh per km.

   The simple average of class consumption rates for the EVs concerned is 0.132 kWh per km, but this does not weigh consumption rates by pro-rata driven distance.

The author would like to see the rates closer (they are 15% apart), but the outcome is accepted as a sensibility check;

Note calculations rely on user reports of the 2014 Nissan Leaf for internal values re vehicle characteristics. The sample values for modelled larger EVs were “guesstimated”, as no real-world data on future, larger vehicles was available.

V2-3.9.3 A Concern - Overnight Home Vehicle Numbers

Inspecting any CICD plot shows that there are less vehicles at home overnight, as start the week. Why do EV numbers drop? This was potentially a major issue, as it may indicate an error within the simulator. No such error was found, rather the “missing” EVs had valid reasons to be away i.e. the vehicle had departed and was not yet due to return.

It was realised that, as far as EV movements go, the simulator has a strategic failing:

> **There is no regional homoeostasis:** i.e. the simulator is missing visitors; those based at away locations who travel “in” to the area studied, as resident EVs travel “out”; the effect is to model a region as if an oasis set in a dessert.

The concern is that, by not modelling visitors, the EV charging load is understated. The way to correct this is not clear. Ideally, a greater region including many EVs would be modelled together with the probability of destination when setting out on a trip. This becomes complex fast and is not the type of correction which can be readily included in the present simulator.

However, the author knows that the trip generator makes tripsets which are slightly long vs. target i.e. a “19 mpd” tripset, as generated, might actually report in the output logs an EV driven distance of 20.5 mpd, approaching 10% too high. This tends to compensate for missing demand as kWh, but understates simultaneity.

The author therefore proposes - to do nothing, other than to note that the present simulator might be understating i.e. peak loads, and the frequency of peaks, may be herein stated low.

V2-3.10 Sequence 1 in Summary

The support capability in Winter, on LV networks exhibiting built per house capability (for a minimum of 100 houses), has been found to be:

Table 3-40: Sequence 1 Heat map of Usable EV Bands (All Dumb EVs, No Regulation)

O Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd	1.2	1.2	1.5	2	2	2.5	2.5	2.5
	27mpd	1.2	1.5	2	2	2	2.5	2.5	3
	38mpd	1.5	1.5	2	2	2.5	2.5	2.5	3
	49mpd	1.5	1.5	2	2.5	2.5	2.5	2.5	>3

Only 3 broaches were seen in the 49mpd 140 EV ply; the author is confident that NPG's 3.7 kW recommendation would be sufficient for BLP EVs. From Table 3-40 it can be seen (for example) that a built 2 kW capable network can support no more than:

- 19mpd: 80 EVs per 100 houses,
- 27mpd: 80 EVs per 100 houses,
- 38mpd: 60 EVs per 100 houses,
- *49mpd: 40 EVs per 100 houses.*

Concerning AFH charging. Given that destination charging is needed by all at a point of attraction, then the charging needs be adequate for all comers i.e. fit to serve the needs of the surrounding catchment area, as well as the immediate environs. That is, an evening venue (a Mall car-park) needs to consider the Winter charging needs of those visiting from 15 miles away as well as those more local. Failing that, in Winter people from 15 miles away may not be willing to visit.

This implies the chargepoint provision policy for (say) a major football stadium in Coventry may need be different vs. a similar stadium in Norwich, as the context of the surrounding areas, driven distances and availability of home supply varies. That is, the region about Coventry is mainly urban, about Norwich is mainly rural.

Vol 2 Chapter 4: Seq. Set 2 (2.1.2 - 2.5.2)

Sequences in Set 2 control network load by EVSE disconnectors aka “clamps”, as in the MEA and Electric Nation projects. Sequences use the Typical network and are in Winter.

V2-4.1 Description of Sequences

Purpose: To investigate use of clamps (forced EV disconnects) controlled by a Managed Charging System (MCS) with rising EV demand. The EVs are all dumb.

Key Concerns to Investigate:

a) by inhibiting kW load level beaches (over hi_limit kW) does clamping permit more EVs to be accommodated on the network?
b) is the identified unutilised kWh (such as in Table 3-12) successfully accessed?
c) does clamping lead to undercharging and to what degree?
d) does driver behaviour (casual vs. perfect plugins) modify the outcome?
e) can Away from Home perfect plugins aid the situation?

V2-4.2 Simulations in Sequence Set 2

Table 4-1: 1.1.2.2 Unused kWh (weekly averages)

Sequence	Simulation ID	Description
Seq_2.1.2 BASELINE	(S_BA)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, control modulation via hi_limit using pattern “DR-B FFR”, normal plugin regime
Seq_2.1.2.8	(S_BC)	Variation on Seq_2.1.2: dumb EV tripsets
Seq_2.1.2.9	(S_93r)	Variation on Seq_2.1.2: no DRFFR control modulation
Seq_2.2.2	(S_A3)	Variation on Seq_2.1.2: clamps ON (1)
Seq_2.3.2	(S_A8)	Variation on Seq_2.1.2: Home perfect plugins
Seq_2.3.2.1	(S_B7)	Variation on Seq_2.1.2: 3 Static Batteries (V2G) per phase
Seq_2.4.2	(S_A5)	Variation on Seq_2.3.2.1: Use alternative clamping method (1)

Table 4-1: 1.1.2.2 Unused kWh (weekly averages)		
Seq_2.5.2	(S_A7)	Variation on Seq_2.3.2: Home and Away perfect plugins with clamps method (2)
Seq_2.6.2	(S_A6)	Variation on Seq_2.5.2: Use alternative clamping method (1)

V2-4.3 Methodology

To save time and effort, only Typical networks are investigated. The EVs are dumb (thus no direct ICT control, no V2G) and are subject to clamping.

Two clamping algorithms are used:

1) C1: clamp all except those EVs with least net kWh delivered to socket (MEA, EN method); that is, if capacity exists for 10 EVs but 15 want charge, favour the EVs with least kWh supplied to date;
2) C2: clamp all that do not meet a criteria calculated as ranked “charging rate needed”. This favours EVs needing the fastest rate of charge, and considers both:
    i. time urgency
    ii. SOC deficiency (present SOC vs departure SOC).

Method (1) attempts to treat all EVs fairly by supplying the same kWh; is easy to implement but is blind to urgency. An EV needing no charge receives as much as an EV needing substantial charge. **Note** that needless charging may impact battery life.

Method (2) needs knowledge of both battery SOC and driver intent, so is likely to be calculated within the EV.

Yet for any clamping system, in extremis constrained EVs “starve” so are forced to charge Away from Home (AFH).

For sequences citing “perfect plugins”, charging management parameters are adjusted, for both Home and Away charging plugins. The options are:

- (standard) always plugin if needed, otherwise AFH with probability 30%, Home by reported count limit;
- always plugin at Home and / or
- always plugin Away from Home.

AFH charging is assumed to supply “whatever the EV deems it needs” i.e. there is no limit.

It was observed during test runs that many EVs arriving home do not plug in hence lose charging opportunities. Therefore in Seq_2.5.2, EVs always plug-in on arrival home.

The 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 or plots of interest, as deemed fit

Excel and LibreOffice tools are also used.

V2-4.4 Findings and Observations

Findings:

a) a 100% clamped local network halts overloads; no broaching events are seen
b) network throughput “saturates” at the hi_limit setpoint and transformer clamps (for cooling) arise
c) it appears possible to accrue EVs ad infinitum on a clamped network
d) clamping reduces per EV net kWh supplied as N EV rises, so
e) from the driver’s viewpoint, at home charging may then be inadequate
f) Away from Home charging is seen to increase, due to two factors:
   - inadequate home charging and
   - EV battery capacity drops due to winter cold and cannot retain sufficient charge. More mid-journey topping-up occurs vs. Summer
g) home perfect plugins assist, but
h) AFH perfect plugins near obviate need for home charging so have major impact
i) the algorithm for clamping selection has a minor impact on charging outcomes
j) adding DR/FFR network value added services is possible, but:
   - provokes undercharging and
   - elevates use of clamps to high levels
k) adding local PV with static batteries (as local energy stores) lifted the count of plies free of severe undercharging from 18 to 23.

Observations:

i) at some point diminution of home supplied charge results in under-charging and likely customer upset

ii) AFH charging becomes necessary, but may be:

  a) expensive (compared to home charging) or

  b) not possible

iii) as a result, customers may home charge via unclamped 13A sockets

iv) in a clamped network an unclamped 13A socket takes preference, consuming kWh otherwise bound for clamped EVs

v) in extremis, “charging wars” may break out with many EVs using 13A sockets (so provoking LV overloads); those that do not suffer reduced ability to charge.

vi) A metric of “what is reasonable to do” is needed which forestalls the above, a metric which can be readily applied by the DNO as a forecasting tool thus allowing the planning of appropriate local network upgrades.

vii) Outcome (h) suggests that local networks are assisted by AFH charging. A targeted AFH scheme or incentive may aid a mitigation strategy to defer network reinforcement. This presupposes the availability of public charging points at reasonable cost.

V2-4.4.1 Broaching: None

In no 2.X sequence did broaching occur. In that regard, clamping is a success.

V2-4.4.2 DR and FFR Injection

Many simulation runs in sequence 2 include a DR / FFR signal. This injects a small variation to the standard hi_limit per period, in the range +/- 0 .. 5%. To allow this to operate, the hi_limit is reduced by a static amount of 5% i.e. the control signal varies about the 95% level. The intent is for this to be functionally invisible to EVs, and to modulate the local load in a similar manner as NGESO might wish to buy as a Value Added Service. The DR signal is a slow time-of-day change (following an external peak), whereas the FFR signal is a rapid random variation which sums to zero over the day.

An intrinsic feature of MCS systems is constant load throughput. If an aggregator contracts with a subset of EVs to offer DR / FFR services to NGESO, the effect of a contracted EV “standing down” (as DR load-lowering) - is undone by the MCS maximising LV throughput. Any capacity release is sensed by MCS and sent to another EV - <u>giving no net change</u>.

By managing the hi_limit successfully, MCS operation may “undo” DR / FFR services. The purpose of including a DR / FFR signal is to generate data for later analysis, to evidence whether the modulation of the hi_limit level can provide a “DR / FFR service”.

Does this impact charging? To allow comparison, two sequences are run with and without the DR / FFR signal.

V2-4.4.3 Perfect Plugins

On arrival home, the EV model determines the present EV SOC. If these is insufficient for next use, the EV is always plugged-in (the driver suffers “range anxiety”). However if SOC is deemed adequate, then the EV may not be plugged in.

Similarly, if on arrival home the EV journeyed further than the depart SOC would allow, the EV must have topped up charge somewhere. This is deemed to be at a point midway in the trip and an SOC top up of whatever charge needed is calculated and attributed as Away from Home / AFH charging. AFH frequency and kWh are recorded both per EV and for the entire fleet (this affords unexpected insights into use of public charge points).

However at times when the EV does not need charge AFH, the code determines if there was opportunity (much parked time AFH) and if so, uses a probabilistic coin-toss to determine if the EV did take on charge.

These approaches allow adjustment of probability to 1 i.e. the EV always plugs in when parked, hence “perfect plugins”. Note that a small number of EVs do this habitually when arriving home; these are top-end models (executive and luxury) which possess inductive charging systems; all they need do to charge is to park at their usual home position (the driver has to do nothing). The cost for this is increased losses (as another electrical stage is introduced) which is modelled by increasing the vehicle charger loss by 8%.

V2-4.4.4 Simulation Plots

Plots from group 8 are shown; this is somewhat arbitrary. Presentation of the same group means EVs performed identical journeys, allowing straightforward comparison.

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

- “part penetration”: 27pmd 40 EVs,
- “parity at 1 EV per house”: 27mpd 100 EVs and

- “high impact”: 48mpd 140 EVs.

V2-4.5 Sequence 2.1.2

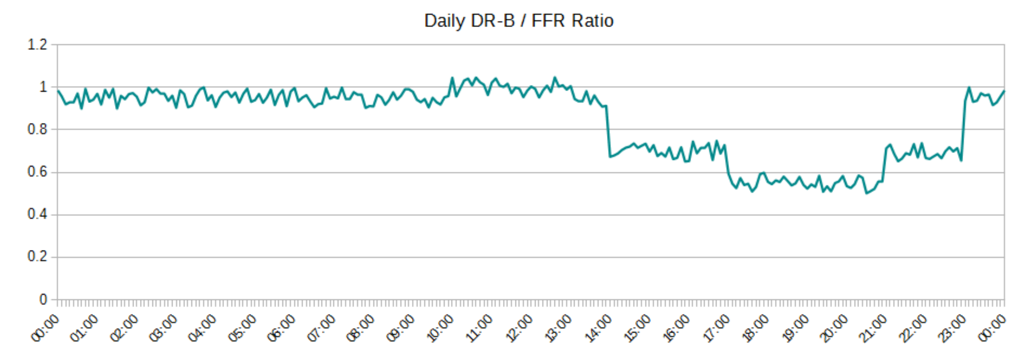
Sequence	Simulation ID	Description
Seq_2.1.2 BASELINE	(S_AC)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, control modulation via hi_limit using pattern “DR-B / FFR”, normal plugin regime

The simulation uses mode 2 clamping strategy: “by ranked need”. Note that “pre-burn V2G” is off; reduction will be employed before using V2G (but there are no V2G EVs).

The DR-B / FFR pattern is repeated daily, with Demand Reduction as follows:

Table 4-2: Demand Reduction regime for DR-B with plot of DR-B plus FFR

	Time of Day	Applied Ratio	Rationale
	each ratio +/- 0.05		*the FFR signal*
	10am to 1pm	variation about 1.0	values > 1 are “Sunshine Signal”
	1pm to 2pm	variation about 0.95	default
	2pm to 5pm	variation about 0.7	afternoon load limiting
	5pm to 9pm	variation about 0.55	evening peak load mitigation
	9pm to 11pm	variation about 0.7	late evening load limiting
	11pm to 10am	variation about 0.95	default



This signal is used to modulate the hi_limit every day. Note that the FFR component is contrived to sum to zero.

Data is viewable in: MetaMeta2.3_Seq_2.1.2.xlsx.

V2-4.5.1 Seq_2.1.2 in Summary

Clear ply cells are acceptable, however the dark red ply is a loss vs. Seq_1.1.2, due to "excessive use of clamps". Broaching is however avoided; assets are secured from risk of damage or power outages following a substation fuse-blow, yet EVs become undercharged as numbers rise.

Table 4-3: 2.1.2 Overall Usable EV Bands

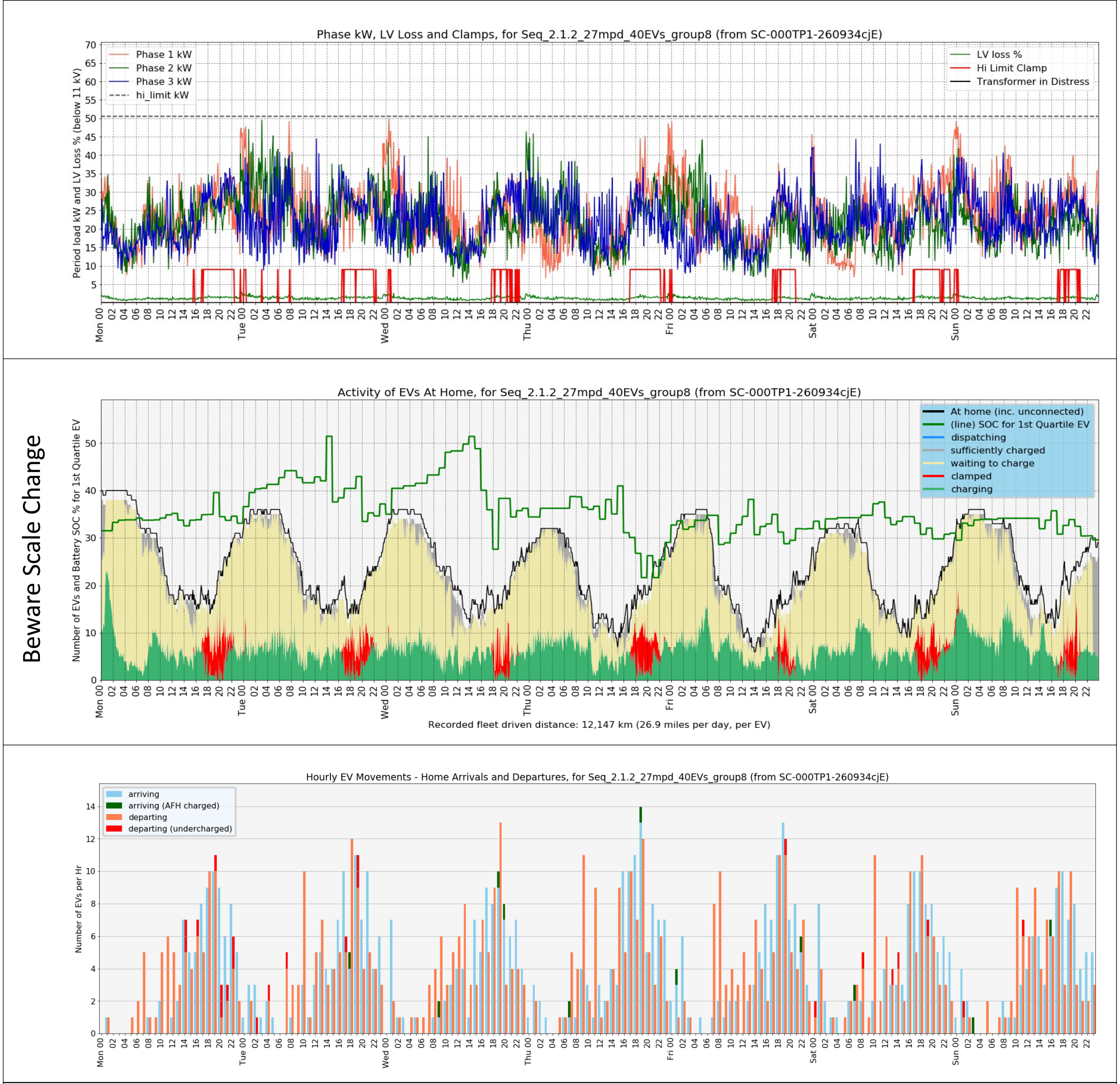
0. Overall Usable Plies	N EV	10	20	40	60	80	100	120	140
	19mpd			C	C	C	C	C	C
	27mpd			C	C	C	C	C	**CS**
	38mpd			**CS**	**CS**	**CS**	**CS**	**CS**	**CS**
	49mpd			**CS**	**CS**	**CS**	**CS**	**CS**	**CS**

C: clamping limit exceeded; S: severe undercharging encountered.

The DR regime is shown to move the EV charging demand from early evening into the overnight period, at the expense of undercharged EVs.

V2-4.5.2 Seq_2.1.2: Feeder and EV Plots

V2-4.5.2.1 Seq_2.1.2: 27mpd 40EVs



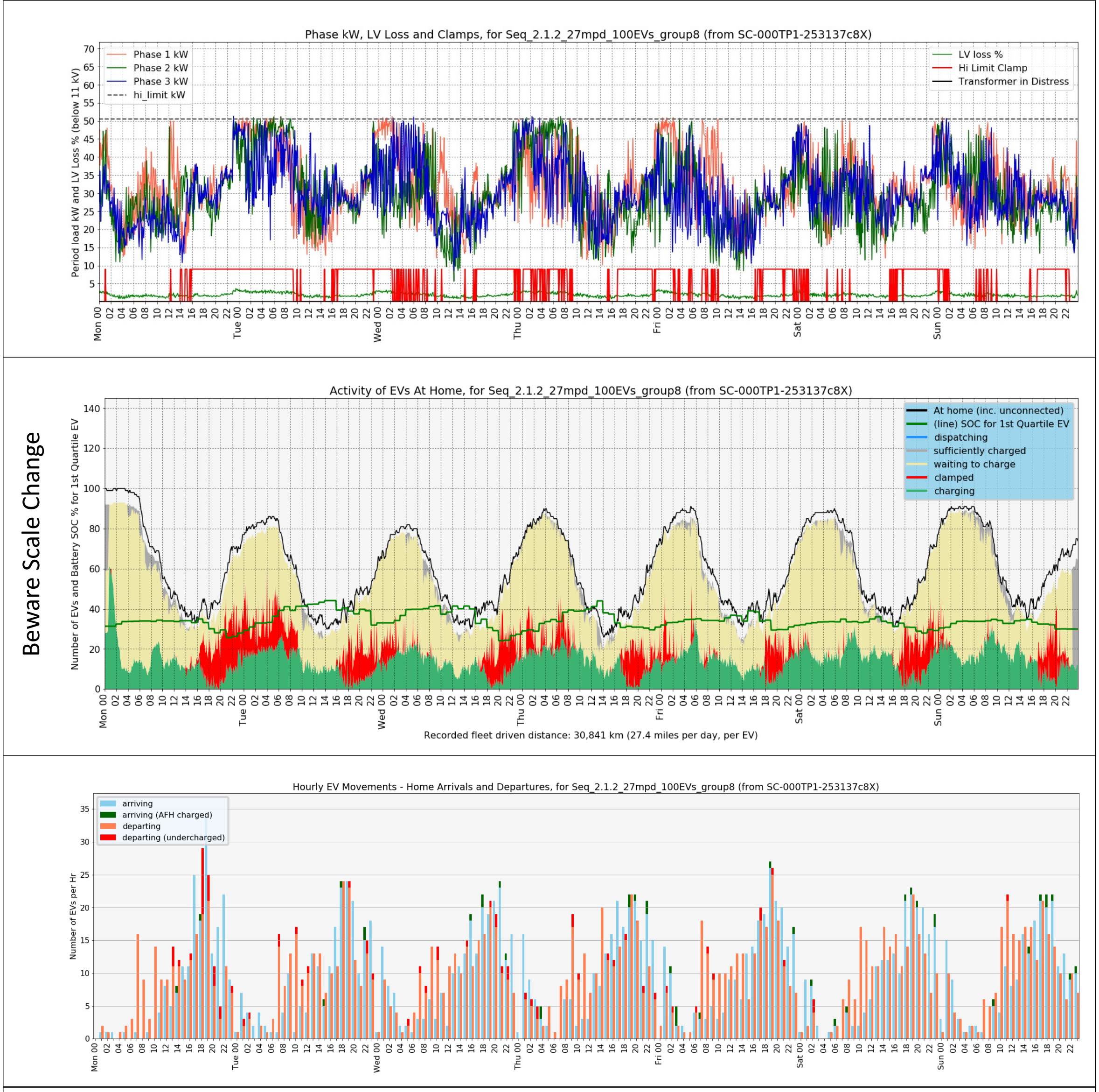
EoW stats: kWh[b] EV total: 2,334 Home: 2,010 AFH: 324 V2G: 0

Figure 4-1: Seq_2.1.2 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,212

Notes re above plots:

- (Feeder) the hi_limit lowered by DR (2pm - 10pm) is causing clamp firings
- (CICD) there is little sign of grey (EVs finished charging) but red marking clamps are seen; EV SOC is good, in the 30 - 50% range. Most EVs are being plugged in implying they do not have enough SOC for the next day
- (Arrive/Depart) there are rare departs undercharged and AFH charging.

V2-4.5.2.2 Seq_2.1.2: 27mpd 100EVs



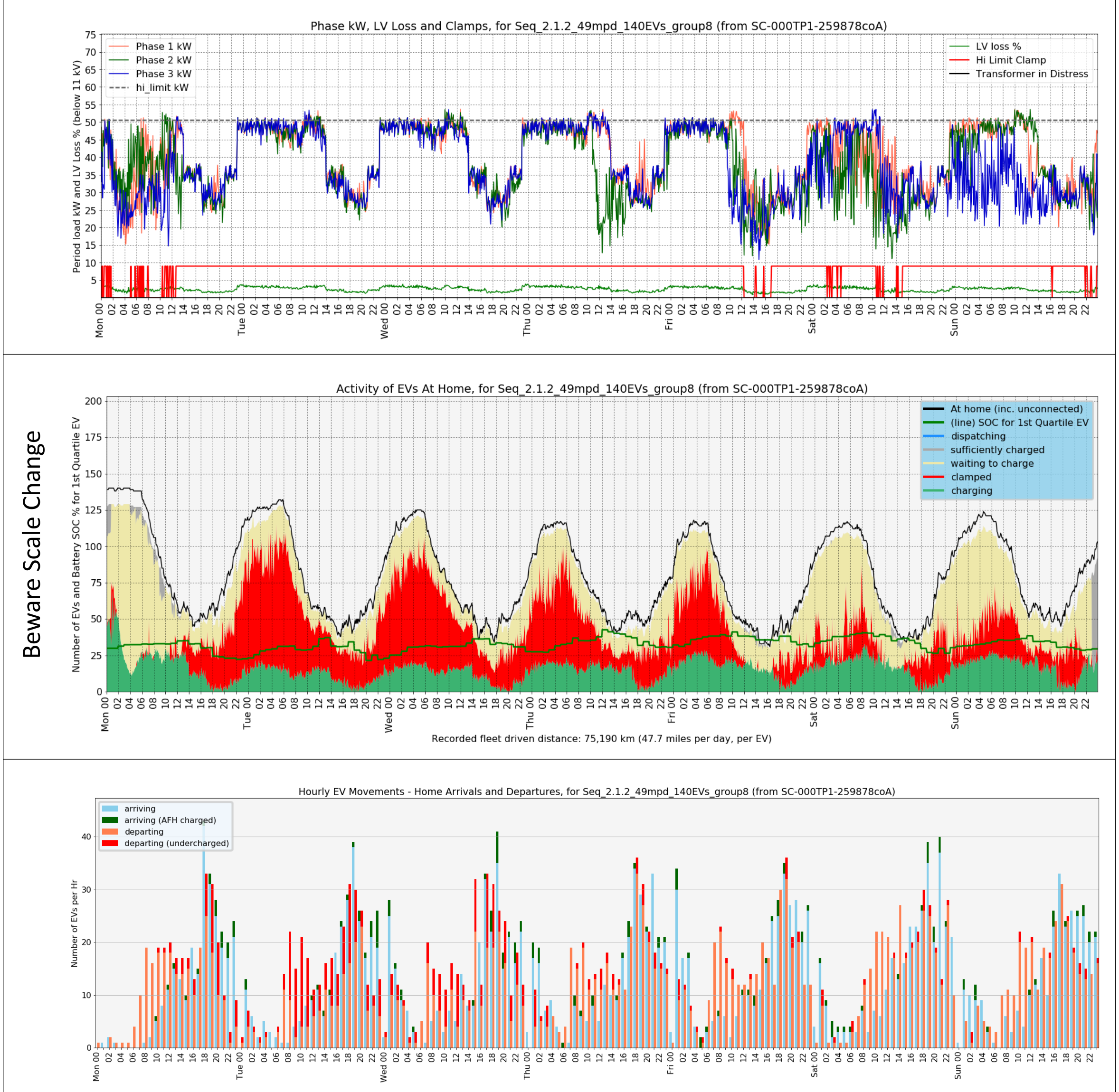
EoW stats: kWh[b] EV total: 5,912 Home: 5,014 AFH: 898 V2G: 0

Figure 4-2: Seq_2.1.2 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,876

Notes re above plots:

- (Feeder) clamps succeed in limiting any broaches; the load curve is just under the hi_limit implying the standing 5% FFR decrement is being applied
- (CICD) EV SOC appears down with more frequent clamps
- (Arrive/Depart) there are more departs undercharged and AFH charging.

V2-4.5.2.3 Seq_2.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,543 Home: 8,224 AFH: 5,320 V2G: 0

Figure 4-3: Seq_2.1.2 49mpd 140EVs group 8 plots. Weekly fleet km: 77,327

Notes re above plots:

- (Feeder) clamps are in use continually for days; the DR/FFR signal is apparent
- (CICD) EV SOCs are subdued; clamping is extensive, reaching 4 of 5 EVs clamped on Tuesday
- (Arrive/Depart) departing undercharged is common as is AFH charging.

V2-4.5.3 Data Tables Seq_2.1.2

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 4-4: 2.1.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,196	18,752	17,913	17,035	16,186	15,341	14,483	13,730
	27mpd	19,059	18,433	17,277	16,080	14,944	**13,806**	12,645	11,582
	38mpd	18,923	18,168	16,645	15,104	13,676	12,161	10,728	9,259
	49mpd	18,753	17,864	16,071	14,294	12,590	10,815	9,101	7,363

No broaches are detected.; the clamps are limiting overloads.

(Tables reordered due to page layout)

Table 4-5: 2.1.2 Difference: Per EV AFH N events (weekly average of away connects)

Difference 2.1.2 - 1.1.2

3. Diff EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	27mpd	0.01	0.01	0.0	0.0	0.0	0.0	0.03	0.04
	38mpd	0.04	0.05	0.04	0.04	0.05	0.06	0.07	0.14
	49mpd	0.07	0.06	0.06	0.06	0.06	0.10	0.16	0.28

These counts show the driver is not noticeably plugging in AFH more often, when experiencing clamps.

Table 4-6: 2.1.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.4	1.5	1.5	1.5	1.5	1.6	1.6	1.6
	27mpd	2.1	2.1	2.2	2.1	2.2	2.2	2.3	2.6
	38mpd	2.7	2.8	2.9	2.9	2.9	3.1	3.5	4.6
	49mpd	3.3	3.4	3.5	3.5	3.5	4.0	4.9	6.3

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 4-7: 2.1.2 Difference: Dumb vs Dumb+Clamped per EV AFH kWh (weekly averages)

		N EV	10	20	40	60	80	100	120	140
Seq_1.1.2	**2. A Dumb AFH kWh**	19mpd	2.7	3.1	3.3	3.3	3.4	3.6	3.6	3.6
		27mpd	6.9	8.0	7.8	8.0	8.4	8.3	8.3	8.1
		38mpd	17.6	17.3	17.9	18.5	18.2	18.5	18.5	18.5
		49mpd	35.5	33.0	31.5	31.3	31.1	30.8	31.2	31.2
Seq_2.1.2	**B Clampd AFH kWh**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.9	3.5	3.5	3.5	3.6	3.9	3.8	3.8
		27mpd	7.0	8.2	8.1	8.5	8.9	9.0	8.9	8.9
		38mpd	18.1	18.3	18.7	19.2	19.1	19.8	20.0	21.5
		49mpd	36.8	34.4	32.9	32.8	32.6	33.1	35.0	38.0
Difference B - A	**C Diff B - A**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.13	0.37	0.23	0.20	0.15	0.30	0.22	0.23
		27mpd	0.08	0.14	0.3	0.4	0.5	0.7	0.59	0.86
		38mpd	0.50	0.95	0.87	0.75	0.92	1.32	1.53	3.06
		49mpd	1.23	1.32	1.36	1.45	1.43	2.31	3.81	6.79

Average AFH charging Winter Seq_2.1.2 (top, A) vs. Summer Seq_2.1.2 (middle, B)

The EVs are acquiring more AFH charge as they cannot obtain kWh at home.

Table 4-8: 2.1.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0004	0.0005	0.0010	0.0007	0.0009	0.0013	0.0013	0.0013
	27mpd	0.0008	0.0010	0.0030	0.0038	0.0039	0.0039	0.0051	0.0104
	38mpd	0.0044	0.0053	0.0099	0.0101	0.0096	0.0168	0.0333	0.0979
	49mpd	0.0076	0.0064	0.0109	0.0113	0.0164	0.0437	0.1148	0.2430

(limit: < 0.007) being 50:50 chance of Once in a Decade

This is the downside of clamping; by being able to add more and more EVs, at some point undercharging and severe undercharging occur. Red highlights unacceptable values.

A severe undercharge is an EV departing knowing the trip cannot be completed e.g. “pushed home”, including “pushed out of driveway”. These are known to cause vociferous upset.

A “50:50 chanced of 1 severe undercharge per EV, per decade” was calculated (for 10 Winter weeks pa) and found the probability as 0.007; this is taken as a limiting value beyond which driver distress might be incurred. Red highlights unacceptable values.

Table 4-9: 2.1.2 MCS Clamps (weekly averages)

6. MCS Clamps	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd	239.7	344.7	541.1	742.4	977.0	1,278.7	1,630.7	2,089.8
	27mpd	246.7	370.6	591.8	855.7	1,199.3	1,659.6	2,211.8	2,866.7
	38mpd	254.7	389.1	655.8	1,010.4	1,495.7	2,138.8	2,816.1	3,499.8
	49mpd	260.7	401.5	697.6	1,132.3	1,726.2	2,472.4	3,166.9	3,787.1

(limit: < 420)

Clamping raises another problem; excessive use to manage levels rather than limit an emergency. It is thought likely (but no decision is reached) that Ofgem will penalise this; DNOs roles is to supply not curtail supply to customers. An arbitrary limit of roughly 2 hours a phase clamped a week over say 2.5 EVs gives about 420 clamp event limits (note this is an approximation and FPB in its present form cannot assess these stats easily).

This highlights a concern: How to rank clamps. Is this:

- per worst-case week (Winter), or
- spread over the year, or
- a nominal “average rate” with a cap of say x2 per week, for winter?

This suggests that clamping is perhaps both more complex and potentially more contentious (as clamps deny charge, which can cause undercharging) then suspected. The author suggests “worst case week” as this is simple to understand.

Table 4-10: 2.1.2 DRFFR Percent Effective Hours (weekly averages)

7. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	29.2%	30.4%	29.8%	33.9%	38.1%	42.3%	52.4%	62.5%
	27mpd	27.4%	28.6%	31.5%	36.9%	41.1%	52.4%	62.5%	73.2%
	38mpd	28.0%	31.0%	32.7%	40.5%	50.0%	58.3%	70.8%	81.5%
	49mpd	28.6%	30.4%	35.1%	42.3%	51.2%	63.1%	77.4%	82.7%

6.2.2 span: [73.8%] => [98.2%]

The measure here is Parson's r comparing the {rate of change between periods} of the DR/FFR signal vs. the observed change of the output. A score of 25% implies random. DR/FFR does though appear to operate well for the parity case and over.

Table 4-11: 2.1.2 Difference in LV Losses kWh (weekly averages)

Difference 2.1.2 - 1.1.2

8. Diff Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	-0.1	-3.3	-2.4	-8.1	-7.2	-19.4	-26.9	-44.0
	27mpd	-0.2	-1.9	-0.9	-8.6	-12.8	-28.9	-48.4	-81.0
	38mpd	-0.1	-0.4	-8.9	-7.5	-18.6	-38.5	-72.9	-137.8
	49mpd	-0.3	-0.6	-9.2	-15.4	-25.3	-59.7	-108.5	-196.2

The peak loss on this network equates to 2.6% at 520 kWh for 49mpd x 140 EVs. Losses are down compared to Seq_1.1.2.

V2-4.5.4 Seq_2.1.2 Summary

The distinction of Seq_2.1.2 from earlier sequences is the use of clamps. Clamps stop overloads, and are shown to be able to allow any number of EVs to be connected to a feeder and prohibit broaching. However as more vehicles are connected, the pro-rata energy drops and more AFH charging results as EVs leave home with insufficient charge.

Without further study into the measurement, use and acceptability of clamps to Ofgem all that can be stated is that:

a) as EV numbers and mpd duty rise, the number of clamps rise

b) as clamps rise undercharging rises.

The net feeder load for 2.1.2 control is shown in Figure 4-4. 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 then smoothed by applying a 1 hour rolling average i.e. for all periods from $pd = 10$ and up, the plots show values:

$$load_{hr} = 0.1 * \sum_{n=pd-10}^{n=pd} load_n \qquad (2)$$

Loads are shown compared to 5.1.2 results, with MCS but no DRFFR signal. To reduce visual clutter, Monday - Friday only are plotted for the parity (27mpd, 100 EVs) case.

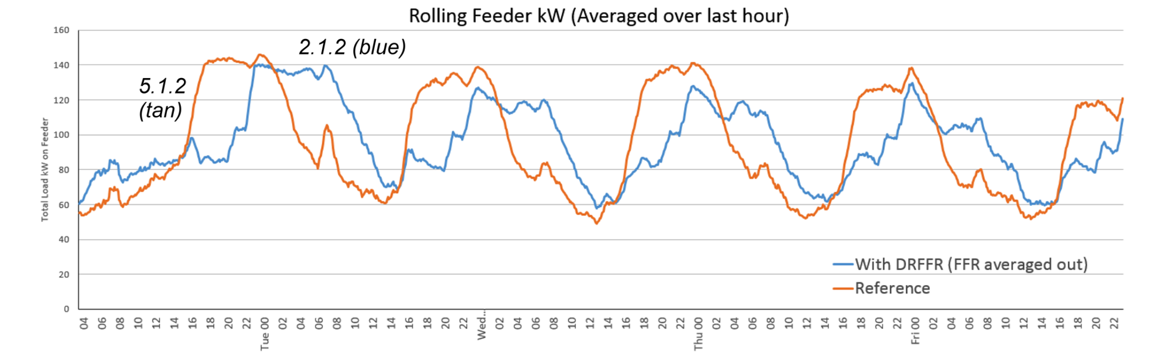


Figure 4-4: DRFFR defers Evening Charging to Overnight

DR steps and a resulting load timeshift are seen (tan plot is the reference, the blue plot is shifted later), with imposed DR outline becoming clearer for higher loads.

Note that by successfully removing incipient overloads, the clamp system has both protected the local network and provided a mechanism to offer DR/FFR.

Yet by using a control level set below the point of risk to assets, and then applying a DR/FFR regime, might this be viewed as an abuse of a protection system?

Further, by protecting its networks the DNO has introduced constraints on EV use.

It is likely that Ofgem will address these issues at some time.

V2-4.6 Sequence 2.1.2.8

Sequence	Simulation ID	Description
Seq_2.1.2.8	(S_BC)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, Alternative Tripsets
Baseline 2.1.2.9		*Used Default Tripsets*

Note the logical progression is more understandable if 2.1.2.9 is read first.

The 2.1.2.8 simulation uses mode C2 clamping strategy: “by equitable need”. The tripsets used are “DumbTypical” as against “DefaultTypical”, which was used in 2.1.2.9.

The purpose is to discover the effect of alternative sets of trips, to highlight any sensitivity due to using different batches of 500 simulations and, hopefully, where those arise.

Data is viewable in: MetaMeta2.3_Seq_2.1.2.8.xlsx

V2-4.6.1 Seq_2.1.2.8 Summary

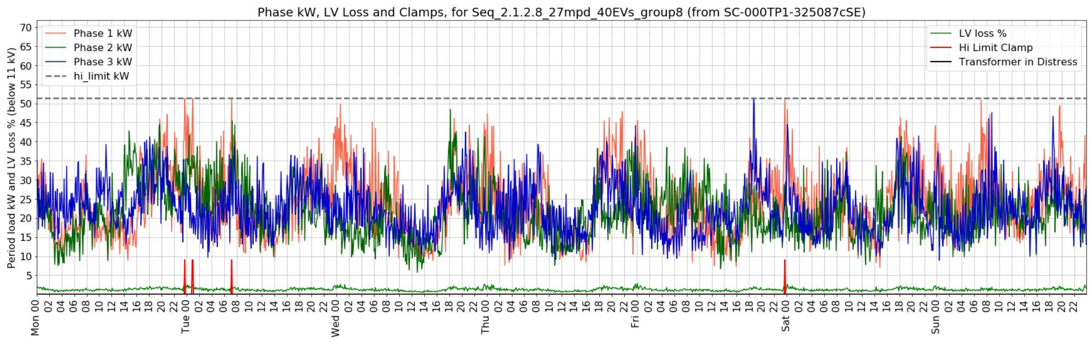
Some variation was seen for small populations, with the degree of variation falling as N EV exceeded 60. No consistent pattern emerged. The method used calculated a percentage and did produce apparently great variation when the denominator was near zero.

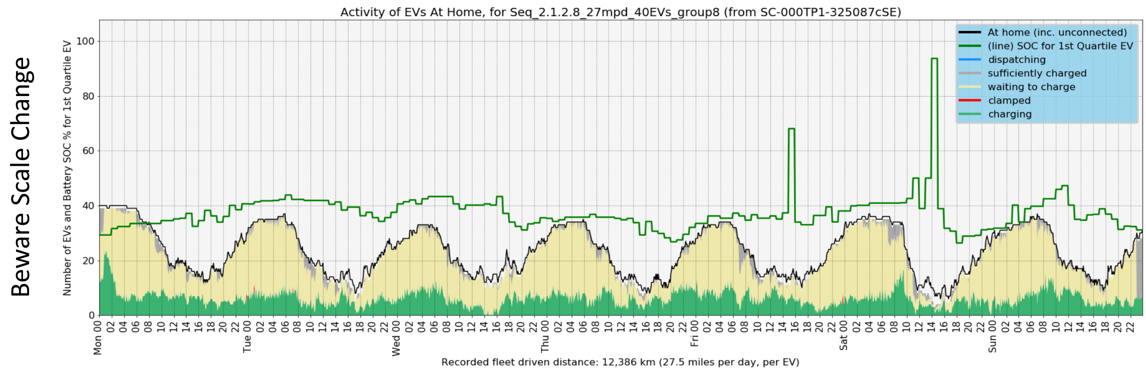
The author conclude that this variation was no cause for concern over particular characteristics of random sequence generation. The specific concern, that the default trips included bias (due to hidden cherry-picking) was not found.

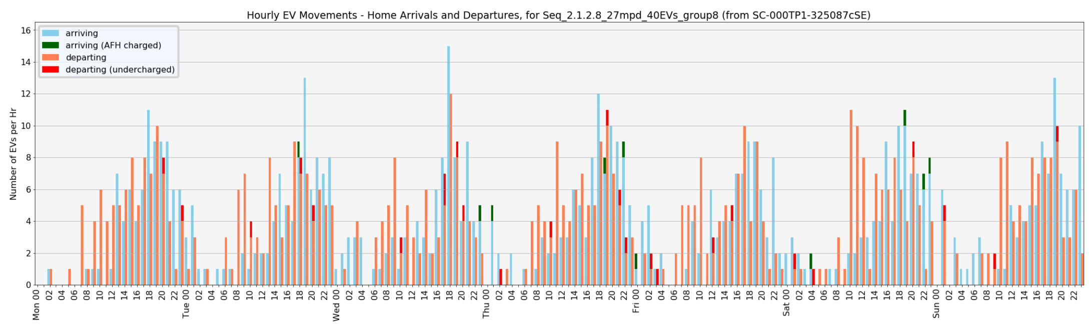
Note that all trips are legal and may arise spontaneously in real-life.

V2-4.6.2 Seq_2.1.2.8: Feeder and EV Plots

V2-4.6.2.1 Seq_2.1.2.8: 27mpd 40EVs







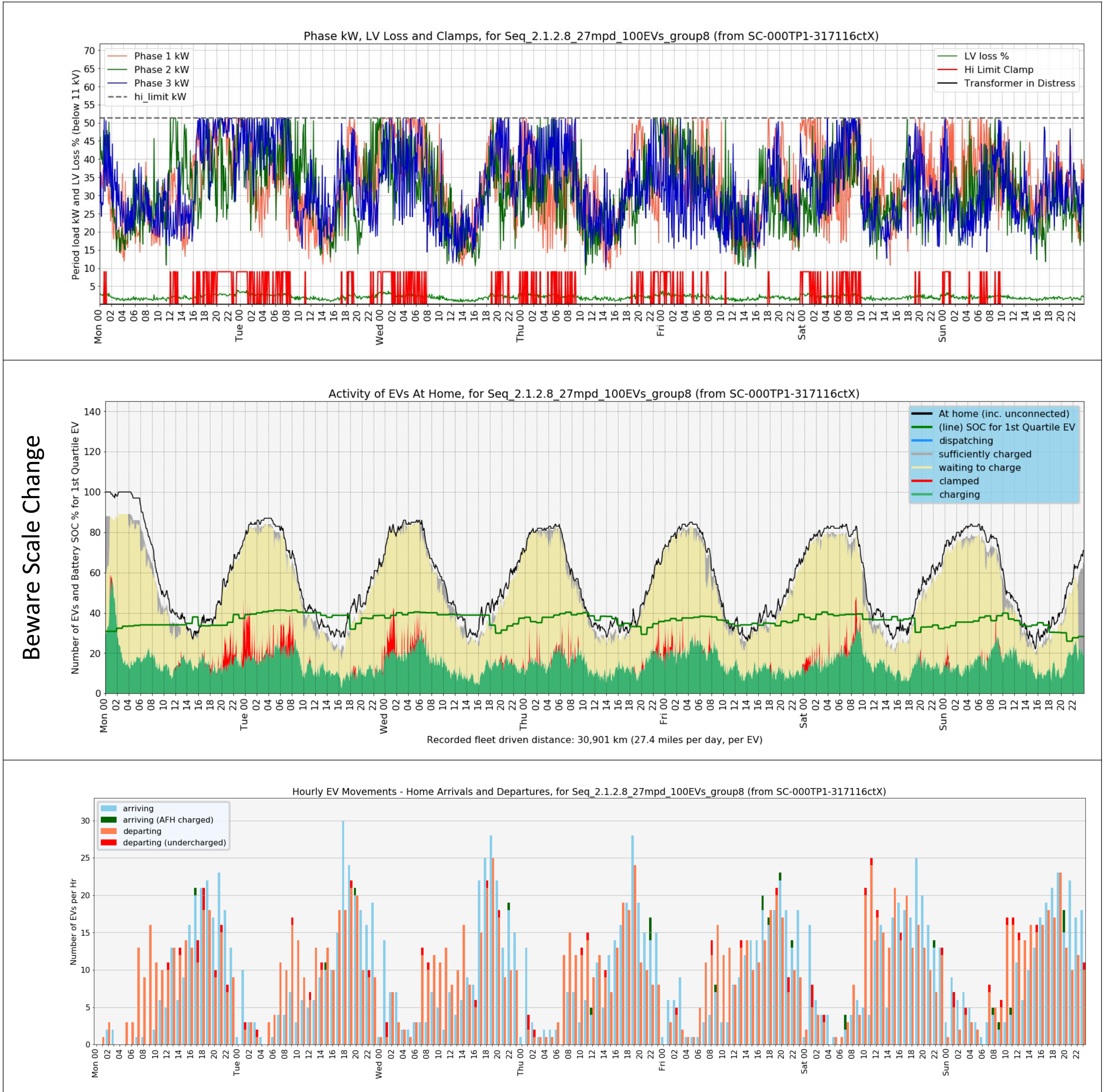
EoW stats: kWh[b]	EV total: 2,345	Home: 2,034	AFH: 311	V2G: 0

Figure 4-5: Seq_2.1.2.8 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,315

Notes re above plots:

- (Feeder) there is less clamping then in 2.1.2.9
- (CICD) EV SOC appears slightly down; the spike at c. 1pm Saturday has caused a scale change;
- (Arrive/Depart) overall marginally better than 2.1.2.9.

V2-4.6.2.2 Seq_2.1.2.8: 27mpd 100EVs



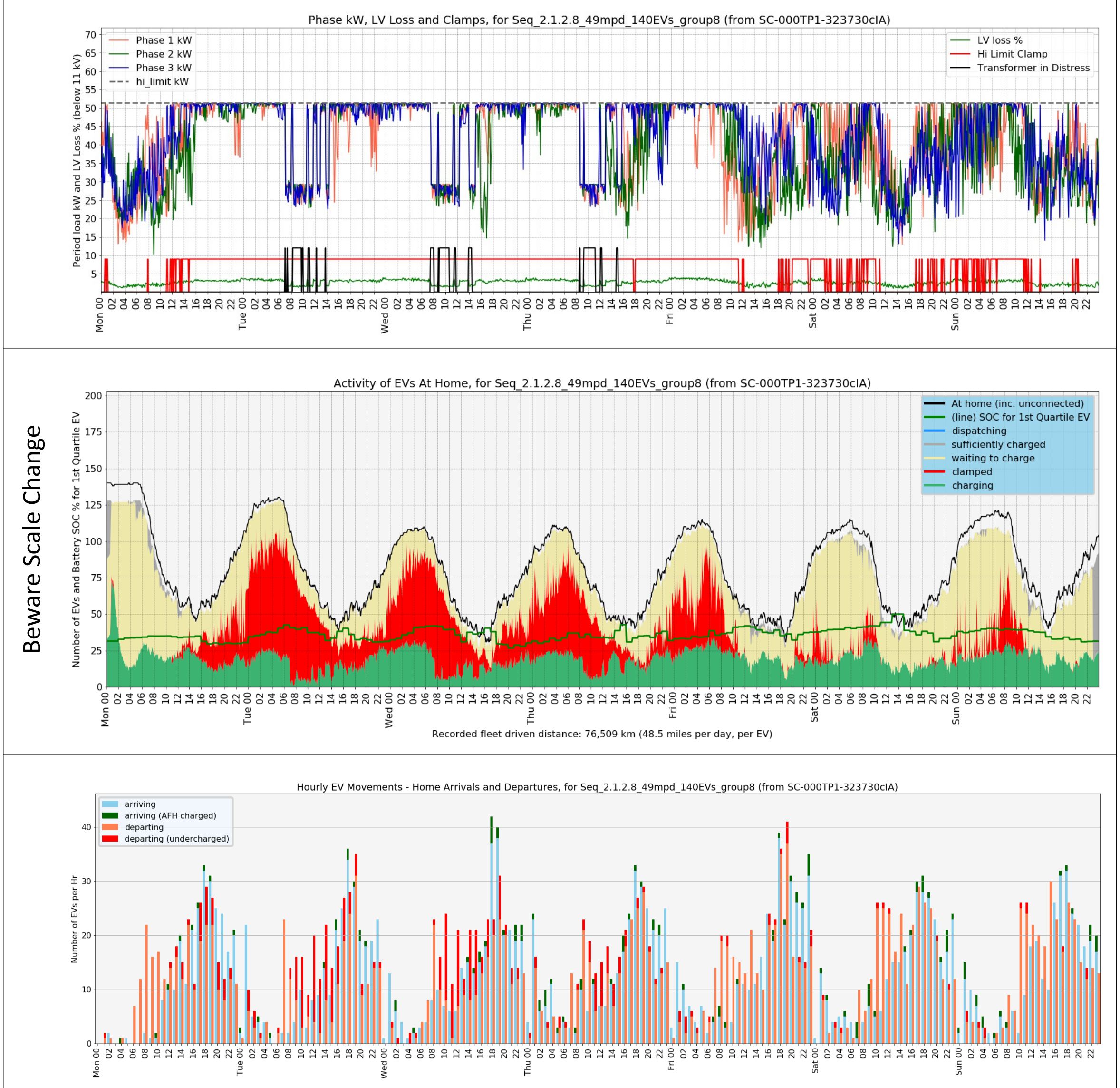
EoW stats: kWh[b] EV total: 5,925 Home: 5,094 AFH: 831 V2G: 0

Figure 4-6: Seq_2.1.2.8 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,988

Notes re above plots:

- these plots are all comparable to those in 2.1.2.9 with no untoward events seen.

V2-4.6.2.3 Seq_2.1.2.8: 49mpd 140EVs



EoW stats: kWh[b] EV total: 16,524 Home: 8,773 AFH: 4,751 V2G: 0

Figure 4-7: Seq_2.1.2.8 49mpd 140EVs group 8 plots. Weekly fleet km: 77,227

Notes re above plots:

- these plots are again very similar in nature to those in 2.1.2.9.

V2-4.6.3 Data Tables Seq_2.1.2.8

Data is from spreadsheet "MetaMeta2.3_Seq_2.1.2.8.xlsx".

The analysis wishes to look at the impact of using a different randomised tripset, by comparing percent changes by ply cell. The calculation formula was:

$$spreadsheet\ cell\ value\,\% = 100 * (value\,2.1.2.8 - value\,2.1.2.9) / value\,2.1.2.9$$

which on sheet "Percent (Meta-Ref)" gives usually under 1% (the electricals being often under 0.1% different). However the EV results are higher, for example:

Table 4-12: Percent cell value difference 2.1.2.8 vs. 2.1.2.9

158		EV Stats TWO	N EV	10	20	40	60	80	100	120	140	0
159	19mpd	av n EV_undercharged	19mpd	4.57%	0.78%	-0.02%	0.38%	-0.04%	-0.33%	0.34%	0.80%	19mpd
160	27mpd	0	27mpd	0.36%	2.44%	0.02%	1.48%	0.55%	-0.93%	1.05%	1.12%	27mpd
161	38mpd	0	38mpd	1.56%	-0.64%	0.85%	0.41%	-0.01%	-0.47%	0.92%	1.60%	38mpd
162	49mpd	0	49mpd	-0.67%	-0.26%	-0.24%	0.34%	0.16%	-0.51%	-0.26%	-0.14%	49mpd
163												
164	19mpd	90th %tile undercharges	19mpd	10.53%	0.00%	-2.84%	0.11%	1.52%	-1.21%	1.60%	-0.46%	19mpd
165	27mpd	0	49mpd	3.85%	1.96%	-2.08%	1.52%	-0.58%	-2.32%	2.41%	0.68%	27mpd
166	38mpd	0	38mpd	0.00%	0.16%	0.85%	-0.59%	-0.91%	0.04%	1.15%	2.02%	38mpd
167	49mpd	0	49mpd	0.00%	0.00%	-1.36%	0.97%	0.00%	0.00%	-0.87%	0.12%	49mpd
168												
169	19mpd	av undercharges per EV	19mpd	4.57%	0.78%	-0.02%	0.38%	-0.04%	-0.33%	0.34%	0.80%	19mpd
170	27mpd	in week	27mpd	0.36%	2.44%	0.02%	1.48%	0.55%	-0.93%	1.05%	1.12%	27mpd
171	38mpd	0	38mpd	1.56%	-0.64%	0.85%	0.41%	-0.01%	-0.47%	0.92%	1.60%	38mpd
172	49mpd	0	49mpd	-0.67%	-0.26%	-0.24%	0.34%	0.16%	-0.51%	-0.26%	-0.14%	49mpd
173												
174	19mpd	av undercharged on disconnect	19mpd	4.28%	0.80%	-0.11%	0.27%	0.02%	-0.32%	0.36%	0.78%	19mpd
175	27mpd	0	27mpd	0.31%	2.34%	0.04%	1.50%	0.49%	-1.02%	0.93%	0.96%	27mpd
176	38mpd	0	38mpd	1.51%	-0.70%	0.65%	0.39%	-0.05%	-0.49%	0.74%	1.43%	38mpd
177	49mpd	0	49mpd	-0.70%	-0.42%	-0.35%	0.18%	0.14%	-0.52%	-0.34%	-0.18%	49mpd
178												
179	19mpd	av n EV_must_rechg_to_finish_trip	19mpd	100.00%	0.00%	-66.67%	14.29%	14.29%	228.57%	0.00%	31.58%	19mpd
180	27mpd	0	27mpd	100.00%	0.00%	45.45%	-6.06%	-7.69%	-1.89%	-6.45%	-4.65%	27mpd
181	38mpd	0	38mpd	-33.33%	14.29%	-23.21%	-21.78%	16.50%	0.59%	1.50%	2.86%	38mpd
182	49mpd	0	49mpd	43.75%	44.44%	-11.11%	12.80%	-0.47%	-11.20%	-3.37%	-0.98%	49mpd

It is observed is that, apart from occasional high values, difference are low and tend to be: highest % difference for small N EV, lowest for high N EV. This is consistent with variability in large populations (e.g. 140 EVs) being lower than small populations (e.g. 10 EVs).

The occasional high values (e.g. row 179, column 100 N EV) were found to arise from situations with denominator cell value (the 2.1.2.9 data) very low i.e. this is a calculation artefact, caused by a low denominator.

The electrical systems and any control algorithms need to cope with extreme ranges of input. Given the predominance of low changes in results, the author concludes that there is no substantive difference due to using alternative tripsets. Note that all drivable tripsets are (by definition) legal, although with perhaps varying "typicality".

V2-4.7 Sequence 2.1.2.9

Sequence	Simulation ID	Description
Seq_2.1.2.9	(S_93r)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, normal plugin regime
Baseline: *2.1.2*		*Difference vs. Baseline: 2.1.2.9 has **no** DR/FFR*

The simulation uses mode 2 clamping strategy: “by ranked need”. This sequence investigates: Does DR/FFR affect clamps? The clamping system remains active but the hi_limit modulation by DR/FFR is removed.

Note that Seq_2.1.2.8 will follow; this arrangement so to present in logical order (there is one degree of change from 2.1.2 => 2.1.2.9, then another from 2.1.2.9 => 2.1.2.8).

Data is viewable in: MetaMeta2.3_Seq_2.1.2.9.xlsx

V2-4.7.1 Seq_2.1.2.9 Summary

Table 4-13: 2.1.2.9 Overall Usable EV Bands

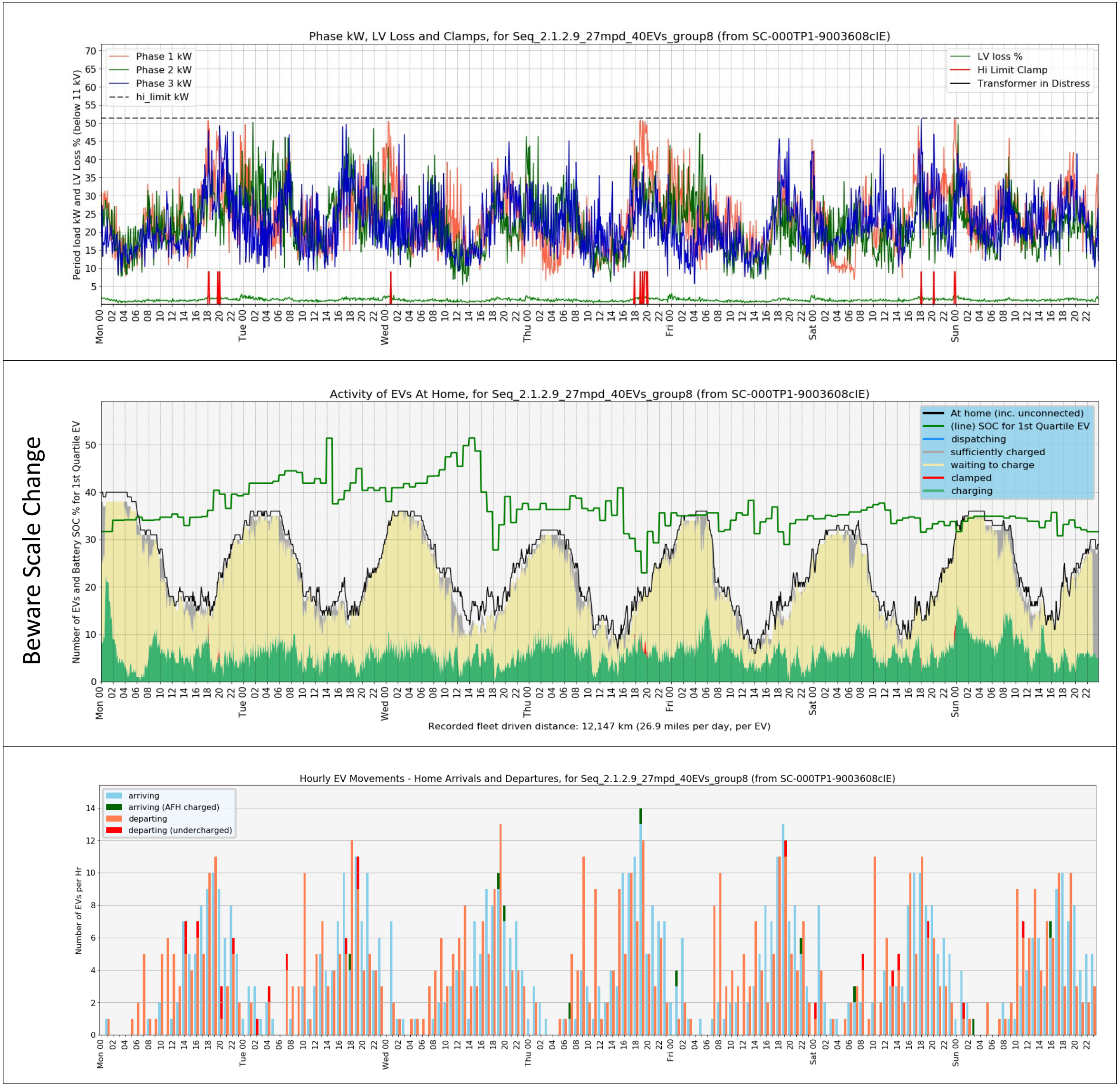
7. Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd								C
	27mpd							C	C
	38mpd						C	C	CS
	49mpd					C	CS	CS	CS

C: clamping limit exceeded; S: severe undercharging encountered. Light green shows plies available in 2.1.2.9 which were not in 2.1.2. The message coming from this is that DR/FFR raises both EV severe undercharging and clamp counts, with the primary cause likely being the DR element.

However it has been demonstrated that DR can reduce total load.

V2-4.7.2 Seq_2.1.2.9: Feeder and EV Plots

V2-4.7.2.1 Seq_2.1.2.9: 27mpd 40EVs



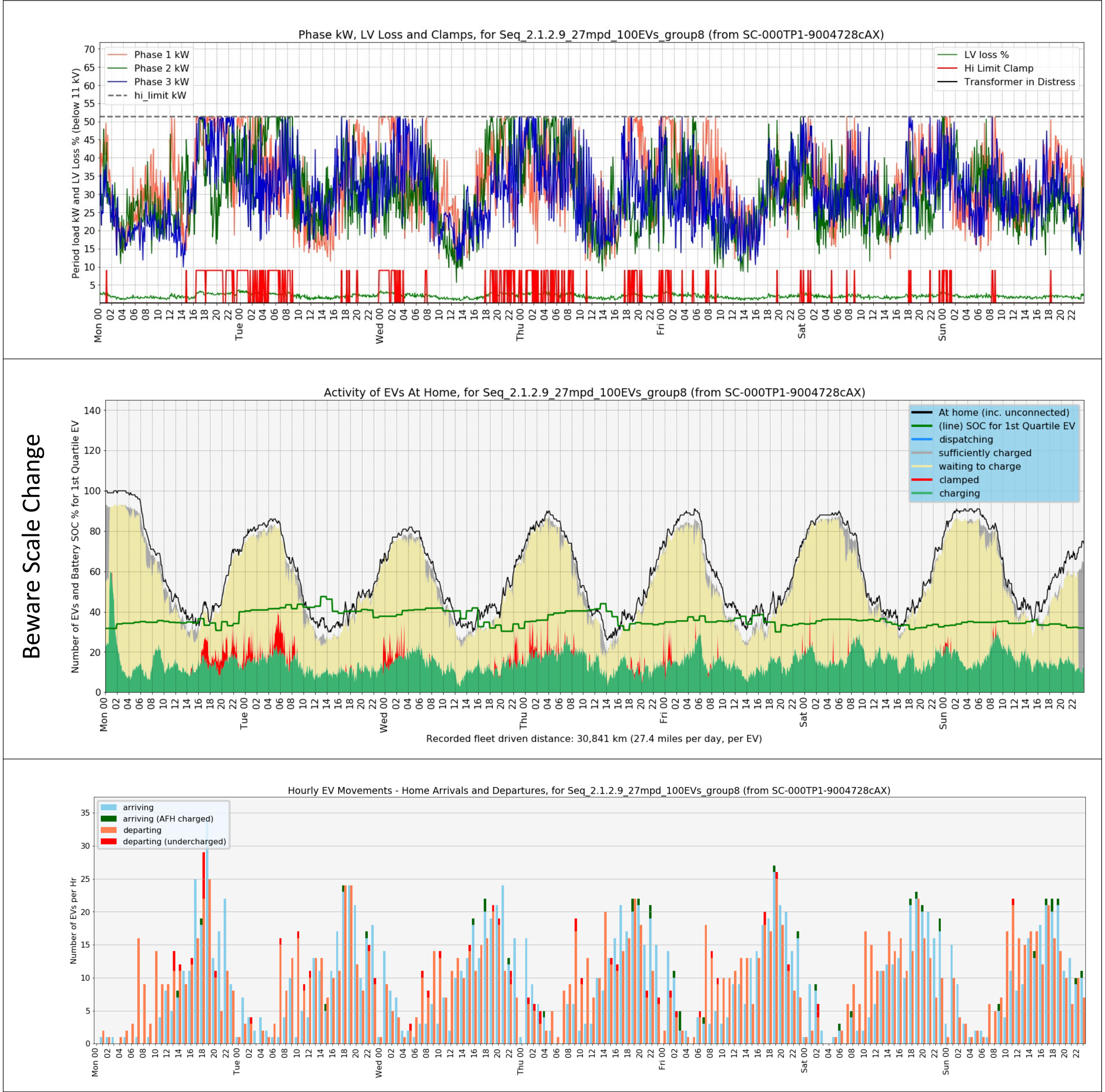
EoW stats: kWh[b] EV total: 2,330 Home: 2,023 AFH: 307 V2G: 0

Figure 4-8: Seq_2.1.2.9 27mpd 40 EVs group 8 plots. Weekly fleet km: 12,212

Notes re above plots:

- (Feeder) there is much less clamping occurring vs. corresponding 2.1.2 plots
- (CICD) there is little sign of grey (EVs finished charging)
- (Arrive/Depart) there are occasional departs undercharged and use of AFH.

V2-4.7.2.2 Seq_2.1.2.9: 27mpd 100EVs



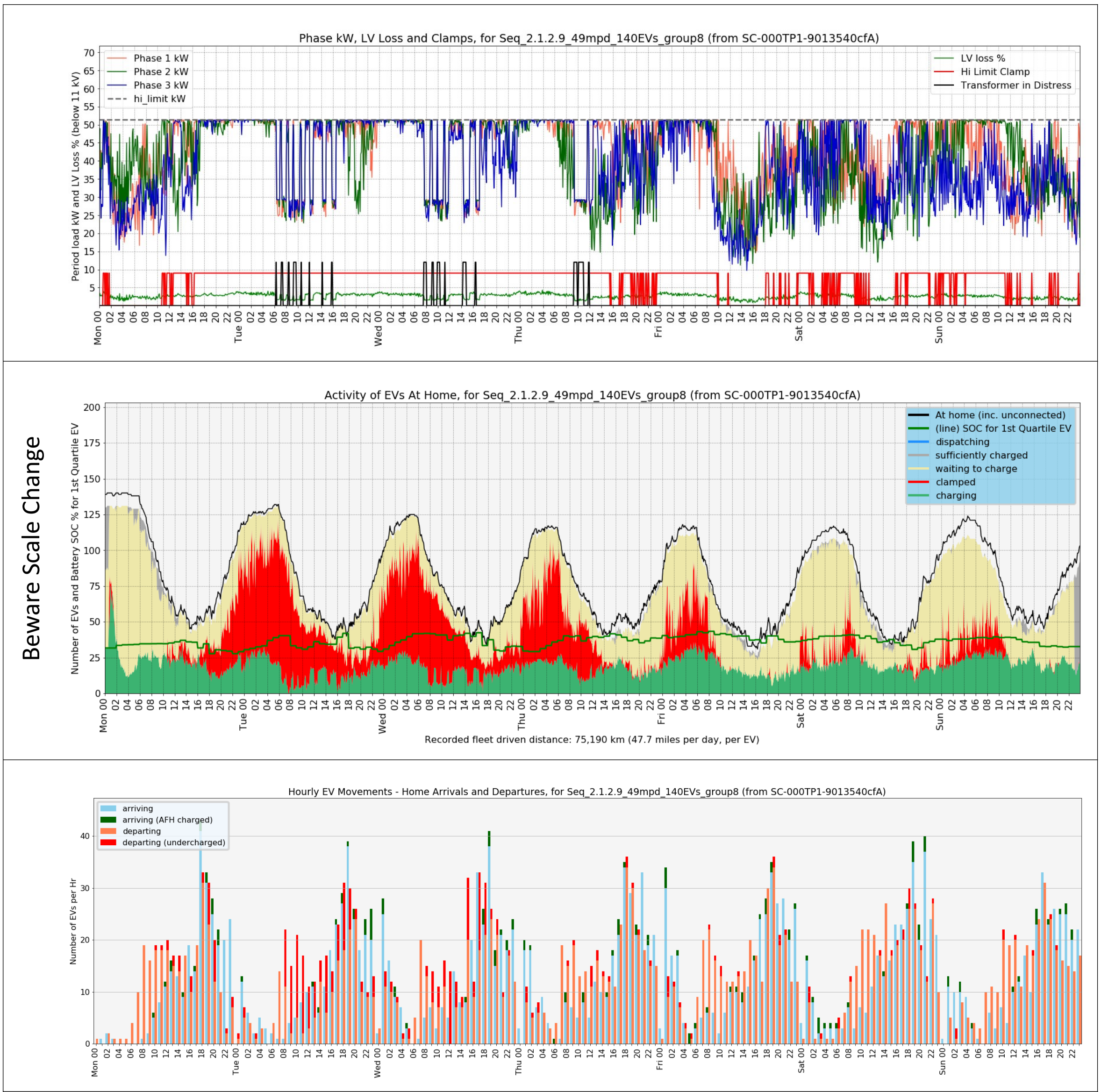
EoW stats: kWh[b]	EV total: 5,902	Home: 5,058	AFH: 844	V2G: 0

Figure 4-9: Seq_2.1.2.9 27mpd 100 EVs group 8 plots. Weekly fleet km: 30,876

Notes re above plots:

- (Feeder) there appears potential for broaches but these are clamped
- (CICD) EV SOC appears slightly down; clamps are beginning to appear
- (Arrive/Depart) increasing numbers of EVs depart undercharged
- other than a reduction in clamping, these plots are very similar to 2.1.2.

V2-4.7.2.3 Seq_2.1.2.9: 49mpd 140EVs



EoW stats: kWh[b] EV total: 9,457 Home: 8,118 AFH: 1,339 V2G: 0

Figure 4-10: Seq_2.1.2.9 49mpd 140EVs group 8 plots. Weekly fleet km: 77,276

Notes re above plots:

- (Feeder) clamps (both hi_limit and transformer) are now endemic, with transformer clamps visible which were not present in 2.1.2
- (CICD) EV SOCs remain similar; there are many clamps but less than 2.1.2
- (Arrive/Depart) there is a noticeable rise in departs undercharging and AFH.

V2-4.7.3 Data Tables Seq_2.1.2.9

The parity case (average mpd with 1:1 household EV penetration) is in yellow and the lower RH corner being grey, as visual references. Red indicates a fail for some reason.

Table 4-14: 2.1.2.9 Unused kWh (weekly averages)

1. Unused kWh	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*

Note: Transformer clamping creates periods in which recorded kWh is not sensible; such plies have ***italic red text***.

Table 4-15: 2.1.2.9 EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.7	3.3	3.3	3.3	3.4	3.6	3.5	3.5
	27mpd	6.6	7.7	7.7	8.0	8.4	8.4	8.3	8.2
	38mpd	17.3	17.5	17.8	18.4	18.2	18.6	18.5	19.1
	49mpd	35.5	33.2	31.7	31.5	31.1	31.1	32.2	34.1

Inspecting “Meta - Ref” sheet in MetaMeta2.3_Seq_2.1.2.9.xlsx” shows that these values are down on 2.1.2 AFH kWh.

Table 4-16: 2.1.2.9 Per EV N AFH (count of away connects, weekly averages)

3. EV N AFH	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	0.29	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

These counts are down vs. 2.1.2, by about 10% in the parity case.

Table 4-17: 2.1.2.9 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	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

Here, an undercharge is any EV departing with SOC < (depart target SOC - 5%).

Table 4-18: 2.1.2.9 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0002	0.0003	0.0003	0.0002	0.0002	0.0001	0.0003	0.0003
	27mpd	0.0002	0.0006	0.0006	0.0011	0.0013	0.0011	0.0010	0.0012
	38mpd	0.0006	0.0021	0.0028	0.0034	0.0026	0.0034	0.0067	0.0325
	49mpd	0.0032	0.0027	0.0050	0.0042	0.0053	0.0079	0.0396	0.1372

(limit: < 0.007)

These values are substantially down vs. 2.1.2, with 9 light green indicating improved plies vs. 2.1.2. Red highlights unacceptable values.

It is noticeable that the DR element of the control modulation in 2.1.2's 27mpd 40 EVs (4.5.2.1) was provoking clamps, whereas clamps are now less prominent in the corresponding figure for 2.1.2.9.

Table 4-19: 2.1.2.9 MCS Clamps (weekly averages)

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0.3	1.0	6.1	23.6	72.6	180.6	335.3	590.8
	27mpd	0.3	1.5	12.2	53.6	161.4	380.0	703.6	1,222.8
	38mpd	0.4	1.9	22.0	100.9	299.5	702.4	1,265.5	2,074.7
	49mpd	0.5	2.6	30.1	150.8	449.8	1,004.7	1,760.4	2,651.9

2.1.2 span: [1,660] => [3,787] (limit: < 420)

Clamps are down vs. 2.1.2, with 14 overall extra plies usable. Light green indicates improved plies. Red highlights unacceptable values.

V2-4.8 Sequence 2.2.2 (in summary)

Sequence	Simulation ID	Description
Seq_2.2.2	(S_A3)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (1), pre-burn_V2G OFF, hi_limit 51.3 kW, DR-B / FFR
Baseline 2.1.2		*2.1.2 uses clamp mode (2); 2.2.2 uses "mimic MEA" clamp mode (1): By uniform kWh delivered.*

The purpose of this sequence is to determine if the clamping prioritisation method effects EV charging outcomes. The clamping protocol only is varied:

- 2.2.2 uses mode (1), EVs are offered the same kWh, but is otherwise identical to:
- 2.1.2 used mode (2); EVs are offered kWh by relative (equitable) need.

The expectation is that the simulations will be nearly identical, other than 2.2.2 will have somewhat more severely undercharged EVs.

Note EVs in 2.2.2 which choose to not consume further kWh drop out of the "wants to charge" priority queue. This self de-selection is unseen by the MCS, effectively allowing the prioritisation system to focus only on those EVs accepting charge.

Table 4-20: Impact of Clamp Prioritisation Mode (1 stats - 2 stats)

235			N_EV=	10	20	40	60	80	100	120	140	
236	19mpd	**AFH kWh charged per EV in week**	19mpd	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.4	19mpd
237	27mpd		27mpd	0.0	0.0	0.1	0.1	0.3	0.5	1.0	1.8	27mpd
238	38mpd		38mpd	0.0	0.1	0.2	0.3	0.6	1.4	2.3	3.2	38mpd
239	49mpd		49mpd	0.0	0.1	0.2	0.5	1.2	2.4	3.2	3.3	49mpd
240												
241			N_EV=	10	20	40	60	80	100	120	140	
242	19mpd	**Severe Undercharges per EV in Week**	19mpd	0.0000	0.0000	0.0003	0.0015	0.0018	0.0036	0.0056	0.0106	19mpd
243	27mpd		27mpd	0.0000	0.0001	0.0013	0.0049	0.0085	0.0139	0.0275	0.0490	27mpd
244	38mpd		38mpd	0.0006	-0.0001	0.0048	0.0060	0.0143	0.0363	0.0575	0.0687	38mpd
245	49mpd		49mpd	0.0004	0.0013	0.0063	0.0154	0.0367	0.0709	0.0755	0.0542	49mpd

The “Meta - Reference” sheet in “MetaMeta2.3_Seq_2.2.2.xlsx” shows the difference between 2.2.2 (mode 1) less 2.1.2 (mode 2). Severe undercharging in 2.2.2 has risen due to use of mode 1 (non-equitable kW allocation). Also, AFH kWh drawn per EV rises, presumably to replace the home-unavailable kWh.

Clamps are within 10% with no plys lost, but due to the limit on severe undercharging of <= 0.007 per EV per week, a further ply is lost to 2.2.2 which was acceptable in 2.1.2:

Table 4-21: 2.2.2 Overall Usable EV Bands

0. Overall Usable Plies	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd			C	C	C	C	C	**CS**
	27mpd			C	**CS**	**CS**	**CS**	**CS**	**CS**
	38mpd			**CS**	**CS**	**CS**	**CS**	**CS**	**CS**
	49mpd		**S**	**CS**	**CS**	**CS**	**CS**	**CS**	**CS**

C: clamping limit exceeded; S: severe undercharging encountered.

Darker red is a ply cell lost vs. 2.1.2, larger underscored S marks plys now with elevated severe undercharging, such that the 0.007 limit is exceeded.

V2-4.9 Sequence 2.3.2 (in summary)

Sequence	**Simulation ID**	**Description**
Seq_2.3.2	(S_A8)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, DR-B / FFR Home Perfect Plugins
Baseline 2.1.2		*In 2.3.2 EVs are forced to plug in on arriving home i.e. "home perfect plugins"*

This sequence is part of a set exploring the impact of driver plugin behaviour. In 2.3.2, plugins on arriving home are forced. See also 2.5.2 which forced both home and away perfect plugins.

Table 4-22: Impact of Home Perfect Plugins

19mpd	**AFH kWh charged per EV in week**	19mpd	0.00	-0.02	-0.02	-0.02	-0.01	-0.02	-0.02	-0.02	19mpd
27mpd		27mpd	0.00	-0.02	0.0	0.0	0.0	0.0	-0.02	-0.04	27mpd
38mpd		38mpd	-0.01	0.00	-0.03	-0.04	-0.04	-0.07	-0.07	-0.10	38mpd
49mpd		49mpd	-0.01	-0.04	-0.04	-0.05	-0.05	-0.09	-0.10	-0.12	49mpd
		N_EV=	10	20	40	60	80	100	120	140	
19mpd	**Severe Undercharges per EV in Week**	19mpd	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	19mpd
27mpd		27mpd	0.0000	0.0000	-0.0001	0.0000	0.0000	-0.0001	-0.0002	-0.0009	27mpd
38mpd		38mpd	-0.0002	0.0000	-0.0002	0.0000	0.0001	-0.0006	-0.0017	-0.0025	38mpd
49mpd		49mpd	0.0000	0.0000	-0.0001	-0.0002	-0.0001	-0.0011	-0.0017	-0.0025	49mpd

The "Meta - Reference" sheet in "MetaMeta2.3_Seq_2.3.2.xlsx" shows the difference between 2.3.2 and 2.1.2 to be: **almost nothing.**

There is a small improvement (drop) from N EV = 100. This result encouraged the author to investigate what is happening. Answer: EVs are routinely sufficiently depleted as to cause the driver to often plugin on arriving home (for the parity case: for 2.1.2, 14.5 times a week per EV vs. 2.3.2's 16.9 times); the net effect of ensuring home plugin was marginal. No extra plies have been gained.

V2-4.10 Sequence 2.3.2.1 (in summary)

Sequence	Simulation ID	Description
Seq_2.3.2.1	(S_B7)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, DR-B / FFR, 3 static batteries per phase, Winter PV (2 kW per house)
Baseline 2.1.2		*In 2.3.2.1 sets of V2G EVs are configured to behave as local static batteries, hosted at the head, midpoint and end of the feeder.*

This sequence is part of a set on combining PV panels and local energy stores.

Unfortunately, PV panels have output during times commuting EVs are away, with useful energy in Winter from c. 9am - 3pm. 9 V2G EVs (3 per phase) mimic fixed local energy stores operating on the LV system i.e. household PV solar panels. The V2G EV profiles have been amended such as they go on no trips, they charge last and dispatch first.

PV data is historic data from 2013-03-11: https://www.solar.sheffield.ac.uk/pvlive/ for the correct week in question, injected as suitable negative load via the scenario Bias.csv file, scaled for 4 kW of PV on every other house i.e. 2 kW per house.

Data are from spreadsheet “MetaMeta2.3_Seq_2.3.2.1.xlsx”.

Interestingly, the simulator is seeing power export and network over-volts, a topic often raised with industry sources who are struggling to fine a simple cure; see Table 4-23.

Table 4-23: Average Weekly Hours Over-Volts

82			N EV	10	20	40	60	80	100	120	140
83	19mpd	**est. n_hrs per week overvolts**	19mpd	9.35	9.00	7.56	6.03	4.54	2.97	1.76	0.92
84	27mpd		27mpd	9.30	8.95	7.04	5.56	3.92	1.88	0.92	0.32
85	38mpd		38mpd	9.18	8.67	6.76	4.61	2.62	1.10	0.27	0.01
86	49mpd		49mpd	9.07	8.56	6.40	4.58	2.66	0.86	0.08	0.00

Table 4-24: Impact of 3 Static Batteries per Phase (27mpd 100 EVs)

Seq_2.1.2	EoW stats: kWh[b]	EV total: 5,912	Home: 5,014	AFH: 898
Seq_2.3.2.1	EoW stats: kWh[b]	EV total: 5,800	Home: 4,949	AFH: 851
Seq_2.3.2.1	plus kWh in	Static Batteries	Home: 765	*(estimated)*

247			N_EV=	10	20	40	60	80	100	120	140
248	19mpd	**V2G per EV**	19mpd	11.1	14.1	22.0	31.7	43.7	59.1	77.5	100.9
249	27mpd		27mpd	11.3	14.7	23.5	35.4	51.5	73.3	101.4	135.2
250	38mpd		38mpd	11.5	15.4	25.8	40.6	61.9	93.4	128.6	167.4
251	49mpd		49mpd	11.9	15.8	27.0	44.6	71.2	107.8	145.3	184.5

kWh exported (dispatched) from the Static Batteries

.

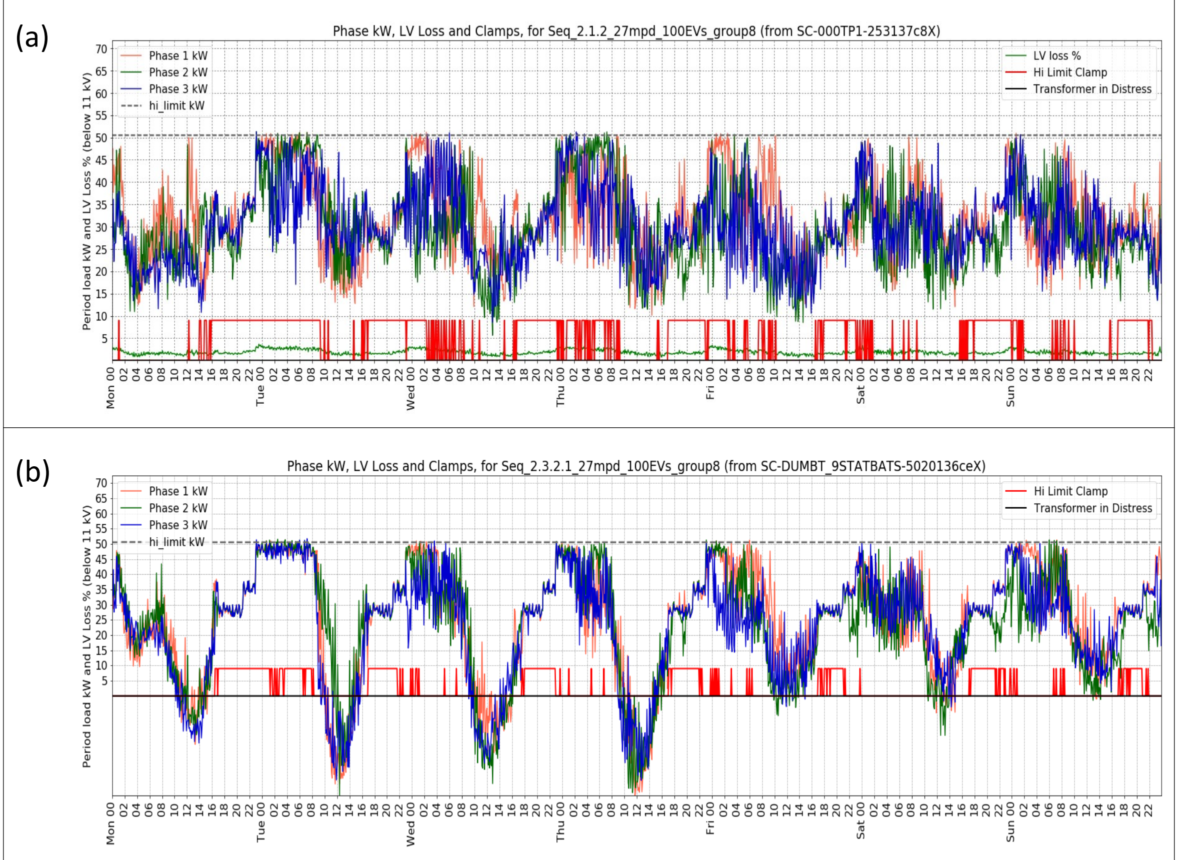


Figure 4-11: Feeder Seq_2.1.2 vs Seq_2.3.2.1 (27mpd 100 EVs group 8 plot)

Notes re Feeder plots:

- (a): 2.1.2 baseline
- (b): 2.3.2.1; the PV panels force power backflow mid-day as there is insufficient local demand.

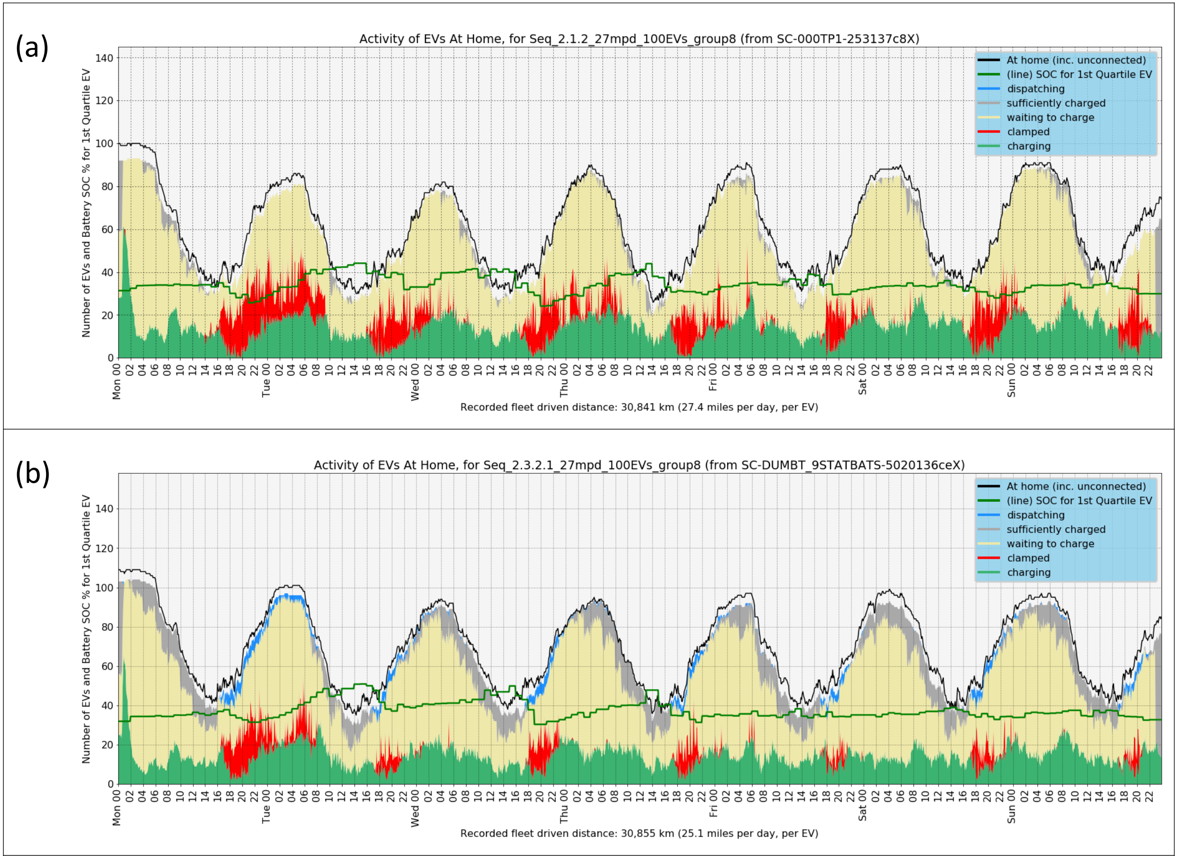


Figure 4-12: CICD plot Seq_2.1.2 vs Seq_2.3.2.1 (27mpd 100 EVs group 8 plot)

Notes re CICD plots:

- (a): Seq_2.1.2 baseline
- (b): 2.3.2.1; there are slight differences in the CICD plots due to using EVs as static batteries, which also impacts return-home time randomiser output. As a result the profiles are close but not identical
  - blue is V2G / static battery power injection, seen exporting during the clamp periods, with other EVs charging (the static batteries are only shown once as either blue export, or green charging);
  - by eye there is clear reduction in clamping
  - far more EVs are completed charging (grey).

The “Meta-Ref” sheet in the MetaMeta2.3 spreadsheet for 2.3.2.1 shows the differences between 2.1.2 and 2.3.2.1:

Table 4-25: Impact of 3 Static Batteries per Phase (Clamp Counts)

87			N EV	10	20	40	60	80	100	120	140
88	19mpd	**av Mand clamps in week**	19mpd	59.0	99.0	197.1	313.6	452.6	624.6	824.0	1,087.3
89	27mpd	**Seq_2.3.2.1**	27mpd	64.7	113.0	229.6	377.0	568.4	819.7	1,142.8	1,542.1
90	38mpd		38mpd	68.5	125.9	271.4	459.6	718.7	1,107.2	1,534.8	2,019.9
91	49mpd		49mpd	74.7	132.6	294.0	521.8	864.3	1,330.6	1,804.0	2,308.0

88	19mpd	**av Mand clamps in week**	19mpd	-180.7	-245.7	-344.0	-428.8	-524.4	-654.1	-806.7	-1,002.5
89	27mpd	**Seq_2.3.2.1 - Seq_2.1.2**	27mpd	-181.9	-257.6	-362.2	-478.7	-630.9	-839.9	-1,069.0	-1,324.6
90	38mpd		38mpd	-186.2	-263.2	-384.4	-550.8	-777.0	-1,031.6	-1,281.3	-1,479.9
91	49mpd		49mpd	-186.0	-268.9	-403.7	-610.5	-861.8	-1,141.7	-1,362.9	-1,479.1

The PV + Static Batteries combination has halved clamps in 2.3.2.1 vs. 2.1.2. Clamps are still high, thought due to the use of DR/FFR, found in 2.1.2.9 to exacerbate clamp counts.

Table 4-26: Impact of 3 Static Batteries per Phase (Severe Undercharging)

241			N_EV=	10	20	40	60	80	100	120	140
242	19mpd	**Severe Undercharges per EV in Week**	19mpd	0.0000	0.0001	0.0004	0.0003	0.0003	0.0005	0.0007	0.0006
243	27mpd	**Seq_2.3.2.1**	27mpd	0.0004	0.0004	0.0007	0.0012	0.0013	0.0017	0.0014	0.0016
244	38mpd		38mpd	0.0018	0.0034	0.0046	0.0049	0.0050	0.0050	0.0053	0.0074
245	49mpd		49mpd	0.0048	0.0043	0.0061	0.0059	0.0078	0.0098	0.0119	0.0232

242	19mpd	**Severe Undercharges per EV in Week**	19mpd	-0.0004	-0.0004	-0.0006	-0.0004	-0.0006	-0.0008	-0.0006	-0.0008
243	27mpd	**Seq_2.3.2.1 - Seq_2.1.2**	27mpd	-0.0004	-0.0006	-0.0023	-0.0026	-0.0027	-0.0022	-0.0038	-0.0088
244	38mpd		38mpd	-0.0026	-0.0019	-0.0053	-0.0052	-0.0046	-0.0118	-0.0280	-0.0905
245	49mpd		49mpd	-0.0028	-0.0021	-0.0048	-0.0054	-0.0087	-0.0339	-0.1030	-0.2199

An improvement in severe undercharging is observed; 2.3.2.1 has gained plies excluded for this reason vs. plies excluded in 2.1.2, however excess clamps still keeps the plies unacceptable.

Table 4-27: 2.3.2.1 Overall Usable EV Bands

7. Overall Usable	N EV	10	20	40	60	80	100	120	140
	19mpd			(c)	(c)	C	C	C	C
	27mpd			(c)	(c)	C	C	C	C
	38mpd			(s)	C	C	C (s)	C (s)	CS
	49mpd			(s)	C (s)	CS	CS	CS	CS

Light green: gain by 2.3.2.1 vs. 2.1.2, red fail due to C: excessive clamps, S: excessive severe undercharging. Gains over 2.1.2: improved severe undercharging: (c), (s)

Batteries and PV can reduce losses, but V2G incurs losses. Did these come from the network or from the PV? What do Ofgem opine about local storage losses? The table below shows the network losses have improved at the parity case by 66 kWh, at 198 kWh detriment from V2G losses; power that might have been usable elsewhere, but not practical without local storage:

Table 4-28: Impact of 3 Static Batteries per Phase (losses)

48	19mpd	weekly network loss kWh	19mpd	-37.7	-40.7	-48.2	-48.9	-58.4	-61.3	-66.7	-70.2	19mpd	weekly network loss kWh
49	27mpd	0	27mpd	-37.5	-44.7	-43.2	-49.8	-59.9	-65.8	-69.0	-68.0	27mpd	(Positive: Meta is Bigger)
50	38mpd	0	38mpd	-37.4	-45.2	-41.5	-52.5	-59.9	-65.1	-66.6	-60.9	38mpd	0.00
51	49mpd	0	49mpd	-37.2	-43.6	-44.6	-49.6	-58.6	-63.9	-62.1	-43.1	49mpd	0.00
52													
53	19mpd	weekly estimated V2G loss kWh	19mpd	30.0	38.1	59.5	85.7	118.0	159.7	209.3	272.5	19mpd	weekly estimated V2G loss kWh
54	27mpd	0	27mpd	30.5	39.8	63.6	95.5	138.9	198.0	273.8	365.1	27mpd	(Positive: Meta is Bigger)
55	38mpd	0	38mpd	31.2	41.6	69.7	109.5	167.2	252.2	347.3	451.9	38mpd	0.00
56	49mpd	0	49mpd	32.1	42.6	72.8	120.3	192.4	291.2	392.3	498.2	49mpd	0.00

V2-4.11 Sequence 2.4.2 (in summary)

Seq_2.4.2 was a mode 1 clamping version of 2.3.2 and has no different results.

V2-4.12 Sequence 2.5.2 (in summary)

Sequence	**Simulation ID**	**Description**
Seq_2.5.2	(S_A7)	Winter, NEV, mpd sets, all dumb EVs, clamps ON (2), pre-burn_V2G OFF, hi_limit 51.3 kW, DR-B / FFR, All Perfect Plugins (Home and Away)
Baseline 2.1.2		*In 2.5.2 EVs are forced to plug in when ever they can, both Home and Away*

This sequence is part of a set exploring the impact of driver plugin behaviour. In 2.5.2, plugins are forced whenever charging is possible. See also 2.3.2 which forced home plugins only. **Note** that this description is out-of-order so to present more linear narration. Also note that the simulations are identical other than the plugins; over the two sequences each of the 16,000 simulations move the same EVs over the same trips.

The upshot: EV kWh taken is nearly identical but now far more is taken AFH. The “Meta - Reference” sheet in “MetaMeta2.3_Seq_2.5.2.xlsx” (see Table 4-29) shows the difference between 2.5.2 and 2.1.2 to be significant, lowering all electrical levels (peak kW to losses).

Table 4-29: Impact of All-Opportunity Perfect Plugins (27mpd 100 EVs)

(a)	Seq_2.1.2	EoW stats: kWh[b]	EV total: 5,912	Home: 5,014	AFH: 898
(b)	Seq_2.5.2	EoW stats: kWh[b]	EV total: 5,910	Home: 2,115	AFH: 3,795

(c)

		N_EV=	10	20	40	60	80	100	120	140	
19mpd	**Severe Undercharges per EV in Week**	19mpd	-0.0004	-0.0005	-0.0008	-0.0006	-0.0008	-0.0009	-0.0010	-0.0010	19mpd
27mpd		27mpd	-0.0008	-0.0009	-0.0024	-0.0028	-0.0029	-0.0027	-0.0036	-0.0089	27mpd
38mpd		38mpd	-0.0016	-0.0026	-0.0053	-0.0055	-0.0052	-0.0113	-0.0280	-0.0914	38mpd
49mpd		49mpd	-0.0042	-0.0039	-0.0067	-0.0062	-0.0097	-0.0343	-0.1049	-0.2308	49mpd

This caused severe undercharging to drop from 12 unacceptable plies in 2.1.2, to 3 in 2.5.2, so suggesting a strategy to combat home undercharging: Encourage AFH charging especially if the residential area has a network unable to meet the needs of the EV load. This may be a means to offset / defer reinforcement. However, we have already seen that AFH chargepoints may be in short supply in Winter.

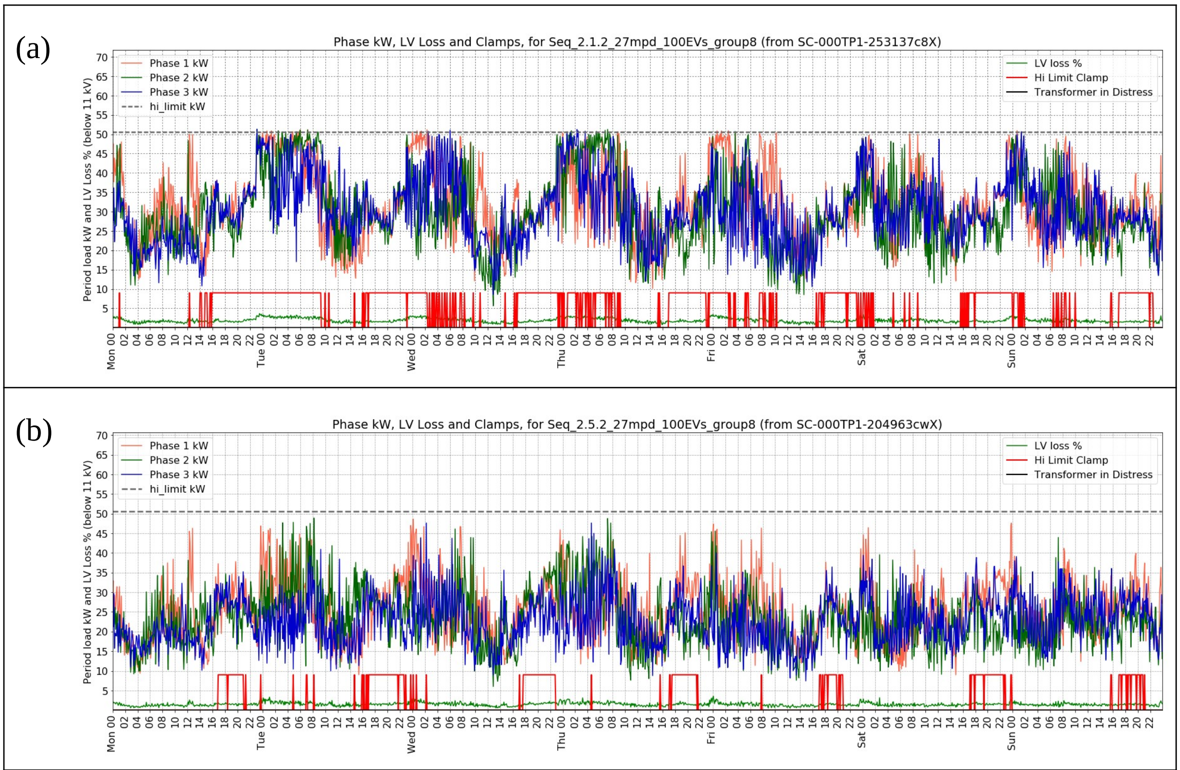


Figure 4-13: Feeder Seq_2.1.2 vs Seq_2.5.2 (27mpd 100 EVs group 8 plot)

Notes re Feeder plots:

- (a): 2.1.2 (no forced perfect plugins)
- (b): 2.5.2 (all opportunity plugins are forced)
    - charging burden is lower
    - clamps are lower.

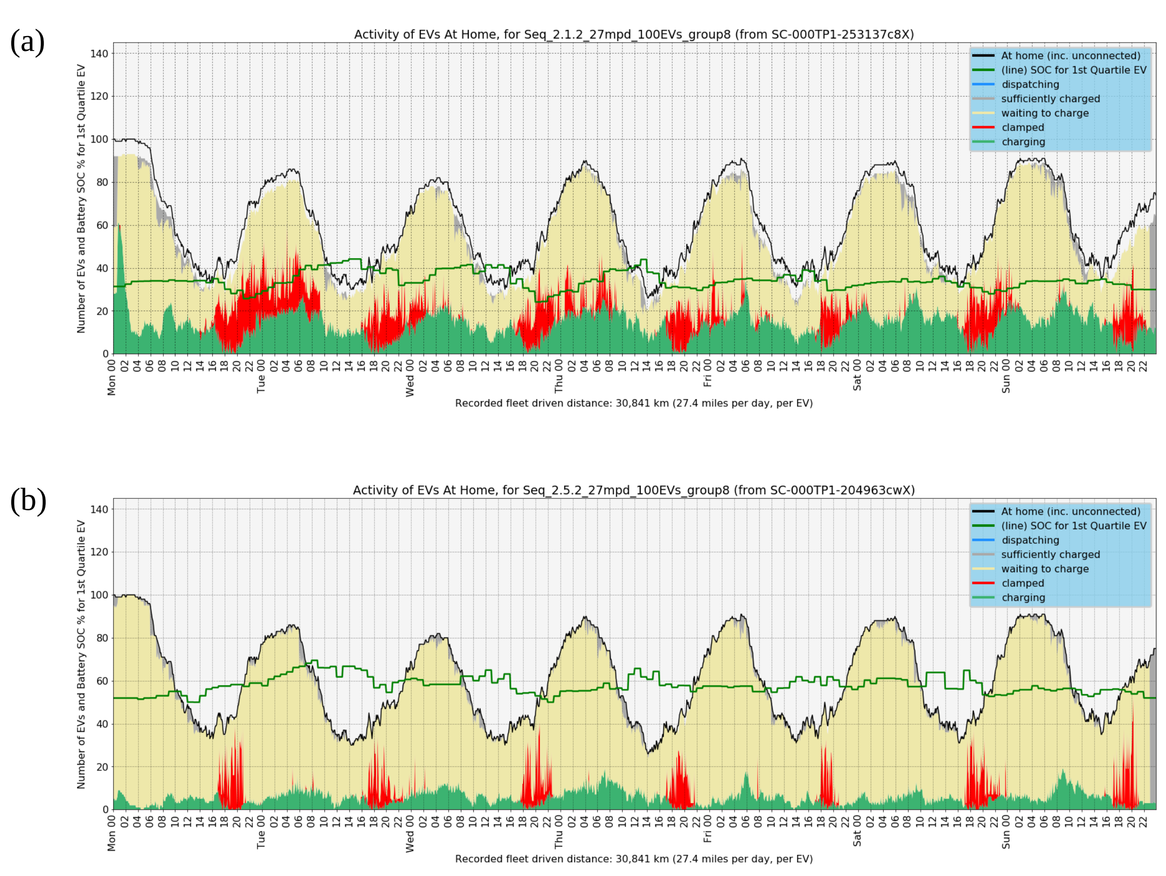


Figure 4-14: CICD plot Seq_2.1.2 vs Seq_2.5.2 (27mpd 100 EVs group 8 plot)

Notes re CICD plots:

- (a): 2.1.2 (no forced perfect plugins)
- (b): 2.5.2 (all opportunity plugins forced)
    - charging (green) is reduced
    - SOC is lifted
    - clamps are much diminished.

V2-4.13 Sequence 2.6.2 (in summary)

Seq_2.6.2 was a mode 1 clamping version of 2.5.2 and has no different results.

V2-4.14 Observations on Sequence 2

The simulations were performed with the Winter configuration. The use of EVSE disconnectors (clamps) removed broaches. By enforcing a hi_limit at the network design capacity, no under-voltages were seen (caveat: this is also a function of specific network topology). However by adding a clamping system an arbitrarily high number of EVs may connect to a network, regardless of the ability of the network to supply. As a result undercharging can occur limited by the network capability (per-EV kWh is inadequate).

Two management protocols have been tried with little to distinguish between these; the MEA-style method of proportional fairness (simple to implement) performed marginally worse than equitable fairness (which needs better EV comms dialogue). Possessing a simplification which likely eases implementation, the MEA method is seen as preferable.

Demand Management and Frequency Response (DRFFR) were trialled and shown to be possible using hi_limit modulation using clamps as the control mechanism. However there were impacts on EV charging.

Perfect plugins (the EV always connect to power on packing) of various types were trialled. Away From Home perfect plugins were found very useful and greatly aided inadequate home charging; however it is already seen that Winter places great demand on AFH chargepoints with much higher use rates. Thus it may not be practical to emphasise AFH charging in Winter, simply as the typical driver will struggle to find a free chargepoint. However, if they do, it is suggested that they are encouraged to fill their EV up as much as possible. This will leverage benefits for themselves and reduce need for home charging (so allowing others to charge). However such a hope is unlikely to forestall the need for other measures - this is more advice to the driver rather than a sufficient and dependable policy.

PV paired with Static Batteries offer advantage, with Static Battery charging likely aiding LV over-voltages from PV, seen during daytime. Again, this is an aid rather than a dependable policy; over-volts can be a real issue which need certain management rather than when-available assistance. However the method looks constructive.

Undercharging and severe undercharging remain a major issue on constrained LV networks; plus the frequency of use of clamps is like to draw Ofgem ire as it is clear from some Sequences that clamps can remain in near-persistent operation.

V2-4.15 Summary of Sequence 2

Clamps succeeded in halting overloads and are strongly recommended to DNOs as means to ensure LV networks are safe from local blackouts and under-voltages (which bring risk of appliance fires; caveats re network topology apply).

The effect of clamps from the EVs view is to reduce charging opportunities, with possibility of inadequate charging for some parties especially those on unbalanced networks, a potentially repeated situation (due to uneven spread of house connections to phases) hence effecting the same parties multiple times.

Of a variety of aids attempted, local ESS / Static Batteries with solar PV were the most successful. DRFFR methods were also operated at a local level successfully, using the local controller to modulate the hi_limit which controlled onset of clamping.

Charging Away from Home was a great help, but in the context of Winter may be found unreliable, given likely excess demand at destinations (all EVs have the same problem and net demand is excessive, leaving many unable to find somewhere to charge).

< ==== end of document ==== >

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