UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

Transport Research Group

Volume 4: Results Analysis for

Sequence Set 6

version 1.1 including corrections

for the EngD Thesis:

Modelling and Managing

The Charging of Massed Electric Vehicles on

Constrained Residential Power Networks

(UK / EU style LV systems)

by

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May 2020

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Vol 4 Chapter 1: Introduction

This document presents and analyses data from the author’s FPB EV on UK LV Network simulator, described in his EngD Thesis. The reader is advised to have the Thesis to hand. The EVs modelled are “mid-Century types” using BLP’s (see Thesis) and in general impose less load then today’s EVs (see Thesis Appendix A: FPB Design Assumptions).

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

V4-1.1 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.

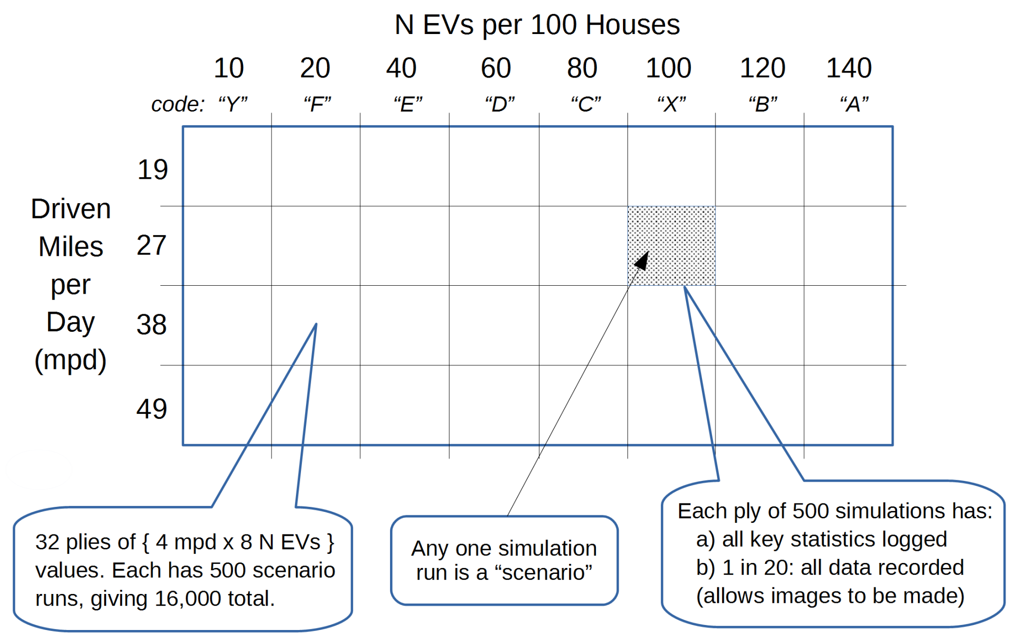

Figure 1-1: Allocation of 16,000 simulations in a Sequence

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.

V4-1.2 The Data Repository Files

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

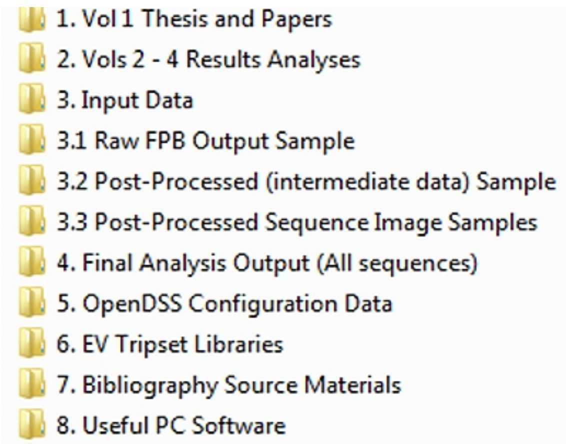

Figure 1-2: Results Data Repository Structure

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.

V4-1.3 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)		
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		

V4-1.4 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).

V4-1.5 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 $kWh^{\mathbf{b}}$ is c. 0.84 of socket kWh, and
    - V2G dispatch has similar losses, so socket received kWh is about 0.84 of $kWh^{\mathbf{b}}$;

- 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.

V4-1.6 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):

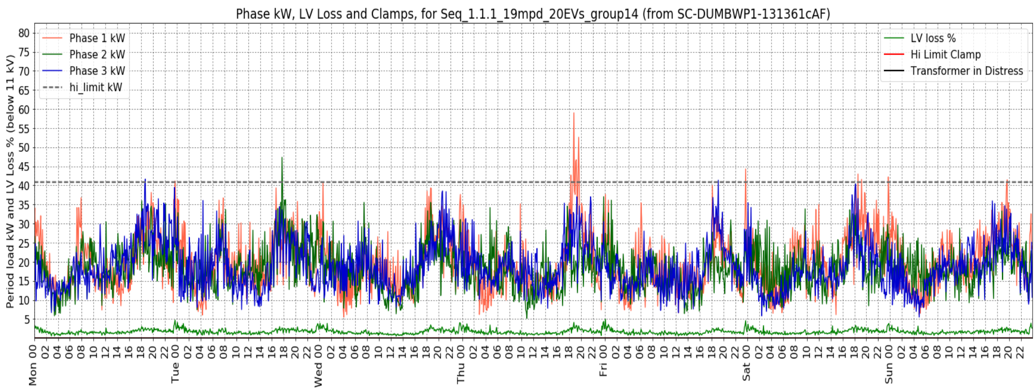

Figure 1-3: Seq_1.1.1 19mpd 20 EVs - passed, no broaches found

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

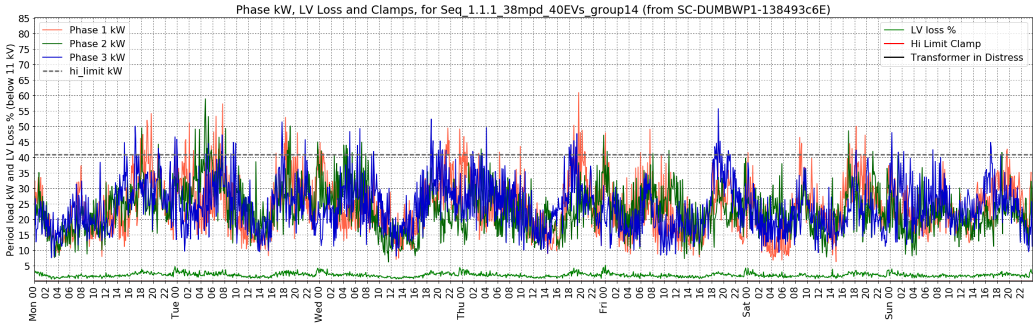

Figure 1-4: Seq_1.1.1 38mpd 40 EVs - failed with broaches

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.

V4-1.7 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.

V4-1.8 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.

V4-1.9 Plots of Simulation Results

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

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

- **blue bars**: count of **arrivals** in the hour (green tip: count of number charged Away from Home AFH i.e. at a destination charging point).

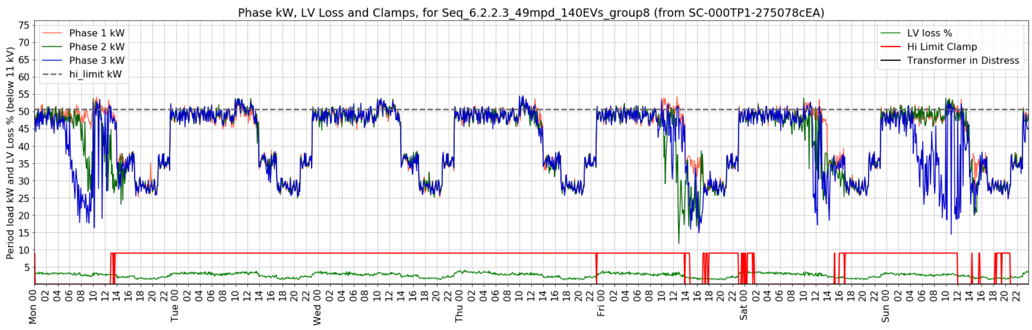

Figure 1-5: Sample of a Feeder plot

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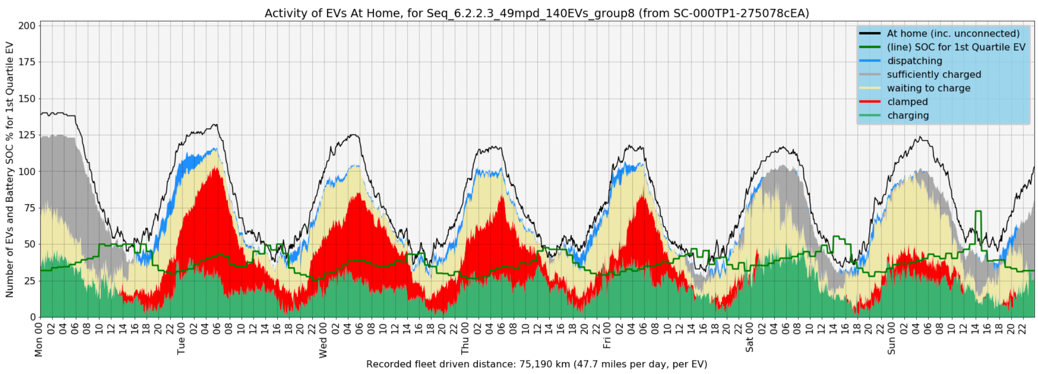

Figure 1-6: Sample of a CICD plot

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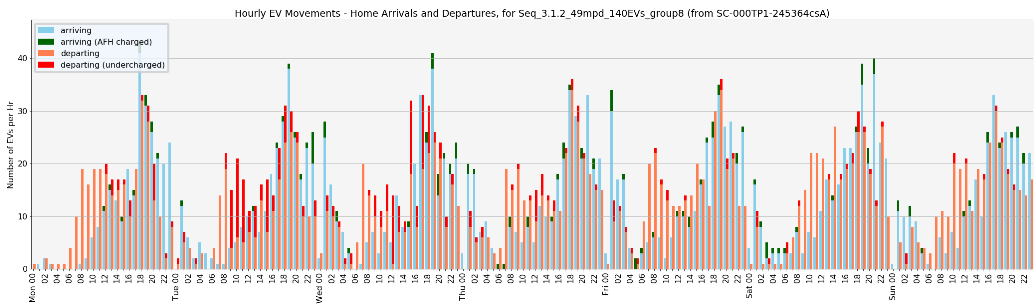

Figure 1-7: Sample of an Arrive / Depart plot

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

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

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Vol 4 Chapter 2: Sequence Set 6

This section presents twenty-plus sequences in Set 6. MCS now operates with clamps and explores further options, together with alternative live data to gain confidence (or not) about generality, by inspecting operation with different inputs. How such a system reacts when faced with uncontrollable real-world events (power-fails, unbalances etc.) is explored later in Sequence Set 7.

A note re Clamp Counts: The clamp count is a record made by the MCS of the number of phase periods (pd) being clamped, summed over the week giving a maximum value of: 3 x 1,680 = 5,040. The clamp count shown does not refer to the number of EVs clamped over the week, rather the MCS view on whether it imposed a clamp on any phase in that pd. This is then a general measure (and may be improved upon in later simulators).

V4-2.1 Sequence Set 6 Description

Purpose: To investigate an LV network, using MCS local control with clamps and to then vary the normal operating conditions.

Key Concerns to Investigate:

a) does MCS work effectively with clamps?
b) the system is trialled with datasets for alternative weeks
c) operation is tested with a small number of Heat Pump heated homes
d) Static batteries are again trailed, with and without V2G “pre-burn”
e) a set of Summer runs are investigated
f) alternative Aggregator control is investigated
g) a run without DR is performed
h) the effect (on system and losses) of much lower hi_limit setpoints is assessed
i) the contribution of PV in Winter is explored.

Methodology:

Standard 32 plys of 4 mpd x 8 N EV x 500 simulations are run, together with the normal tools:

- the intermediate and post processing analysis suites

- 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.

V4-2.2 Simulations in Sequence Set 6

Sequence	Simulation ID	Description
Seq_6.1.2 BASELINE	(S_65)	Typical network, Winter, EV mix is 19% dumb, 48% SV1G, 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW, normal plugin regime
Seq_6.1.3	(S_BG)	Strong network with clamps and DRB/FFR
Seq_6.1.3.1	(S_B5)	Variation vs. Seq_6.1.3: Strong Network, 20 Heat Pump Houses,
Seq_6.2.2	(S_85)	Variation vs. Seq_6.1.2: DR/FFR
Seq_6.2.2.1	(S_AR)	Variation vs. Seq_6.2.2: Static Batteries, Pre_Burn V2G OFF
Seq_6.2.2.2	(S_AS)	Variation vs. Seq_6.2.2: Static Batteries, Pre_Burn V2G ON
Seq_6.2.2.3	(S_BD)	Variation vs. Seq_6.2.2: Static Batteries, “Pre_BurnSave” V2G
Seq_6.3.2	(S_67)	Variation vs. Seq_6.2.2: Aggregator-B commands
Seq_6.3.2.1	(S_AD)	Variation vs. Seq_6.2.2: Aggregator-B commands in Summer
Seq_6.3.2.2	(S_B0)	Variation vs. Seq_6.3.2.1: SV1G EVs replace V2G
Seq_6.4.2	(S_91)	Variation vs. Seq_6.2.2: 1 in 4 EVs follow Agg-B commands
Seq_6.5.2	(S_BE)	Variation vs. Seq_6.2.2: Hybrid Aggregator control scheme
Seq_6.6.2	(S_AH)	Variation vs. Seq_6.2.2: 1 in 4 EVs follow hybrid agg. scheme
Seq_6.7.2	(S_A1)	Variation vs. Seq_6.1.2: DR only (no FFR)
Seq_6.8.2	(S_A2)	Variation vs. Seq_6.2.2: lowered hi_limit setpoint (1)
Seq_6.9.2	(S_Ai)	Variation vs. Seq_6.8.2: low hi_limit setpoint, ?? ~X$ EV mix, DR/FFR “C”, pre_burn V2G OFF

Sequence	Simulation ID	Description
Seq_6.9.2.1	(S_AK)	Variation vs. Seq_6.8.2: low hi_limit setpoint, DR/FFR “C”, pre_burn V2G OFF
Seq_6.9.2.2	(S_AT)	Variation vs. Seq_6.8.2: low hi_limit setpoint, DR/FFR “C”, pre_burn V2G ON
Seq_6.10.2	(S_AJ)	Variation vs. Seq_6.8.2: No V2G, low hi_limit setpoint, DR/FFR “C”, pre_burn V2G OFF ??~X$
Seq_6.11.2	(S_AY)	Variation vs. Seq_6.2.2.1: Static Batteries, hi_limit 24 kW
Seq_6.12.2	(S_AZ)	Variation vs. Seq_6.2.2.1: Static Batteries, hi_limit 32 kW
Seq_6.13.2	(S_BF)	Variation vs. Seq_6.2.2.1: Static Batteries, Winter PV, hi_limit 39 kW

V4-2.2.1 Simulation Results Overview

Plots are from group 8 to allow comparison. To show progression as EV number rise, the plots are for:

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

Data is available in the repository.

V4-2.2.2 Broaching and Blowing of Fuses: None

No simulation in sequence set 6 experienced a broach; this is due to the use of MCS controlled clamps (red areas in CICD plots), without which there would have been many broaches.

V4-2.3 Results for Sequence 6.1.2

Sequence	Simulation ID	Description
Seq_6.1.2	(S_65)	Typical network, Winter, EV mix is 19% dumb, 48% SV1G, 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW, normal plugin regime

The data below are from MetaMeta spreadsheets for Seq_6.1.2.

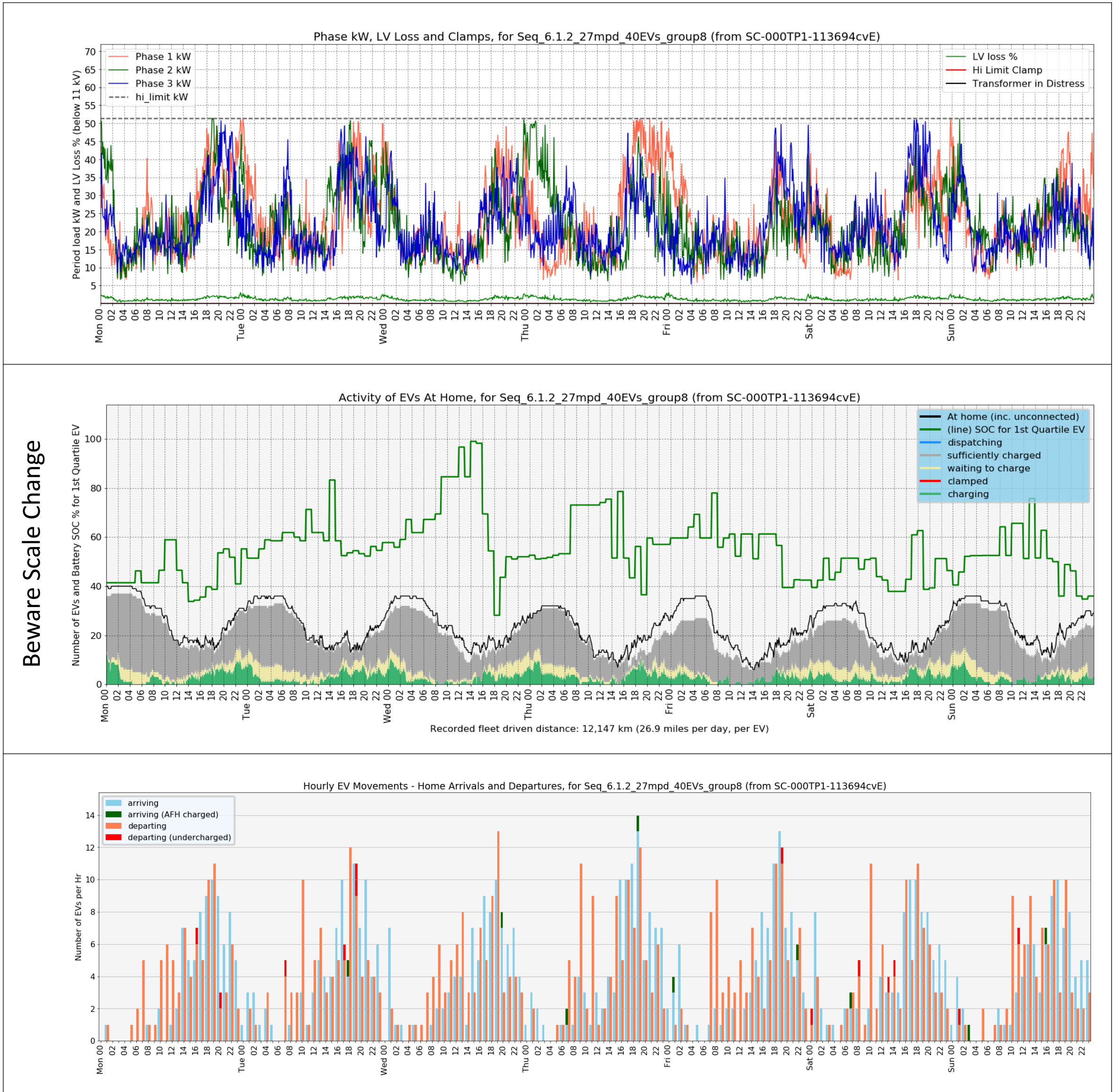
Note "kWh**b**": indicates the kWh stored in the battery, not as drawn from the socket.

V4-2.3.1 Seq_6.1.2 Outcomes

This has been a very successful sequence with only 3 extreme plies unacceptable. There are no broaches or out-of-volt range events. This will become a baseline for further sequences.

V4-2.4 Seq_6.1.2: Feeder and EV Plots

V4-2.4.1 Seq_6.1.2: 27mpd 40EVs



EoW stats: kWh[b]	EV total: 2,304	Home: 2,017	AFH: 287	V2G: 0

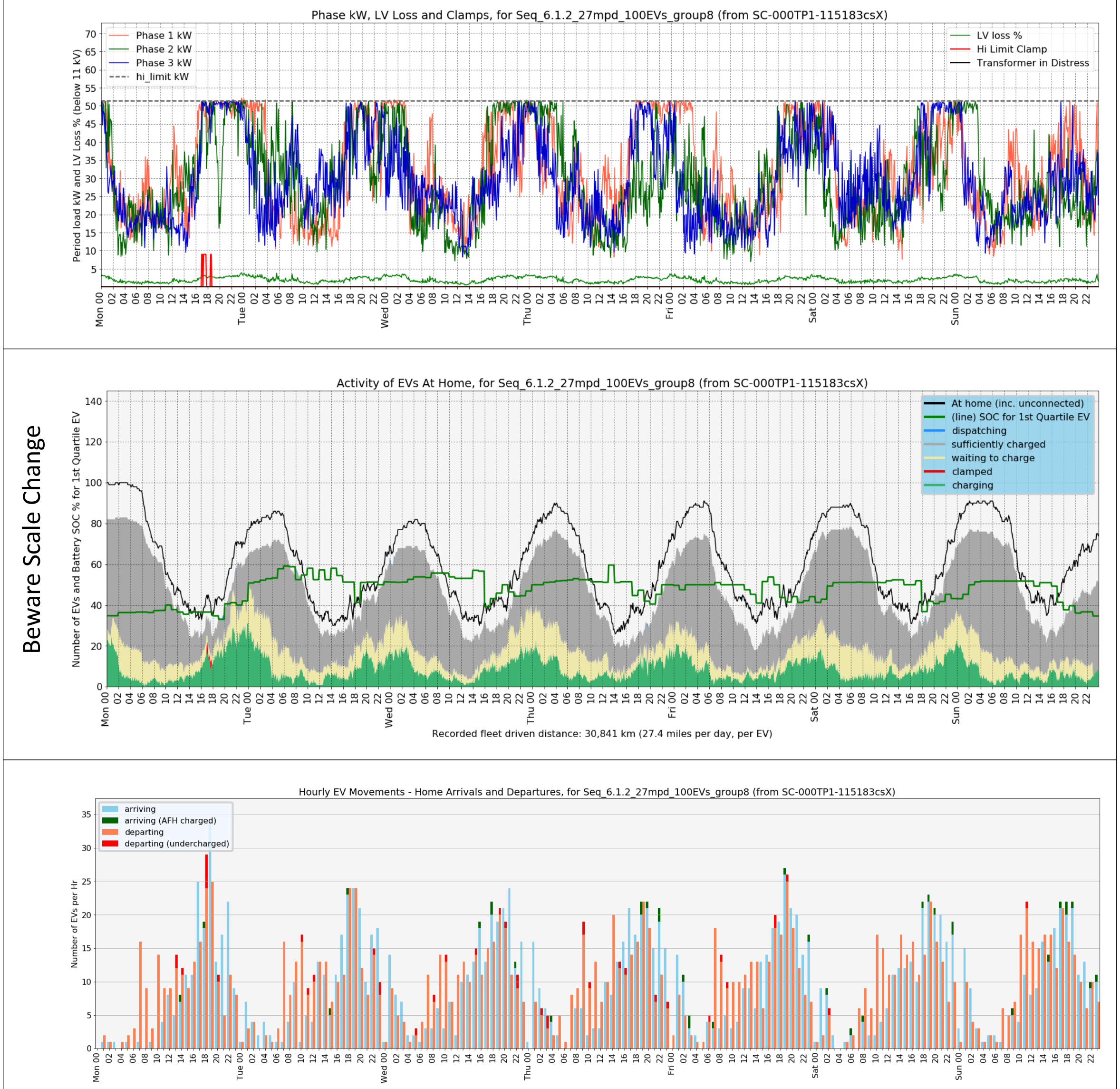
Figure 2-1: Seq_6.1.2 27mpd 40 EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- (Feeder) the plot is unremarkable, with no clamps
- (CICD) EV SOC appears very healthy in the 40 - 100% band.

  Note the prominent numbers of charged and waiting to depart EVs in grey.
- (Arrive/Depart) occasional colourised tips show undercharging or use of AFH
- AFH charging supplies c. 14% of EV charge.

V4-2.4.2 Seq_6.1.2: 27mpd 100EVs



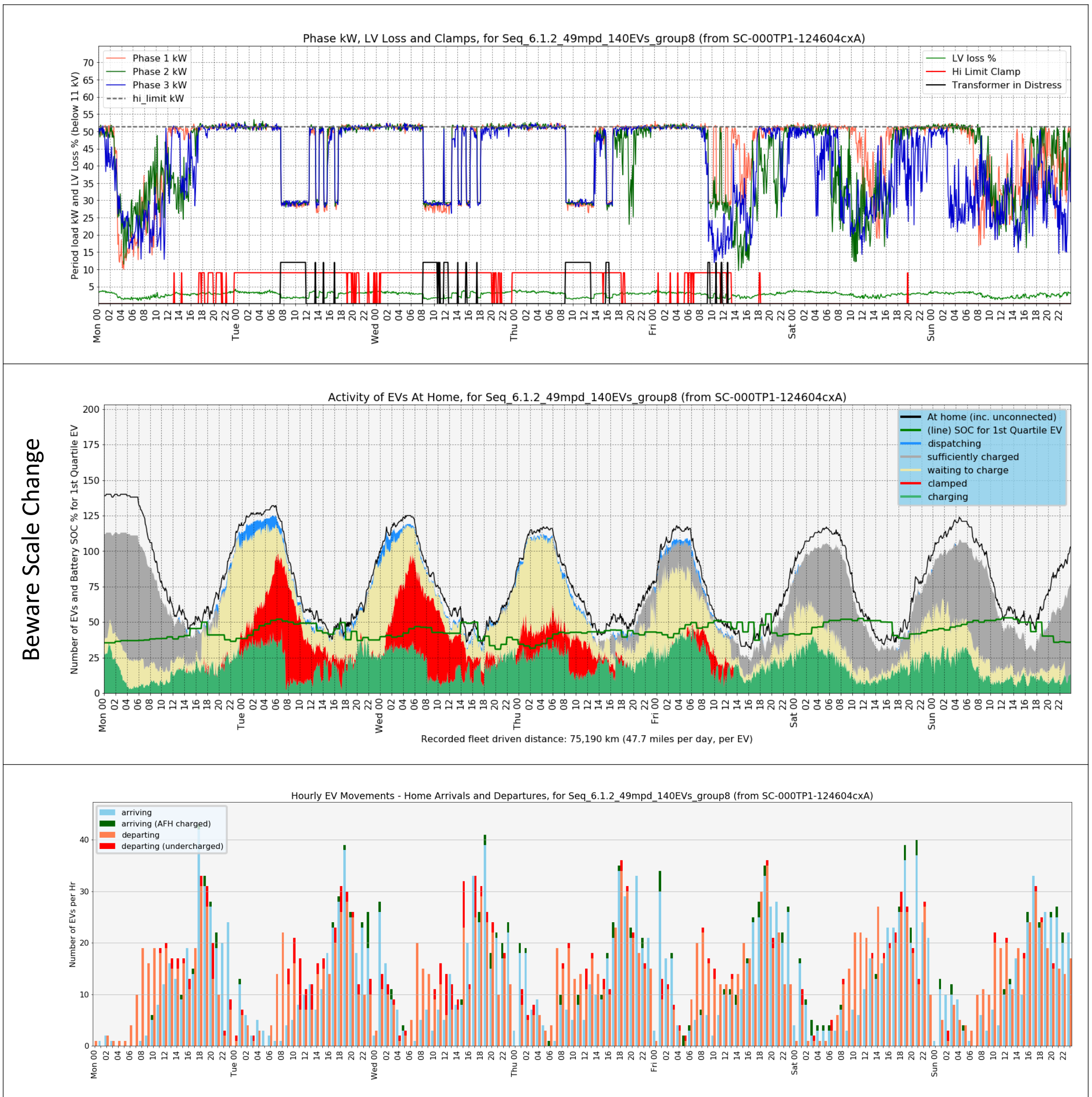
EoW stats: kWh[b] EV total: 5,882 Home: 5,083 AFH: 799 V2G: 7

Figure 2-2: Seq_6.1.2 27mpd 100 EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- (Feeder) clamps are occasionally present
- (CICD) EV SOC is down slightly; large grey and clear areas show EVs are coping well
- (Arrive/Depart) colourised tips show more undercharging and use of AFH
- AFH charging now supplies c. 16% of EV charge.

V4-2.4.3 Seq_6.1.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,213 Home: 9,773 AFH: 4,440 V2G: 678

Figure 2-3: Seq_6.1.2 49mpd 140EVs group 8 plots. Weekly km: 77,327

Notes re above plots:

- (Feeder) clamping has greatly increased; transformer clamps are seen; the substation transformer is reaching thermal saturation
- (CICD) EV SOC is down; clamps and V2G (blue) are seen. Pre-burn of V2G is visible; c. 23:00 Monday V2G is operating without clamps
- (Arrive/Depart) colour tips are common; undercharging and use of AFH has risen
- AFH charging now supplies 31% of EV charge.

V4-2.5 Data Tables Seq_6.1.2

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

Table 2-1: 6.1.2 Unused kWh (weekly averages)

1. Unused kWh	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd	17,118	16,489	15,245	13,985	12,719	11,450	10,206	8,947
	27mpd	17,001	16,235	14,731	13,214	11,723	10,219	8,686	6,899
	38mpd	16,901	16,037	14,282	12,514	10,793	8,984	6,151	175
	49mpd	16,816	15,868	13,927	11,996	10,137	7,778	480	0

Each cell is the average over 500 simulation runs, varied only in EV trip timing.

Table 2-2: 6.1.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
	19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
	27mpd	6.2	7.2	7.2	7.5	8.0	8.0	7.9	7.7
	38mpd	16.2	16.3	16.8	17.4	17.4	17.8	17.6	17.7
	49mpd	33.9	31.6	30.3	30.1	30.0	30.0	30.5	31.7

Table 2-3: 6.1.2 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	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
	27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
	38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.59
	49mpd	1.06	0.96	0.90	0.89	0.91	0.90	0.92	0.96

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

Table 2-4: ***6.1.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.6	0.8	0.8	0.9	0.9	1.0	0.9	1.0
	27mpd	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.4
	38mpd	1.7	1.8	1.9	1.9	2.0	2.0	2.0	2.1
	49mpd	2.3	2.3	2.4	2.4	2.4	2.4	2.5	3.5

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

Table 2-5: ***6.1.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0003	0.0003	0.0001	0.0001	0.0001	0.0002	0.0002
	27mpd	0.0002	0.0002	0.0005	0.0010	0.0010	0.0008	0.0008	0.0008
	38mpd	0.0008	0.0014	0.0017	0.0025	0.0019	0.0024	0.0022	0.0051
	49mpd	0.0028	0.0016	0.0037	0.0030	0.0043	0.0051	0.0089	0.0736

(limit: < 0.007)

A severe undercharge is an EV departing knowing the trip cannot be completed e.g. “must be pushed home”, including “pushed out of driveway”. These events are known to cause great upset and blowback, especially as they tend to be prompted by regular network conditions so can 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 the probability as 0.007; this is taken as a limiting value beyond which driver distress might be incurred. Red highlights unacceptable values.

Table 2-6: ***6.1.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0	0.0	0.1	0.5	1.1	3.6	1.5	3.3
	27mpd	0.0	0.0	0.3	1.1	3.1	9.5	5.7	14.6
	38mpd	0.0	0.1	0.7	2.5	7.6	24.7	34.5	443.0
	49mpd	0.1	0.2	1.5	4.6	14.6	74.0	320.6	1,548.4

(limit: < 420)

The counts in red might concern Ofgem as they exceed 420 clamps (2hrs clamped a day).

Note that this measure is arbitrary and hobbled by:

- FPB not offering further detail (needs improving) and
- no known as yet Ofgem stance.

Table 2-7: ***6.1.2 LV Losses kWh (weekly averages)***

7. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	96.4	112.7	138.3	181.3	235.9	298.5	363.1	426.1
	27mpd	97.7	115.8	154.8	204.2	267.9	344.6	427.2	508.9
	38mpd	99.9	118.2	162.4	226.2	303.0	398.2	496.1	590.6
	49mpd	101.6	120.2	169.3	239.4	324.4	430.4	537.8	631.5

Table 2-8: ***6.1.2 Estimated V2G Losses kWh (weekly averages)***

8. V2G Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0	0.0	0.0	0.1	0.2	0.7	1.4	3.1
	27mpd	0.0	0.0	0.0	0.1	0.5	2.0	4.4	12.4
	38mpd	0.0	0.0	0.1	0.3	1.3	6.8	19.3	93.4
	49mpd	0.0	0.0	0.1	0.5	2.6	17.4	68.4	203.3

V2G losses (i.e. within the EV) are only significant in extreme cases.

V4-2.6 Seq_6.1.2 Results Summary

Table 2-9: ***6.1.2 Overall Usable EV Plies***

N EV	10	20	40	60	80	100	120	140
19mpd								
27mpd								
38mpd								C
49mpd							S	SC

Clear are Usable. Yellow: Severe undercharging too high, blue: Clamp limits exceeded, lime: both too high.

Smart charging, V2G and clamps are used under MCS control to provide a viable system.

Rejecting the highlighted cases due to excesses, this arrangement appears to be viable for:

a) locations experiencing 49mpd: up to 100 EVs

b) locations experiencing 38mpd: up to 120 EVs

c) locations experiencing 27mpd: up to 140 EVs

This is assuming other effects (flicker, harmonics etc.) do not prohibit operation.

This appears a successful run, demonstrating the utility of clamps, MCS and V2G working together. SV1G EVs are present, which follow MCS commands. c. 19% of EVs are dumb.

Note that systems without broaches implicitly operate within design limits, so will not experience under-volts or cable overloads (none were seen) - but this does not mean that PV cannot cause over-volts.

V4-2.7 Results for Sequence 6.1.3

Sequence	Simulation ID	Description
Seq_6.1.3	(S_BG)	Version of Seq_6.1.2: with Strong Network, DR/FFR "B" and clamps in mode (2) and 65 kW phase hi_limit. EV mix is 19% dumb, 48% SV1G, 33% V2G

This sequence uses the Strong network (built to ADMD 2 kW) vs. 6.1.2's Typical network (of 1.5 kW ADMD).

Data is from MetaMeta Seq_6.1.3, which confirms that the broach count is zero.

This sequence includes daily repeating Demand Reduction and Fast Frequency Response signals (DR-B and FFR aka DRFFR), applied as a ratio to the nominal hi_limit setpoint:

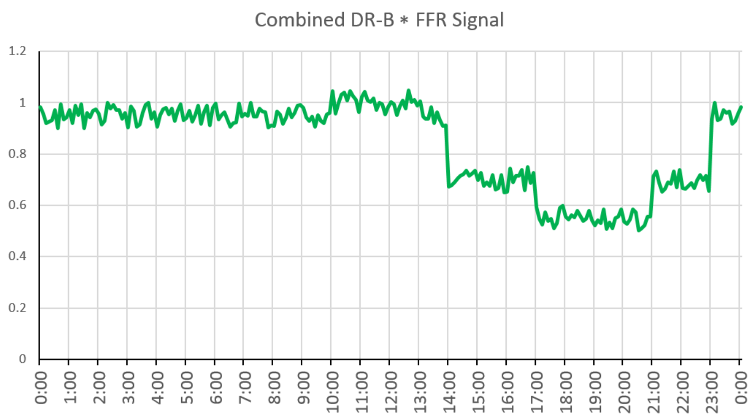


Figure 2-4: Combined DR-B / FFR Signal

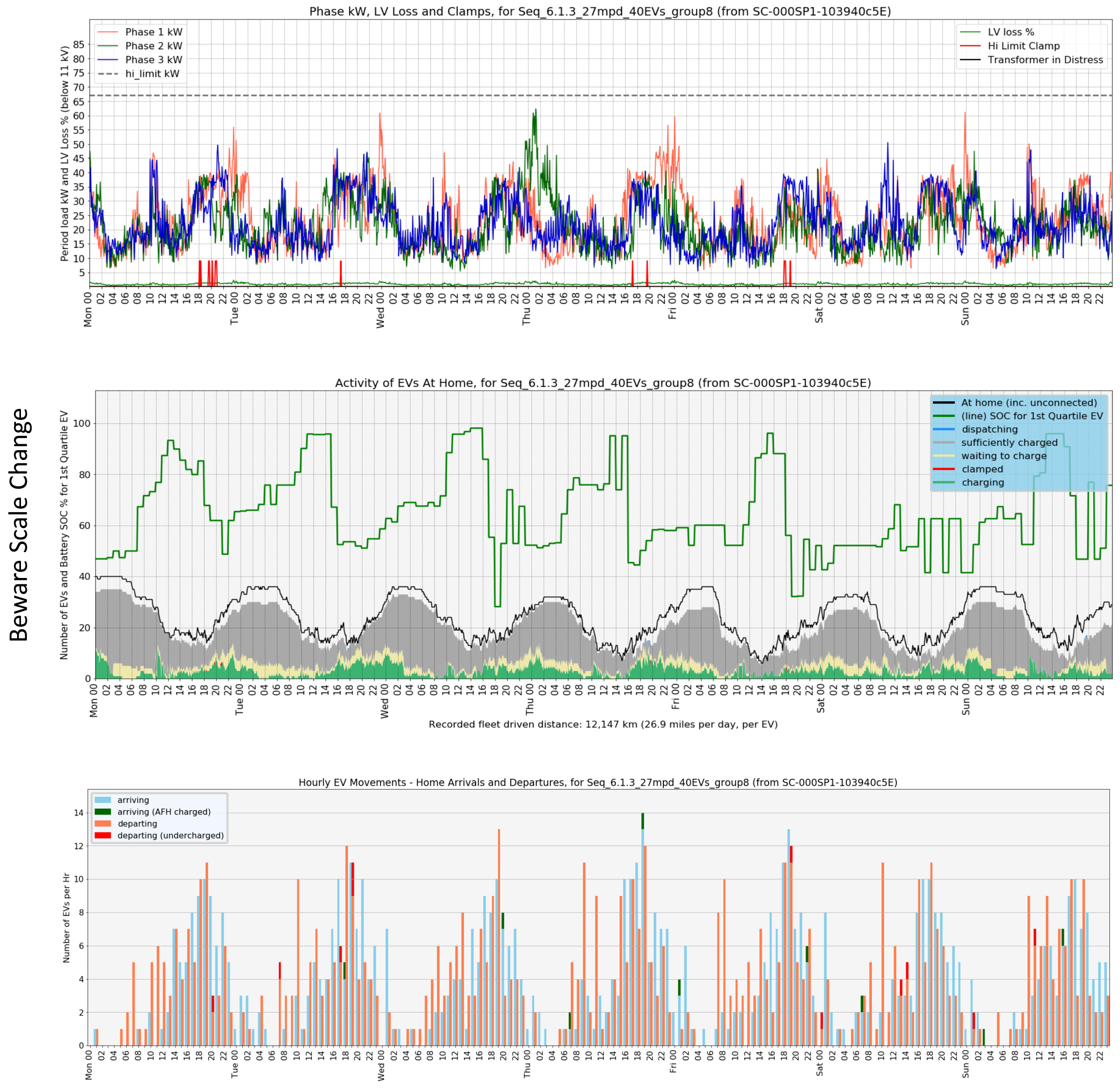
See also Thesis Appendix E.

V4-2.7.1 Seq_6.1.3 Outcomes

The combination of Strong network, MCS, V2G and clamps have produced the first clean sweep of results, with no problems experienced, with DR and FFR added value services.

V4-2.8 Seq 6.1.3 Feeder and EV Plots

V4-2.8.1 Seq_6.1.3: 27mpd 40EVs



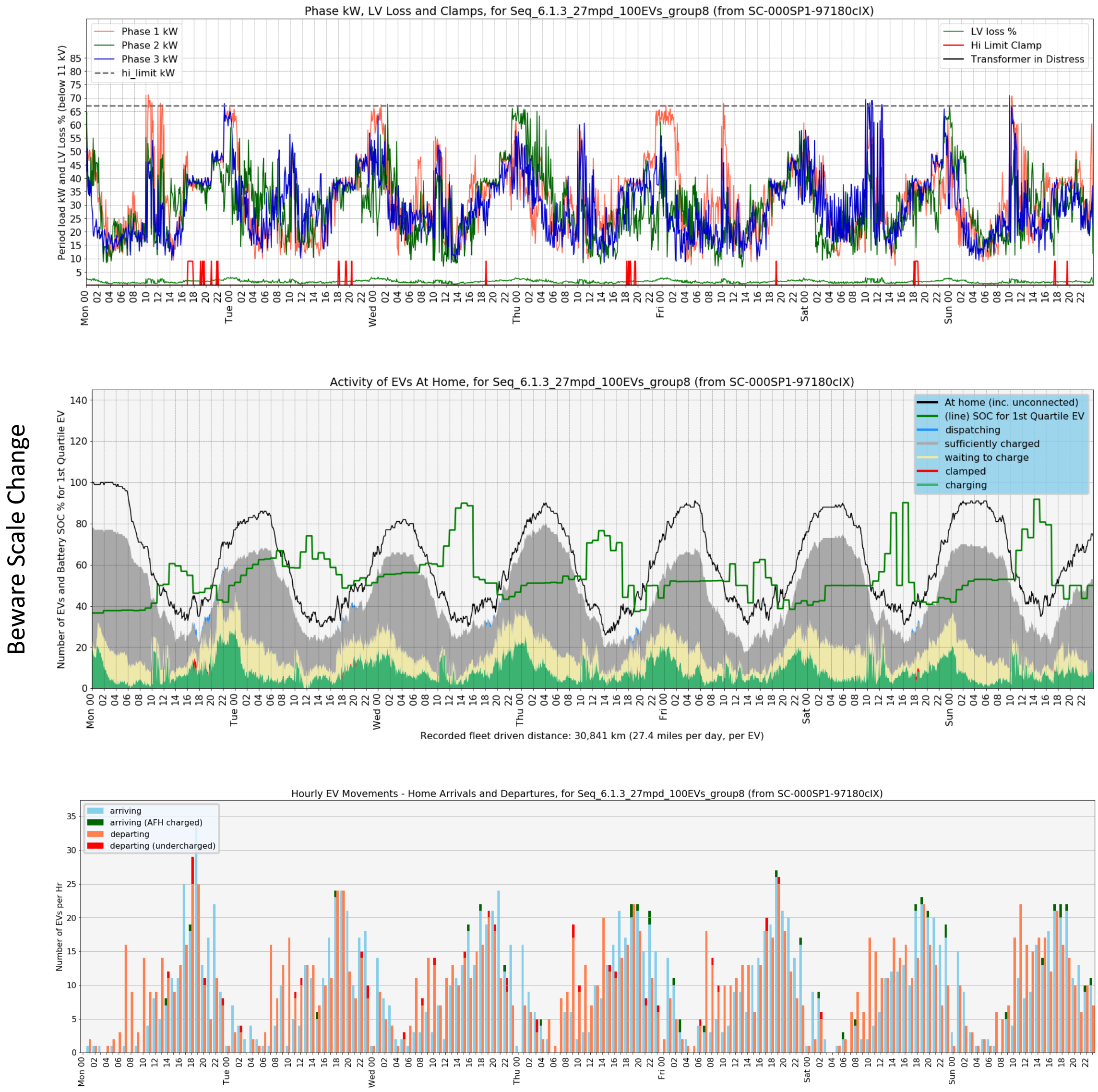
EoW stats: kWh[b] EV total: 2,311 Home: 2,029 AFH: 282 V2G: 4

Figure 2-5: Seq_6.1.3 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot shows plenty of unused headroom
- (CICD) EVs have good SOC; there are rare champs and no visible V2G dispatch
- (Arrive/Depart) undercharged departs and AFH charging are rare.

V4-2.8.2 Seq_6.1.3: 27mpd 100EVs



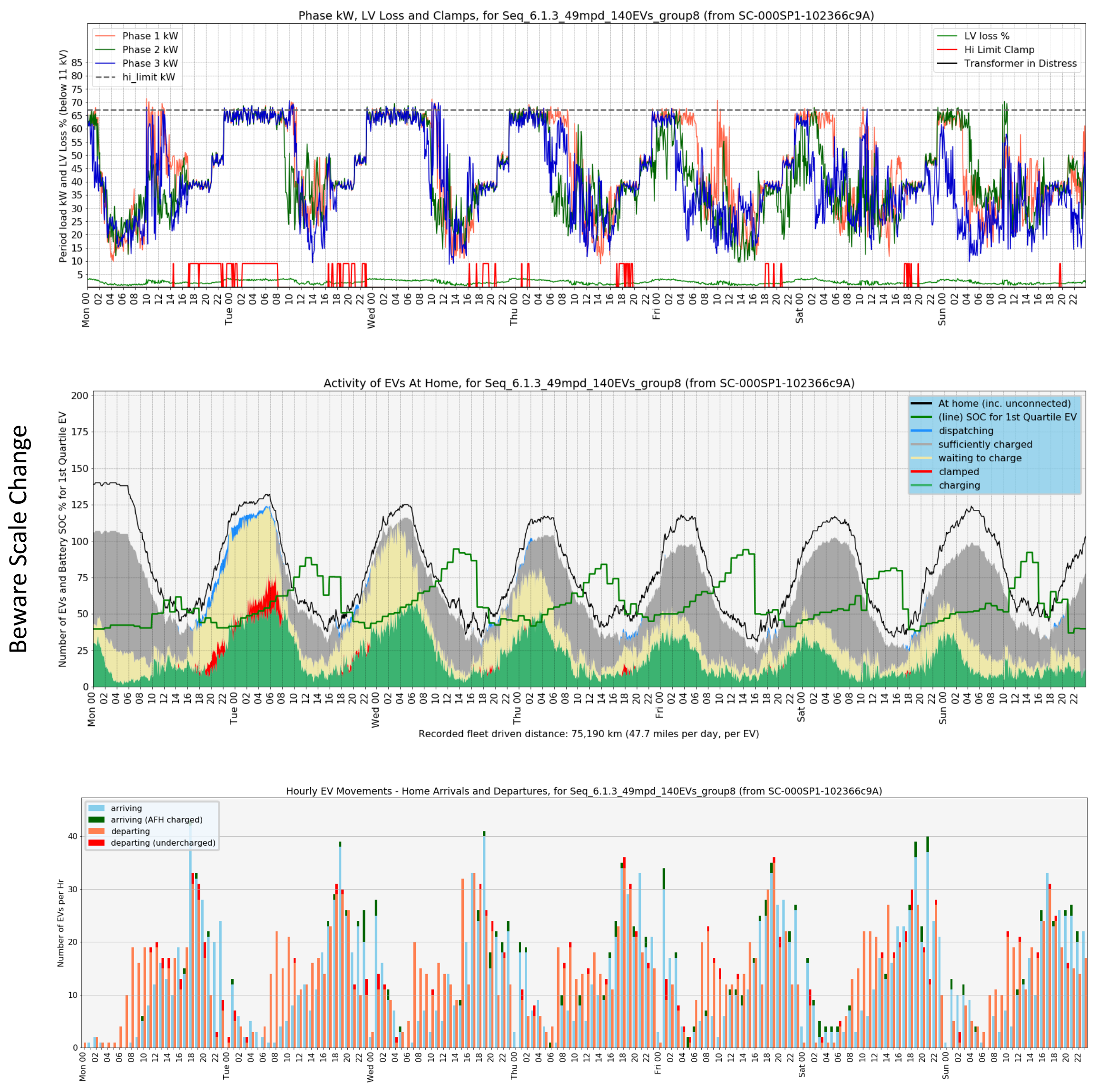
EoW stats: kWh[b] EV total: 5,915 Home: 5,130 AFH: 785 V2G: 34

Figure 2-6: Seq_6.1.3 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows increased clamps
- (CICD) SOC is similar with significant numbers of EVs ready to depart; there is little range anxiety as many do not connect on return home
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. Both are low.

V4-2.8.3 Seq_6.1.3: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,944 Home: 9,749 AFH: 4,195 V2G: 361

Figure 2-7: Seq_6.1.3 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot has increased clamps
- (CICD) EVs are not “starving” for there are non-connects and EVs waiting to depart. Clamps and V2G are evident on only one period in the week
- undercharging and AFH charging have risen but remain low overall.

V4-2.9 Data Tables Seq_6.1.3

Table 2-10: ***6.1.3 Unused kWh (weekly averages)***

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	25,571	24,948	23,715	22,470	21,224	19,972	18,739	17,509
	27mpd	25,453	24,688	23,190	21,676	20,197	18,711	17,196	15,664
	38mpd	25,351	24,485	22,730	20,961	19,249	17,456	15,708	13,876
	49mpd	25,265	24,314	22,366	20,425	18,565	16,572	14,626	12,597

Unutilised network capacity drops relatively evenly between plys.

Table 2-11: 6.1.3 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.4	2.9	3.0	3.0	3.1	3.3	3.2	3.2
	27mpd	6.1	7.2	7.0	7.3	7.8	7.8	7.7	7.6
	38mpd	15.9	16.1	16.6	17.2	17.1	17.6	17.3	17.3
	49mpd	33.6	31.2	29.9	29.8	29.6	29.6	29.9	29.9

AFH uptake appears to be linked to the driven distance.

Table 2-12: 6.1.3 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	0.11	0.13	0.12	0.12	0.13	0.14	0.14	0.13
	27mpd	0.27	0.28	0.26	0.27	0.30	0.29	0.29	0.28
	38mpd	0.55	0.54	0.55	0.56	0.56	0.58	0.57	0.57
	49mpd	1.04	0.93	0.88	0.87	0.88	0.88	0.89	0.89

AFH connections are also seen linked to distance travelled.

Table 2-13: ***6.1.3 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.6	0.7	0.7	0.8	0.8	0.9	0.8	0.8
	27mpd	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.3
	38mpd	1.6	1.7	1.8	1.8	1.9	1.9	1.9	1.9
	49mpd	2.2	2.2	2.3	2.3	2.3	2.4	2.4	2.4

Undercharges are again seen as a function of mpd.

Table 2-14: ***6.1.3 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0003	0.0003	0.0001	0.0001	0.0001	0.0002	0.0002
	27mpd	0.0002	0.0003	0.0004	0.0009	0.0009	0.0009	0.0007	0.0007
	38mpd	0.0008	0.0018	0.0018	0.0028	0.0021	0.0026	0.0024	0.0029
	49mpd	0.0028	0.0021	0.0038	0.0032	0.0048	0.0056	0.0056	0.0055

(limit: < 0.007)

The Strong network shows across all-ranges sufficiently low severe undercharging.

Table 2-15: ***6.1.3 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	4.0	9.8	15.5	23.5	33.8	20.1	28.2
	27mpd	3.8	6.4	15.1	25.9	40.9	58.3	44.8	61.8
	38mpd	4.9	9.4	24.0	41.3	68.2	103.2	97.6	144.1
	49mpd	7.0	13.1	32.6	58.5	96.6	146.3	163.6	323.9

(limit: < 420)

The Strong network shows across all-ranges sufficiently low clamping.

Table 2-16: ***6.1.3 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.3	0.2	0.2	0.2	0.4	0.6	0.8	1.0
	27mpd	0.3	0.2	0.2	0.4	0.6	1.0	1.4	1.8
	38mpd	0.3	0.2	0.4	0.6	1.1	1.9	2.7	3.9
	49mpd	0.3	0.3	0.4	0.8	1.6	2.9	4.4	7.2

The V2G EVs have very low dispatch rates, however the extreme case (grey) equates to 1 days driving per week, hence over a 10 week Winter period c. 10 days of battery duty is used, approximately 100 days use over 10 years. It is not clear how much battery life reduction accrues from this, however the amount likely needs assessing and some form of recompense provided.

Table 2-17: ***6.1.3 Estimated Total Losses inc. V2G kWh (weekly averages)***

8. Total Losses inc. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	70.6	76.9	97.5	132.3	171.5	217.2	268.9	322.0
	27mpd	71.5	79.4	112.2	145.0	192.4	256.4	328.7	401.1
	38mpd	72.3	88.2	117.9	164.7	222.2	306.3	402.4	503.2
	49mpd	73.0	91.0	122.0	175.0	249.2	347.3	458.8	603.1

cf. 6.1.2: [347, 535] kWh

These are comparable to losses seen in Seq_6.1.2, being lower here in the parity case.

V4-2.10 Seq_6.1.3 Results Summary

Table 2-18: ***6.1.3 Compared to Earlier Sequences***

Sequence	having	Highest N EVs Tolerated (at 19, 27, 38, 49mpd)
1.1.3	Strong network, no control	80, 80, 60, 40
5.1.3	Strong network, MCS, V2G	140, 140, 140, 120
6.1.3	Strong network, MCS, V2G, clamps	140, 140, 140, 140

This is the first “clean sweep” in which every studied EV penetration has acceptable performance, indicating that the combination of:

- a Strong network (min. 2 kW per house built ADMD),
- MCS,
- V2G and
- clamps

represent a practical (deployable) case.

V4-2.11 Results for Sequence 6.1.3.1

Sequence	**Simulation ID**	**Description**
Seq_6.1.3.1	(S_B5)	Version of Seq_6.1.3: with Strong network, DR/FFR “B”, and 20 Heat Pumps. Resident load is scaled to 1.8 kW EV mix is 19% dumb, 48% SV1G, 33% V2G
Baseline Seq	***Description***	
Seq_6.1.3	*Strong network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 65 kW*	

Data is from MetaMeta Seq_6.1.3.1, which has a broach count of zero. The author wanted to inspect ability to support Heat Pumps (HP). These figure large for HP are to follow EVs as part of the UK’s carbon reduction strategy. Although notionally out of scope, it would be foolish to work on a solution for EVs which cannot operate with HP. A sequence was run with a modest number of HP; 20 spread evenly over the 100 houses, about as many as might operate without clear need for network reinforcement.

Heat Pumps deliver a low-grade heat; radiators run cool. As a result, HPs run for long periods to transfer heat. Spot heating for various duties (e.g. hot water) becomes necessary; these are “auxiliary loads”. HP load is made up to two components:

- timed bursts of HP direct load, c. 4 - 6 kW, typically in the early hours to pre-heat the home then sporadically throughout the day
- modelling of auxiliaries by raising residential load ADMD to 1.8 kW per home.

The intent then is:

- to confirm the continued ability to operate, and
- broadly characterise EV / HP interworking.

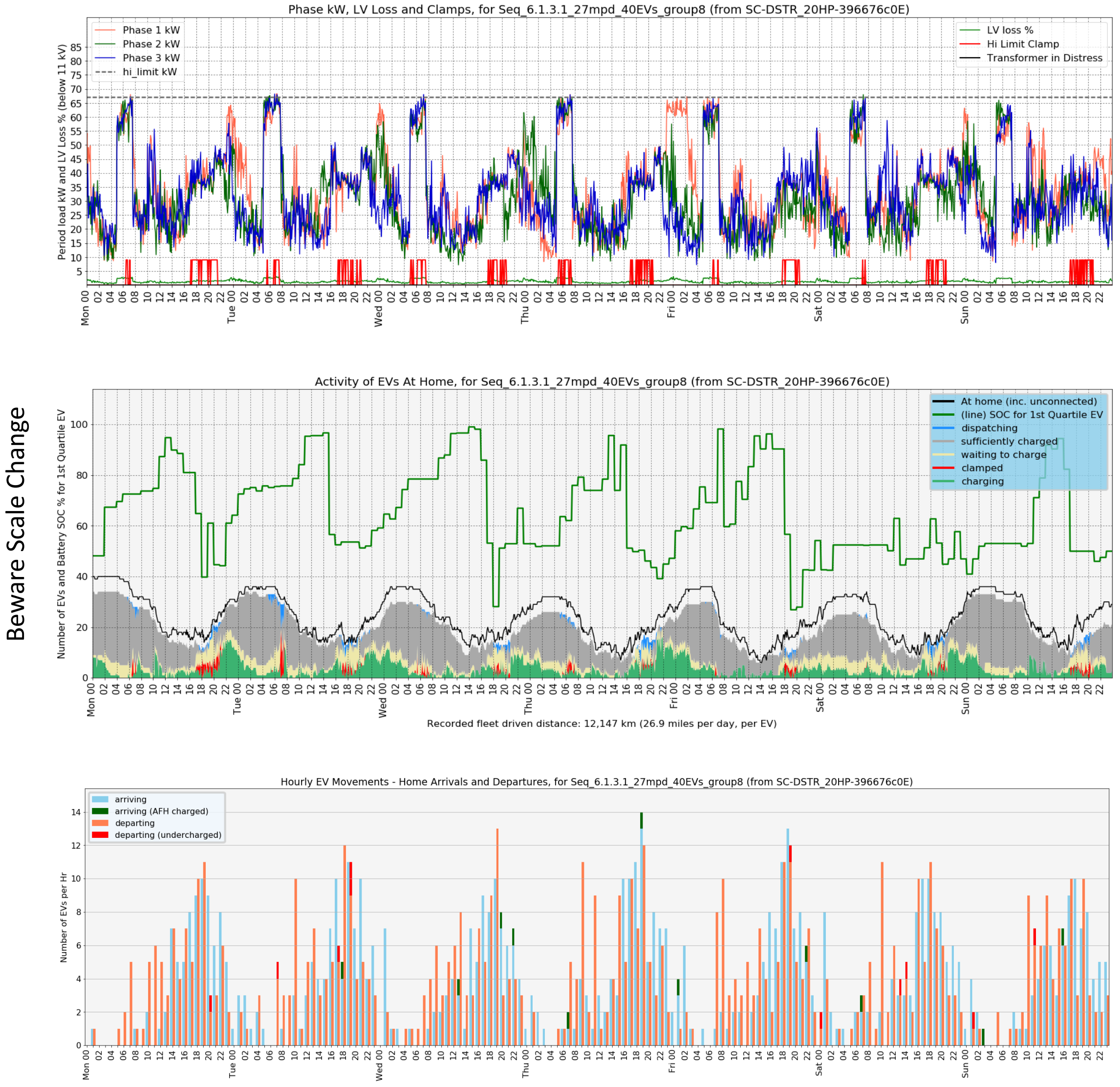
Note DR/FFR is included as a likely operational scenario (HP are expected from 2040 on) and are a prime Smart Grid controlled load.

V4-2.11.1 Seq_6.1.3.1 Outcomes

The Strong network could not cope with both 20% HP and DRFFR. EV charging was not acceptable for the parity case and over, suffering clamp over-counts and undercharging.

V4-2.12 Seq_6.1.3.1 Feeder and EV Plots

V4-2.12.1 Seq_6.1.3.1: 27mpd 40EVs



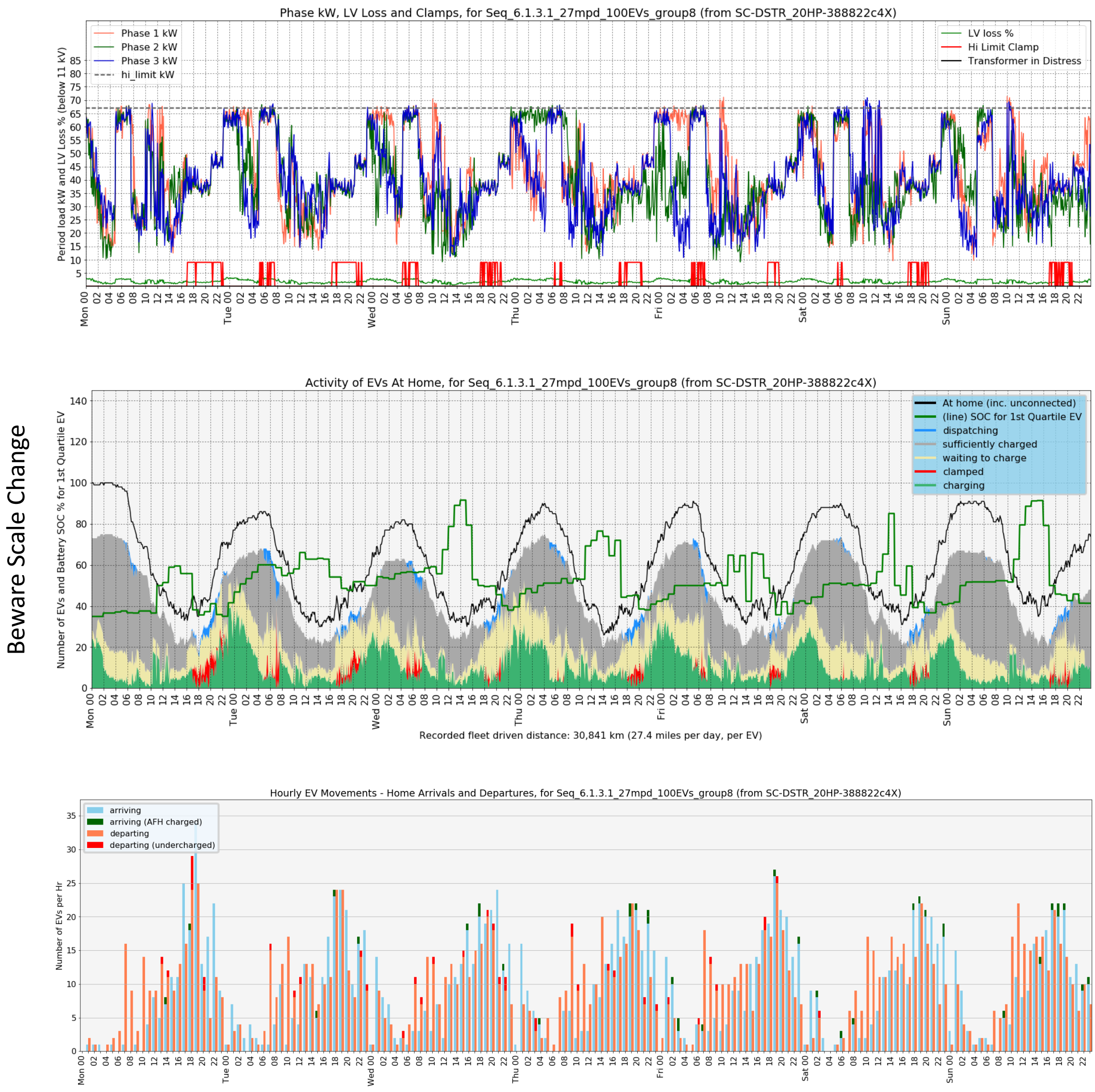
EoW stats: kWh[b] EV total: 2,467 Home: 2,177 AFH: 290 V2G: 163

Figure 2-8: Seq_6.1.3.1 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot shows the operation of HP in the early hours of each day, provoking clamping during the periods HP operate
- (CICD) EVs have good SOC; there are desultory champs and V2G dispatch
- (Arrive/Depart) undercharged departs and AFH charging are occasional.

V4-2.12.2 Seq_6.1.3.1: 27mpd 100EVs



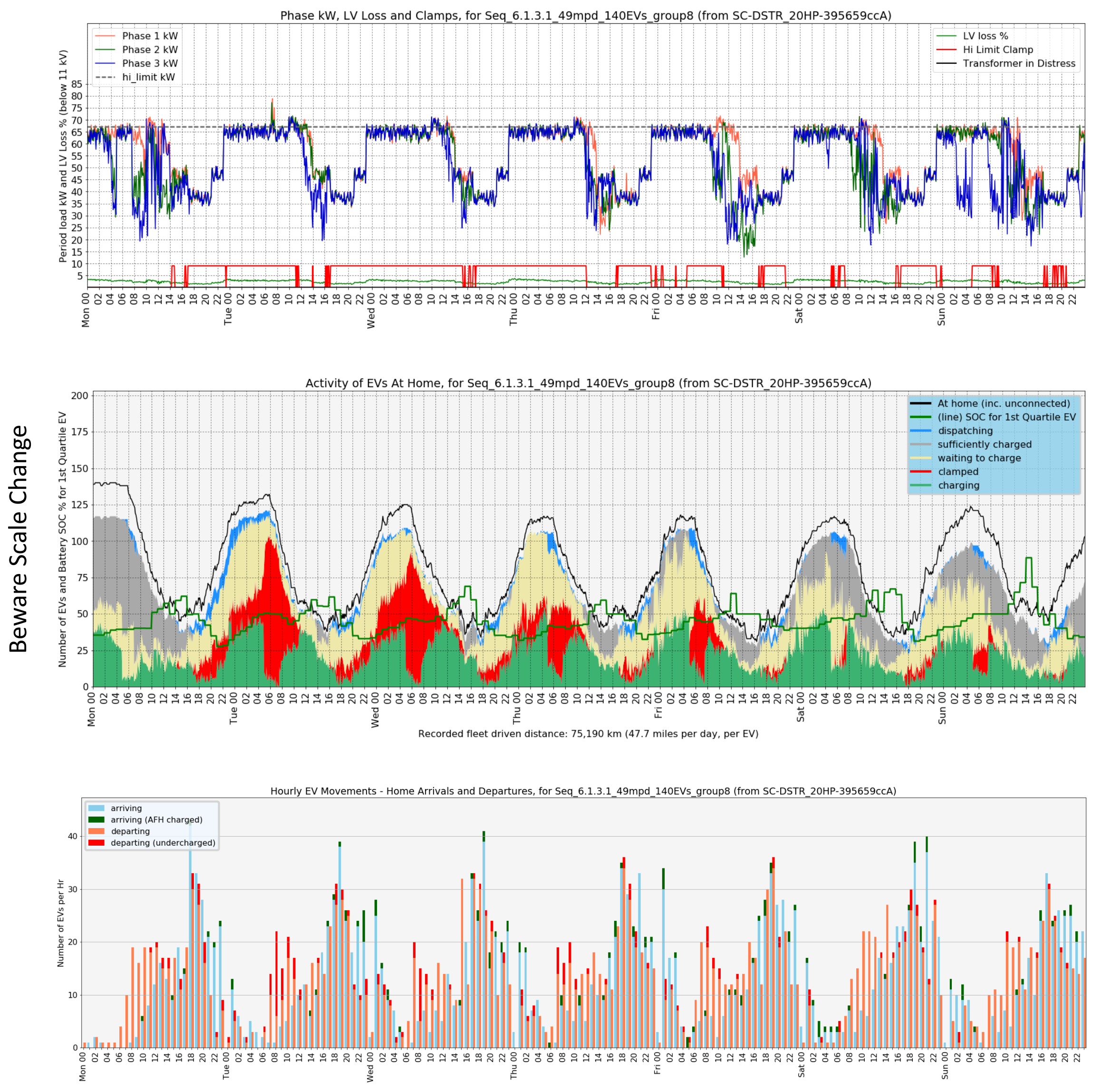
EoW stats: kWh[b] EV total: 6,337 Home: 5,529 AFH: 809 V2G: 448

Figure 2-9: Seq_6.1.3.1 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot is not remarkable
- (CICD) SOC is similar with significant numbers of EVs ready to depart; there is little range anxiety as many do not connect on return home
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. Both are low.

V4-2.12.3 Seq_6.1.3.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 15,005 Home: 10,534 AFH: 4,470 V2G: 1,424

Figure 2-10: Seq_6.1.3.1 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot has frequent clamps and evidences the DR/FFR signal. The MCS control algorithm is successfully “working around” the HP load,
- (CICD) EVs are not “starving” for there are non-connects and EVs waiting to depart. Early morning HP firing causes both clamps and V2G; we are at the limit of what the system can cope with e.g. 7pm Tuesday - no charging but occasional V2G support of local load (HP).
- by eye, undercharging and AFH charging have risen but remain low overall.

V4-2.13 Data Tables Seq_6.1.3.1

***Table 2-19:** 6.1.3.1 Unused kWh (weekly averages)*

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	20,216	19,578	18,327	17,070	15,792	14,491	13,175	11,882
	27mpd	20,102	19,323	17,806	16,269	14,757	13,209	11,571	9,930
	38mpd	20,005	19,129	17,357	15,553	13,803	11,928	10,074	8,261
	49mpd	19,922	18,961	16,997	15,030	13,126	11,091	9,125	7,352

Unutilised network capacity drops relatively evenly between plys.

Table 2-20: 6.1.3.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.1	3.1	3.1	3.2	3.4	3.3	3.3
	27mpd	6.4	7.4	7.2	7.6	8.0	8.1	7.9	7.8
	38mpd	16.6	16.6	17.1	17.6	17.6	18.1	17.8	18.1
	49mpd	34.4	31.9	30.7	30.4	30.3	30.5	31.0	31.9

AFH uptake appears to be linked to the driven distance.

Table 2-21: 6.1.3.1 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	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14
	27mpd	0.28	0.29	0.27	0.28	0.31	0.30	0.30	0.29
	38mpd	0.58	0.57	0.57	0.58	0.58	0.60	0.59	0.60
	49mpd	1.08	0.96	0.91	0.90	0.91	0.92	0.93	0.96

AFH connections is also seen linked to distance travelled.

Table 2-22: ***6.1.3.1 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.8	0.9	1.0	0.9	0.9
	27mpd	1.2	1.3	1.3	1.4	1.4	1.4	1.4	1.5
	38mpd	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.6
	49mpd	2.6	2.5	2.6	2.6	2.7	2.9	3.1	4.1

Undercharges are seen as a function of mpd, rising when excess number of EV are present. This is presumably due to scarcity / charge contention.

Table 2-23: ***6.2.2.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0028	0.0019	0.0012	0.0009	0.0006	0.0008	0.0005	0.0006
	27mpd	0.0008	0.0005	0.0012	0.0017	0.0016	0.0017	0.0010	0.0013
	38mpd	0.0034	0.0044	0.0058	0.0052	0.0051	0.0066	0.0063	0.0133
	49mpd	0.0078	0.0056	0.0082	0.0074	0.0092	0.0154	0.0267	0.0749

(limit: < 0.007)

Table 2-24: ***6.1.3.1 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	170.7	201.4	258.2	290.4	328.0	348.3	257.8	296.6
	27mpd	183.5	226.3	292.2	336.4	395.3	439.7	385.7	528.2
	38mpd	205.3	250.7	341.5	405.5	498.1	631.5	744.7	1,265.7
	49mpd	214.1	272.9	386.7	470.0	600.0	880.4	1,211.0	2,009.2

(limit: < 420)

The counts in red might concern Ofgem, as they exceed 420 clamps (2hrs clamped a day).

V4-2.14 Seq_6.1.3.1 Results Summary

***Table 2-25:** 6.1.3.1 Compared to Earlier Sequences*

Sequence	having	Highest N EVs Tolerated (at 19, 27, 38, 49mpd)
1.1.3	Strong network, no control	80, 80, 60, 40
5.1.3	Strong network, MCS only	140, 140, 140, 120
6.1.3	Strong network, MCS, V2G + clamps	140, 140, 140, 140
6.1.3.1	Strong network, MCS, V2G, clamps, plus 20% houses have HP	140, 80, 60, 20

20 HP appear too many for the parity case. This does however show that the MCS system will "work about" the HP, but the HP's consumption restricts acceptable EV charging. A clear message is:

- a network adequate for EVs will be compromised to some degree by HP
- therefore HP cannot be ignored.

***Table 2-26:** 6.1.3.1 Overall Usable EV Plies*

N EV	10	20	40	60	80	100	120	140
19mpd								
27mpd						C		C
38mpd					C	C	C	SC
49mpd			S	SC	SC	SC	SC	SC

Yellow: Severe undercharging too high, blue: Clamp limits exceeded, red: both too high

V4-2.15 Results for Sequence 6.2.2

Sequence	**Simulation ID**	**Description**
Seq_6.2.2	(S_85)	Variation vs. Seq_6.1.2: DR/FFR “B” added as a hi_limit modulation
Baseline Seq	***Description***	
Seq_6.1.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

This Sequence adds DRFFR to Seq_6.1.2 on the Typical network.

DR/FFR “B” has been described in Seq_6.1.3, and includes:

- a timed DR signal lasting hours and
- a quickly varying FFR signal which repeat daily.

Implementation is by modulating the hi_limit setpoint.

Data originate from MetaMeta spreadsheets (as online) for Seq_6.2.2.

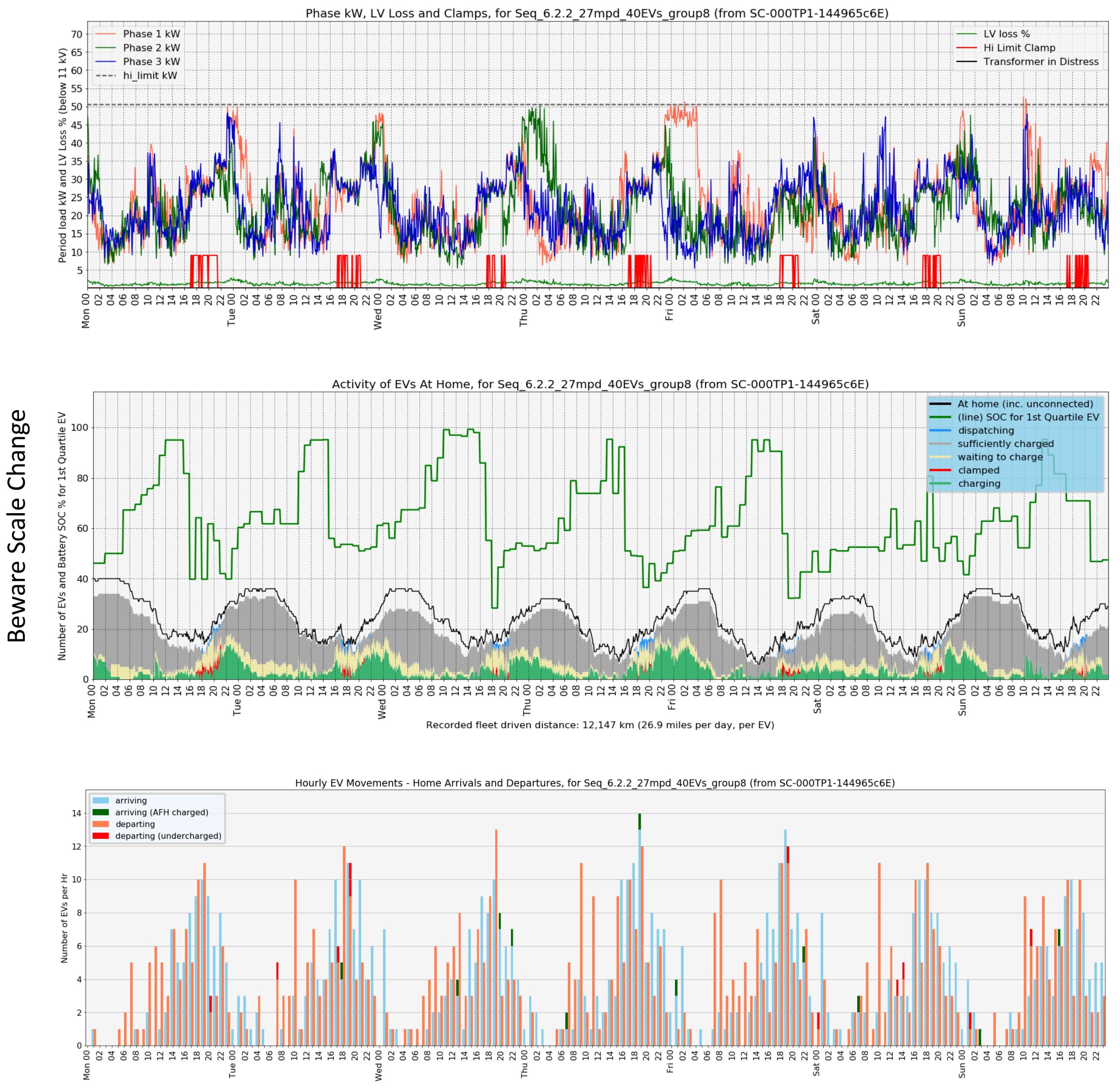
V4-2.15.1 Seq_6.2.2 Outcomes

Whereas the 19mpd plies were unaffected, 27mpd dropped from 140 to 120 EVs support, 38mpd collapsed from 120 to 60 EVs supported and 49mpd from 100 to 60 EVs (with an happenstance / outlier fail at 40 EVs).

For most locations this is likely acceptable.

V4-2.16 Seq_6.2.2 Feeder and EV Plots

V4-2.16.1 Seq_6.2.2: 27mpd 40EVs



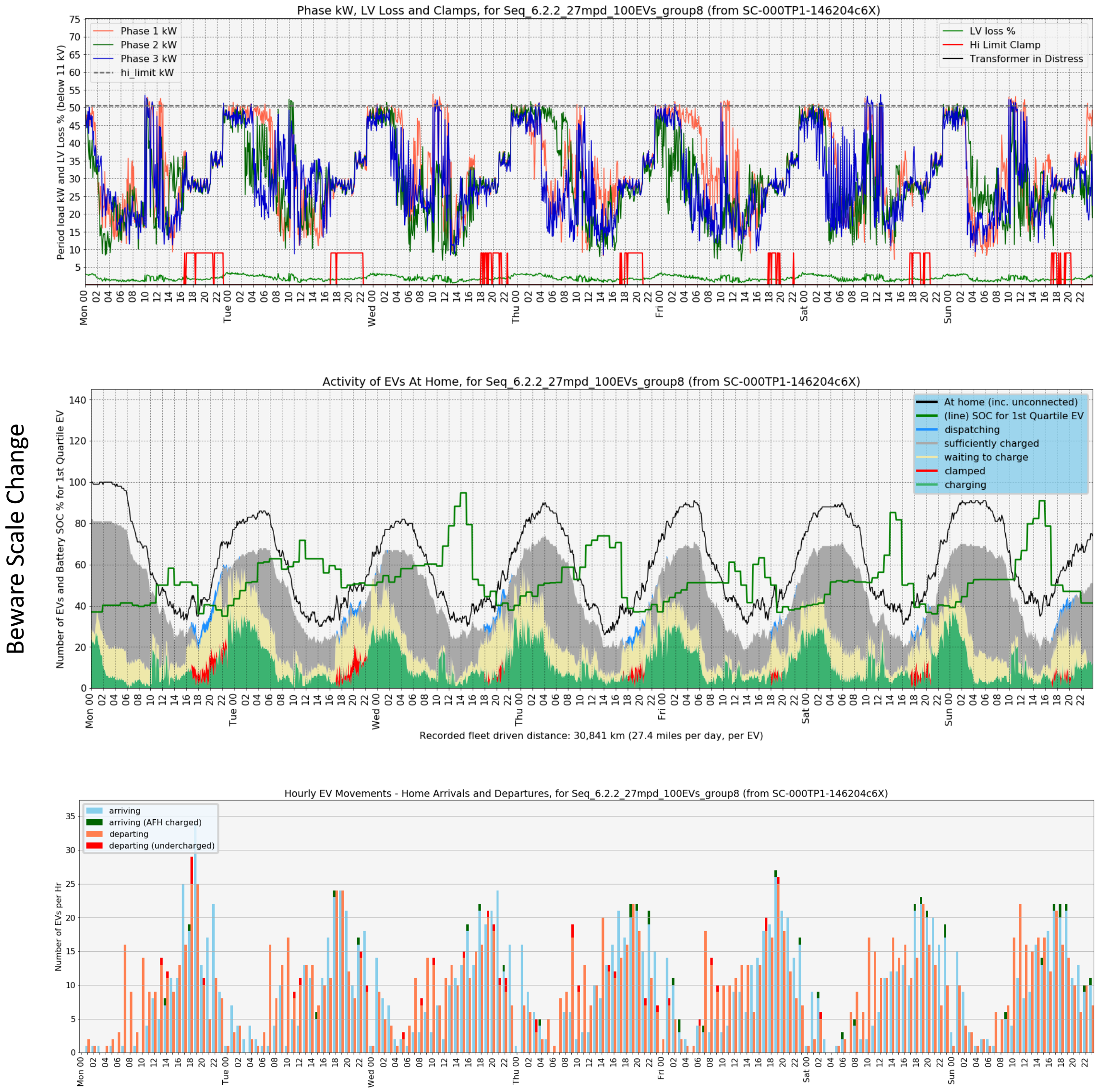
EoW stats: kWh[b] EV total: 2,394 Home: 2,105 AFH: 289 V2G: 79

Figure 2-11: Seq_6.2.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC and many are ready to depart (grey). A scattering of V2G and clamps
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.16.2 Seq_6.2.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 6,165 Home: 5,359 AFH: 806 V2G: 260

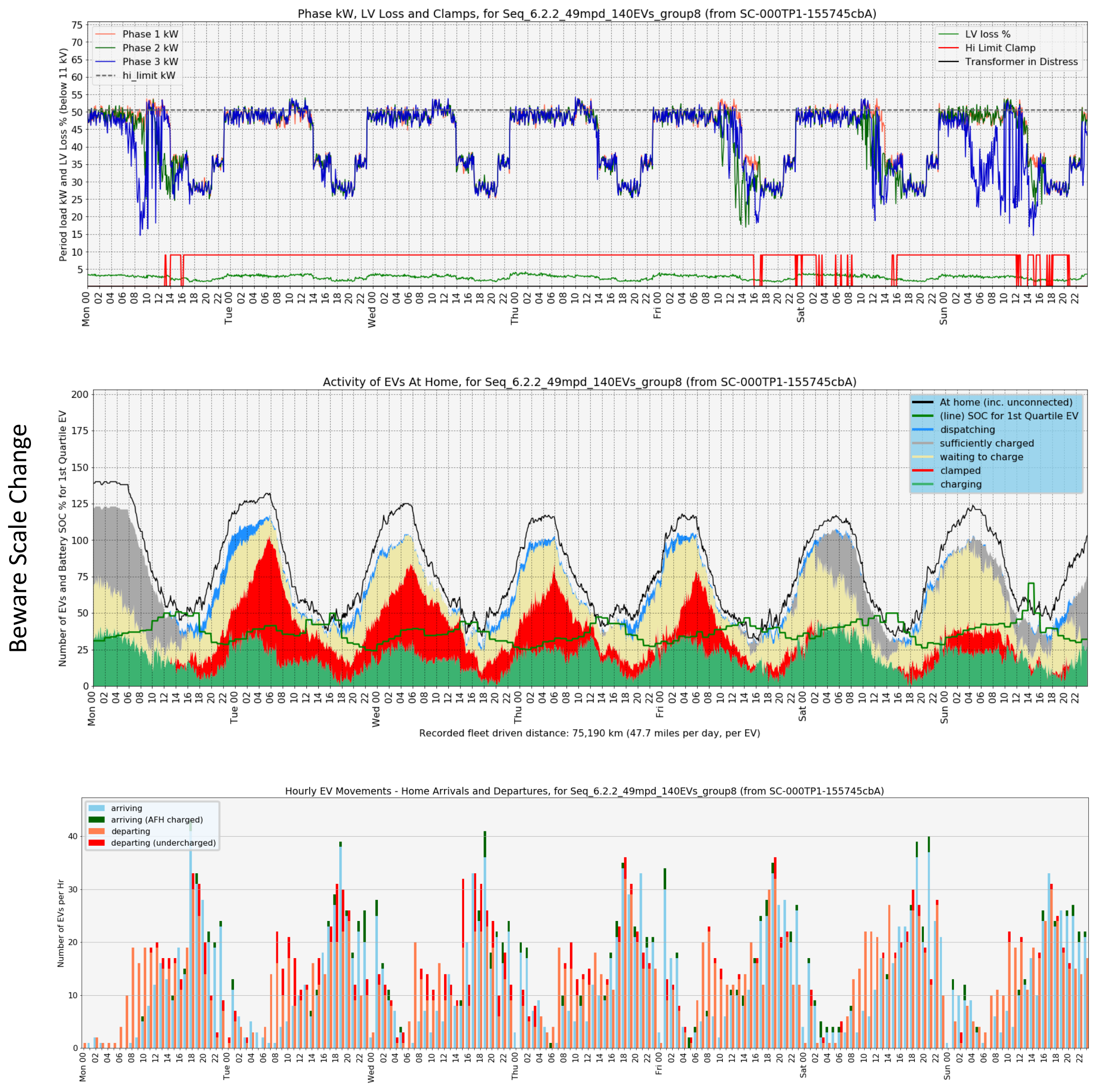
Figure 2-12: Seq_6.2.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) SOC is similar with many EVs ready to depart; some V2G and clamps
- (Arrive/Depart) small increase in undercharged departs and AFH charging
- charging for V2G duty is 1.36 * 260 kWh = 354 kWh (10.7 kWh per V2G EV); without V2G kWh draw is c. 6,165 - 354 = 5,814 kWh i.e. about 58 kWh per EV, thus battery life falls. Estimated loss per notional 10 weeks of duty pa is roughly 10 * (58 + 10.7) / 58 = 10 * 1.184 = 11.8 weeks notional life consumed in 10 weeks pa

i.e. a burden of 1.8 weeks which is 18 weeks over the life of the vehicle, if lifetime is proportional to throughput kWh.

V4-2.16.3 Seq_6.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,920 Home: 10,133 AFH: 4,787 V2G: 1,351

Figure 2-13: Seq_6.2.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows an apparent regular broach at 11am; this is a DR “Sunshine” signal (“please increase loading”). There are very frequent clamps;
- (CICD) V2G in blue is evident with widespread persistent clamps
- undercharging and AFH charging has clearly risen but do not seem extreme.

V4-2.17 Data Tables Seq_6.2.2

Table 2-27: 6.2.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	17,107	16,476	15,231	13,973	12,694	11,390	10,075	8,760
	27mpd	16,992	16,221	14,711	13,175	11,654	10,098	8,470	6,805
	38mpd	16,895	16,026	14,258	12,452	10,690	8,822	6,969	5,279
	49mpd	16,813	15,858	13,895	11,925	10,012	7,990	6,087	4,763

Note that DRFFR "B" makes 1,134 kWh capacity unutilised, which cools the transformer.

Table 2-28: 6.2.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.0	3.1	3.0	3.2	3.4	3.3	3.3
	27mpd	6.3	7.3	7.2	7.5	8.0	8.0	7.9	7.8
	38mpd	16.5	16.6	17.0	17.6	17.6	18.0	17.8	18.7
	49mpd	34.4	31.8	30.6	30.4	30.2	30.4	31.3	34.2

It is noticeable that 140 EVs driving 38 and 49 mpd require more AFH charge.

Table 2-29: 6.2.2 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	0.11	0.13	0.13	0.13	0.13	0.14	0.14	0.14
	27mpd	0.28	0.29	0.27	0.28	0.30	0.30	0.30	0.29
	38mpd	0.58	0.57	0.57	0.58	0.58	0.60	0.59	0.63
	49mpd	1.08	0.96	0.91	0.90	0.91	0.92	0.94	1.05

The number of connects does not noticeably rise with N EV.

***Table 2-30:** 6.2.2 Counts of Undercharging events per EV (weekly averages)*

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9
	27mpd	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5
	38mpd	1.8	1.9	2.0	2.0	2.1	2.2	2.2	2.9
	49mpd	2.6	2.5	2.6	2.6	2.6	2.8	3.2	5.0

A small increase is seen.

***Table 2-31:** 6.2.2 Counts of Severely Undercharged EVs in Week, per EV*

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0022	0.0013	0.0010	0.0008	0.0005	0.0007	0.0006	0.0005
	27mpd	0.0002	0.0006	0.0012	0.0015	0.0016	0.0015	0.0010	0.0014
	38mpd	0.0038	0.0039	0.0048	0.0052	0.0049	0.0062	0.0060	0.0350
	49mpd	0.0070	0.0045	0.0071	0.0065	0.0087	0.0115	0.0336	0.1631

(limit: < 0.007)

The darker red cells show elevated risk of severe undercharging, vs. 6.1.2.

***Table 2-32:** 6.2.2 MCS Clamps (weekly averages)*

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	91.4	119.6	168.3	205.3	243.5	269.8	208.6	248.9
	27mpd	98.6	139.1	203.6	252.6	308.6	366.3	340.2	582.4
	38mpd	115.7	163.6	248.1	321.8	419.5	606.6	932.5	2,091.9
	49mpd	124.1	183.3	286.7	380.3	548.7	1,032.0	1,757.8	2,985.2

(limit: < 420)

The failed counts might concern Ofgem, as they exceed 420 clamps (2hrs clamped a day).

Table 2-33: ***6.2.2 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	8.1	5.4	4.5	4.2	5.0	5.8	6.7	7.3
	27mpd	7.5	5.2	4.7	4.9	6.3	7.9	9.9	14.0
	38mpd	7.4	5.2	5.2	5.9	8.2	12.3	18.3	25.0
	49mpd	7.2	5.2	5.6	6.8	10.3	17.0	23.7	27.0

For the parity case, V2G EVs suffer about an extra day's duty, which if occurring 10 weeks a year over 10 years looses c. 100 days life, about 1/4 a year, which may be acceptable. However the elevated duties beyond the parity case are likely not acceptable.

The costs for this, especially for the higher duties, need be recognised and repaid to the owner (it is not clear if this is the vehicle driver or manufacturer, who may retain battery ownership).

Table 2-34: ***6.2.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.7%	35.1%	41.7%	49.4%	57.1%	67.3%	71.4%	78.0%
	27mpd	31.5%	35.7%	44.6%	53.6%	66.7%	73.8%	81.0%	88.1%
	38mpd	32.1%	36.9%	45.8%	59.5%	72.6%	79.2%	86.9%	94.6%
	49mpd	31.5%	36.9%	49.4%	62.5%	75.6%	82.1%	89.9%	98.2%

Note that random noise scores c. 25%.

V4-2.18 Seq_6.2.2 Results Summary

The sequence is a baseline and shows that, with DR/FFR “B”:

- the system still functions, but
- severe undercharges rise (yellow areas)
- clamp counts rise (blue areas)

reaching levels which are thought unacceptable. This is likely due to the DR component which limits available kWh by 1,134 kWh a week.

Table 2-35: ***6.2.2 Overall Usable EV Plies***

N EV	10	20	40	60	80	100	120	140
19mpd								
27mpd								C
38mpd					C	C	C	SC
49mpd			S		SC	SC	SC	SC

Yellow: Severe undercharging too high, blue: Clamp limits exceeded, red: both too high

Smart charging, V2G and clamps are used under MCS control to provide a viable system.

Rejecting the highlighted cases due to excesses, this arrangement appears to be viable for:

a) locations experiencing 49mpd: up to 20 EVs

b) locations experiencing 38mpd: up to 60 EVs

c) locations experiencing 27mpd: up to 120 EVs

This is assuming other effects (flicker, harmonics etc.) do not prohibit operation.

V4-2.19 Sequence 6.2.2.1

Sequence	**Simulation ID**	**Description**
Seq_6.2.2.1	(S_AR)	Variation vs. Seq_6.2.2: Pre-Burn V2G OFF
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

This was an attempt for another duty which on review was found misconfigured, however the run is valid and has achieved:

- pre-burn V2G is **OFF**

resulting in a mimic of Seq_6.2.2, identical other than V2G use is made a last-resort (aids limit clamping), not a first resort (auto-lifts headroom). The simulation is retained as this is an interesting permutation. Note that run-time notes talk about Static Batteries; please ignore those comments.

The data shown originates from MetaMeta spreadsheets (as online) for Seq_6.2.2.1.

Pre-Burn V2G Refresher: if the MCS knows V2G is available, it can choose to "pre-burn" it by adding it to the phase headroom kW for allowed EV charging (the alternative is to keep it as a last resort). Pre-burn aids "mandatory" charging EVs such as dumb EVs; with Pre-Burn ON they receive more kWh. Pre-Burn V2G can be seen operating as the leading-edge blue in Seq_6.2.2: 49mpd 140EVs CICD plot e.g. for 00:00 hrs Tuesday:

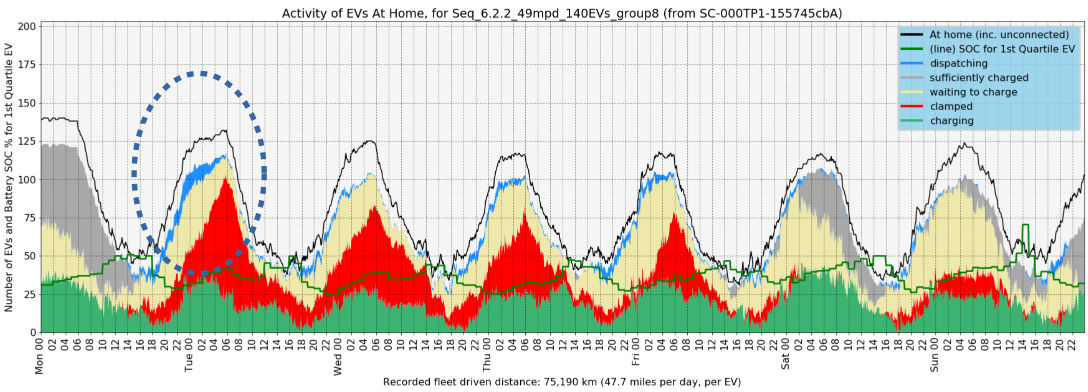


Figure 2-14: Illustration of V2G Pre-Burn (indicated in blue area)

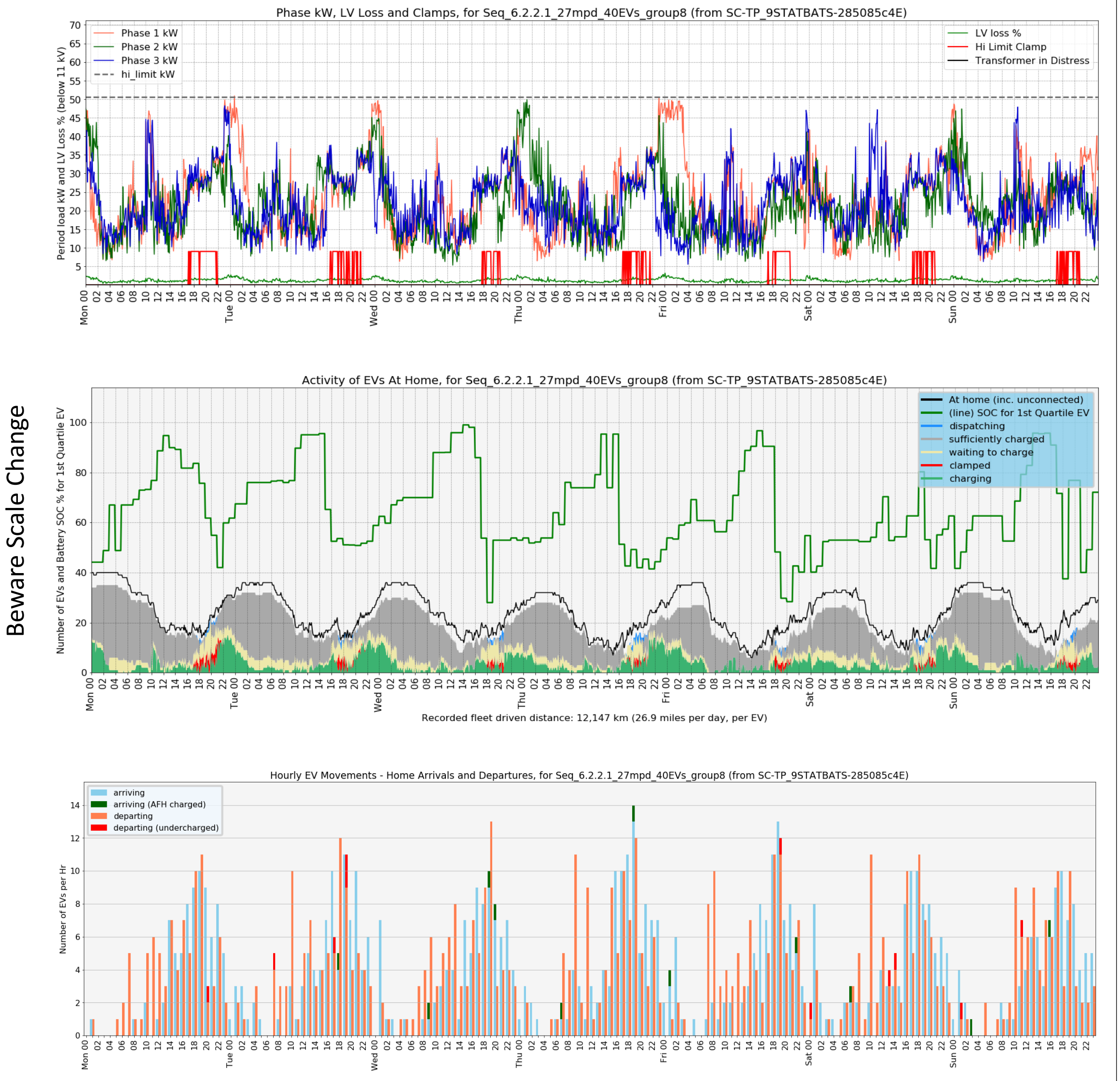
6.2.2.1 has turned this feature OFF. As a result, effective headroom drops: EVs are like to suffer undercharging.

V4-2.19.1 Seq_6.2.2.1 Outcomes

The effect is very noticeable, causing use of clamps to rise. 6 plies have been lost due to excess clamp counts and an extra severe undercharge.

V4-2.20 Feeder and EV Plots

V4-2.20.1 Seq_6.2.2.1: 27mpd 40EVs



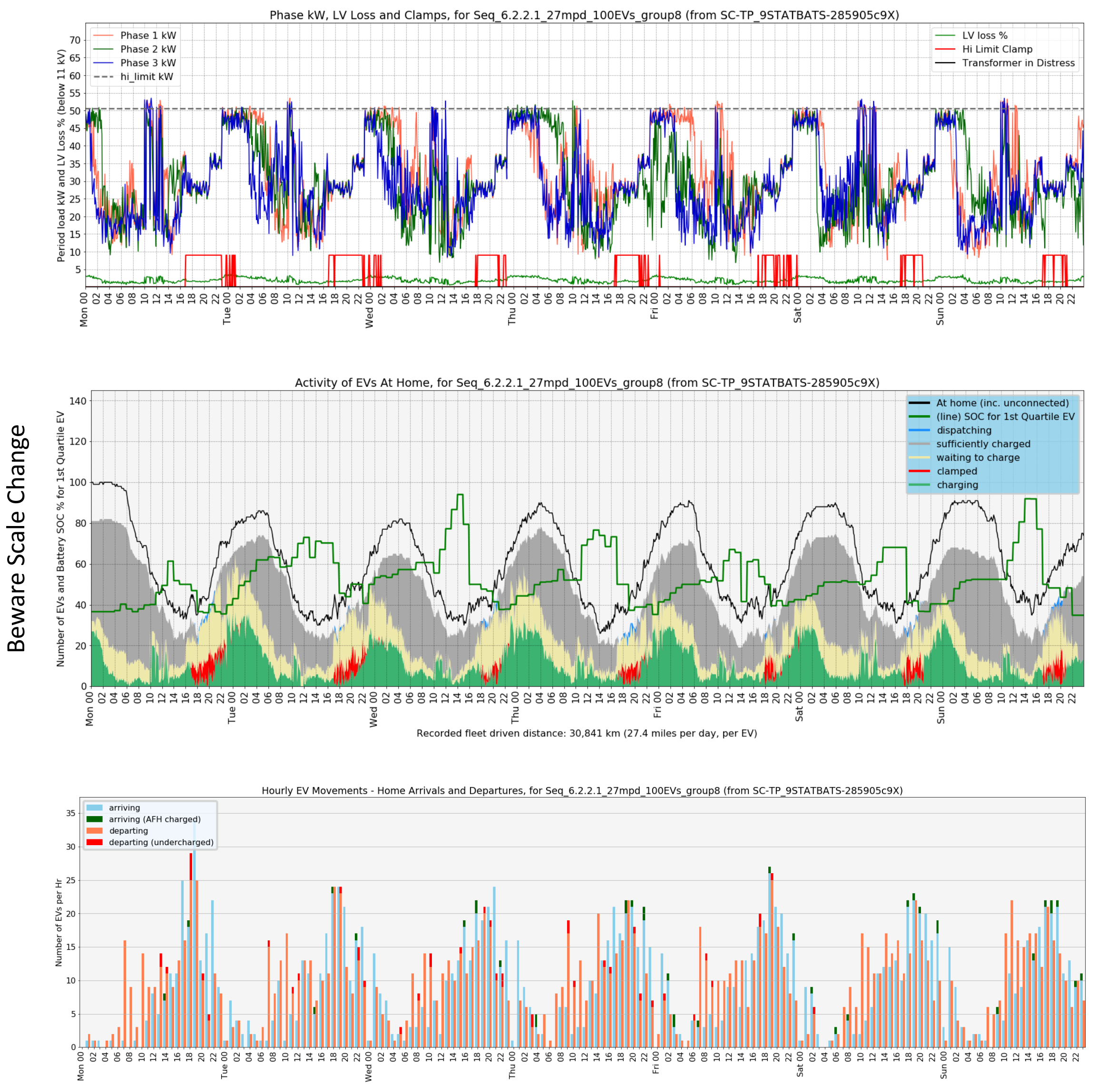
EoW stats: kWh[b] EV total: 2,375 Home: 2,083 AFH: 291 V2G: 61

Figure 2-15: Seq_6.2.2.1 27mpd 40EVs group 8 plots. Weekly km: 12,212

V2G is down on the week from 6.2.2's 79 kWh,

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC. This plot shows no substantive departures from 6.2.2
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.20.2 Seq_6.2.2.1: 27mpd 100EVs



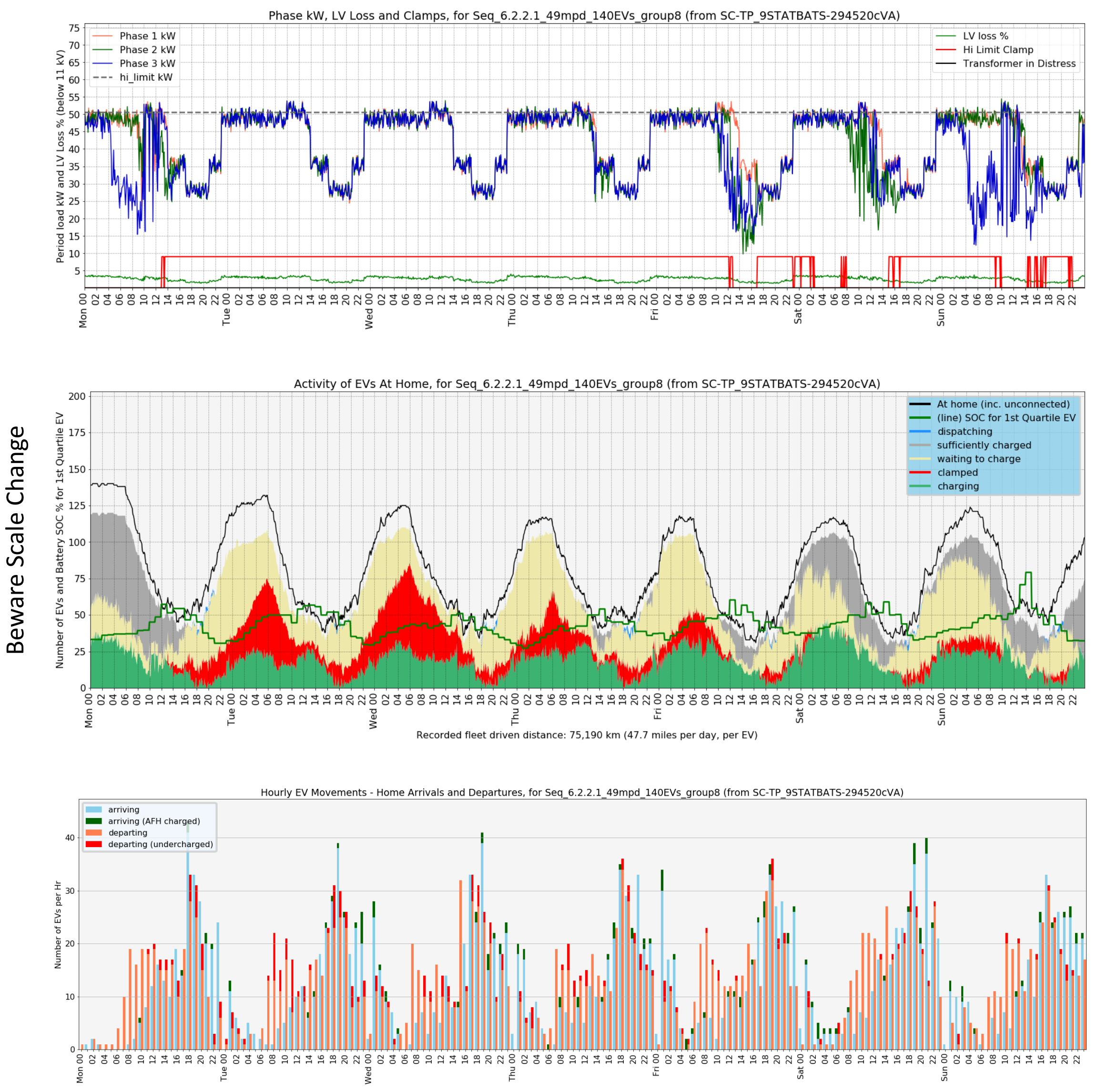
EoW stats: kWh[b] EV total: 5,983 Home: 5,161 AFH: 822 V2G: 79

Figure 2-16: Seq_6.2.2.1 27mpd 100EVs group 8 plots. Weekly km: 30,876

V2G use has dropped from 6.2.2’s 260 kWh,

- the Feeder plot is again unremarkable
- (CICD) again very similar to 6.2.2. Pre-burn in 6.2.2 (Monday evening) is reduced
- (Arrive/Depart) by eye identical to 6.2.2.

V4-2.20.3 Seq_6.2.2.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,709 Home: 8,997 AFH: 4,712 V2G: 95

Figure 2-17: Seq_6.2.2.1 27mpd 140EVs group 8 plots. Weekly km: 77,327

V2G use has greatly dropped from 6.2.2's 1,351 kWh usage

- the Feeder plot has long periods of clamping
- (CICD) V2G in blue is again almost invisible vs. in 6.2.2, highly apparent
- (Arrive/Depart) again, by eye identical to 6.2.2.

V4-2.21 Data Tables Seq_6.2.2.1

Table 2-36: 6.2.2.1 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	17,108	16,479	15,247	13,998	12,743	11,479	10,220	8,958
	27mpd	16,993	16,225	14,728	13,213	11,726	10,233	8,705	7,182
	38mpd	16,896	16,031	14,282	12,513	10,801	9,040	7,376	5,754
	49mpd	16,814	15,864	13,930	12,003	10,159	8,280	6,548	5,110

6.2.2 span: [10,098] => [4,763]

Unutilised kWh has risen vs. 6.2.2.

Table 2-37: 6.2.2.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.0	3.1	3.1	3.2	3.5	3.4	3.4
	27mpd	6.4	7.4	7.3	7.6	8.2	8.2	8.1	8.0
	38mpd	16.5	16.7	17.2	17.8	17.8	18.4	18.2	18.7
	49mpd	34.4	31.9	30.8	30.7	30.6	30.9	31.7	33.6

6.2.2 span: [8.0] => [34.2]

In general, slightly elevated vs. 6.2.2.

Table 2-38: 6.2.2.1 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	0.12	0.13	0.13	0.13	0.14	0.15	0.14	0.14
	27mpd	0.28	0.29	0.27	0.29	0.31	0.31	0.31	0.31
	38mpd	0.58	0.57	0.58	0.59	0.60	0.61	0.61	0.63
	49mpd	1.09	0.96	0.92	0.91	0.93	0.94	0.96	1.03

6.2.2 span: [0.3] => [1.05]

There is a slight increase in need to AFH charge vs. 6.2.2

Table 2-39: ***6.2.2.1 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.0
	27mpd	1.2	1.3	1.4	1.4	1.5	1.5	1.5	1.6
	38mpd	1.9	1.9	2.1	2.1	2.2	2.3	2.4	2.8
	49mpd	2.6	2.6	2.7	2.7	2.8	3.0	3.3	4.6

6.2.2 span: [1.4] => [5.0]

A small increase is seen, other than 49mpd 140 EVs.

Table 2-40: ***6.2.2.1 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0028	0.0020	0.0015	0.0011	0.0012	0.0015	0.0011	0.0011
	27mpd	0.0002	0.0005	0.0016	0.0025	0.0025	0.0026	0.0028	0.0031
	38mpd	0.0040	0.0041	0.0072	0.0067	0.0068	0.0087	0.0086	0.0224
	49mpd	0.0072	0.0050	0.0087	0.0082	0.0119	0.0164	0.0299	0.1194

(limit: < 0.007) 6.2.2 span: [0.0015] => [0.1631]

These show an increase in severe undercharging vs. 6.2.2, from 5 plies to 11.

Table 2-41: ***6.2.2.1 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	107.4	159.8	273.1	349.6	432.8	520.9	590.3	684.5
	27mpd	114.2	180.4	307.2	410.5	522.7	660.8	787.0	1,056.6
	38mpd	131.6	207.3	363.3	498.4	663.9	944.2	1,311.2	2,121.2
	49mpd	139.3	226.7	404.3	567.0	806.7	1,303.2	1,915.5	2,887.2

(limit: < 420) 6.2.2 span: [366] => [2,985] (suggest 420 peak value)

These show an increase in high-clamp counts vs. 6.2.2, from 8 plies to 18.

Table 2-42: ***6.2.2.1 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	8.0	5.0	3.6	2.8	2.7	2.4	2.1	1.8
	27mpd	7.3	4.8	3.6	2.9	2.7	2.4	2.1	1.8
	38mpd	7.2	4.7	3.6	2.9	2.7	2.4	2.1	1.9
	49mpd	7.0	4.6	3.6	2.9	2.8	2.5	2.1	1.9

6.2.2 span: [7.9] => [27.0]

These values are noticeably down vs. 6.2.2

Table 2-43: ***6.2.2.1 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.7%	35.1%	41.7%	48.2%	57.1%	66.1%	72.0%	78.0%
	27mpd	31.5%	35.7%	44.0%	53.6%	66.7%	72.6%	79.2%	86.3%
	38mpd	31.5%	36.9%	45.2%	58.9%	71.4%	78.6%	85.7%	92.3%
	49mpd	31.5%	36.9%	48.8%	63.1%	73.8%	80.4%	89.9%	96.4%

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

Note that random noise scores c. 25%. These values are < 2% down on 6.2.2 values.

V4-2.22 Seq_6.2.2.1 Results Summary

Seq_6.2.2.1 has greatly reduced V2G at the cost of increased clamps and degraded undercharging. V2G has hidden expenses (primarily in accelerating capex for battery replacement, complex billing and likely double charging).

Is there middle-ground between these?

As a result, a clamp count-cap is being pursued; hopefully this will remove V2G for the more trivial cases and reduce costs. These results also highlight that the clamping count at present does not reflect the EV view; it is difficult to determine when there are too many. To aid visibility concerning this issue, simulator enhancements are needed.

Table 2-44:* *6.2.2.1 Overall Usable EV Plies

N EV	10	20	40	60	80	100	120	140
19mpd								
27mpd					C	C	C	C
38mpd			S	C	C	SC	SC	SC
49mpd			S	SC	SC	SC	SC	SC

Yellow: Severe undercharging too high, blue: Clamp limits exceeded, red: both too high

Recommendations (based on location from metropolis of (mpd -8) / 2):

- utilise MCS plus clamps and monitor
    - the following assume MCS plus clamps are operating
- if located over 20 miles from a metropolis:
    - secure alternative sources of charge (e.g. AFH)
    - reinforce once EV population > 20
- if located over 15 miles from a metropolis: reinforce once EV population > 20
- if located over 10 miles from a metropolis: reinforce once EV population > 60
- if located under 10 miles from a metropolis: no likely need to reinforce.

Does the MCS not indicate these limits approaching? In general, increasing incidence rates of clamping and undercharging.

V4-2.23 Sequence 6.2.2.2

Sequence	**Simulation ID**	**Description**
Seq_6.2.2.2	(S_AS)	Variation vs. Seq_6.2.2: All mobile EVs are dumb. 9 total Static Batteries are added. All EVs perform home perfect plugins (100% connectivity)
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

These sequence adds 3 immobile V2G EVs per phase, so mimicking Static Batteries. These have standard inverters (7.2 kW output) and large batteries at 150 kWh. EVs always plug-in on arriving home, so receive the maximum available kWh. AFH charging is standard.

Per phase these Static Batteries only offer 21.6kW of support as against the 11 * 7.2 kW = 79 kW usually available. However they are run with pre-burn ON.

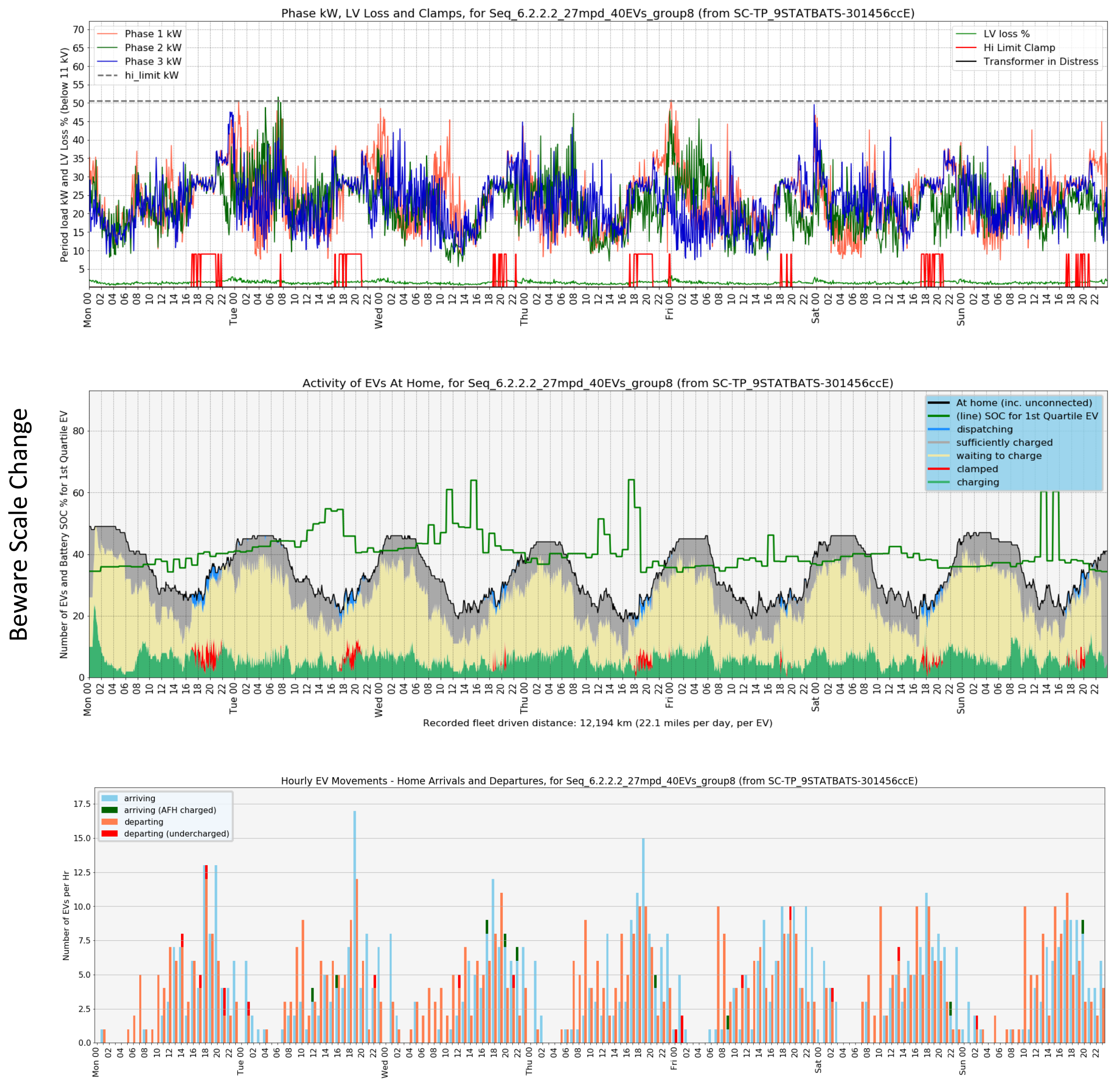
Note that as the mobile EVs are 100% dumb, clamps must be used - the EVs are deaf to the MCS ICT dialogue. Clamping is the only control over EVs, although the MCS is managing Static Battery charging and dispatch.

V4-2.23.1 Seq_6.2.2.2 Outcomes

Removing the Smart EVs had immediate detrimental impact. Although the Static Batteries helped, the test might be usefully re-run with 81% SV1G EVs i.e. to make all V2G EVs SV1G.

V4-2.24 Seq_6.2.2.2 Feeder and EV Plots

V4-2.24.1 Seq_6.2.2.2: 27mpd 40EVs



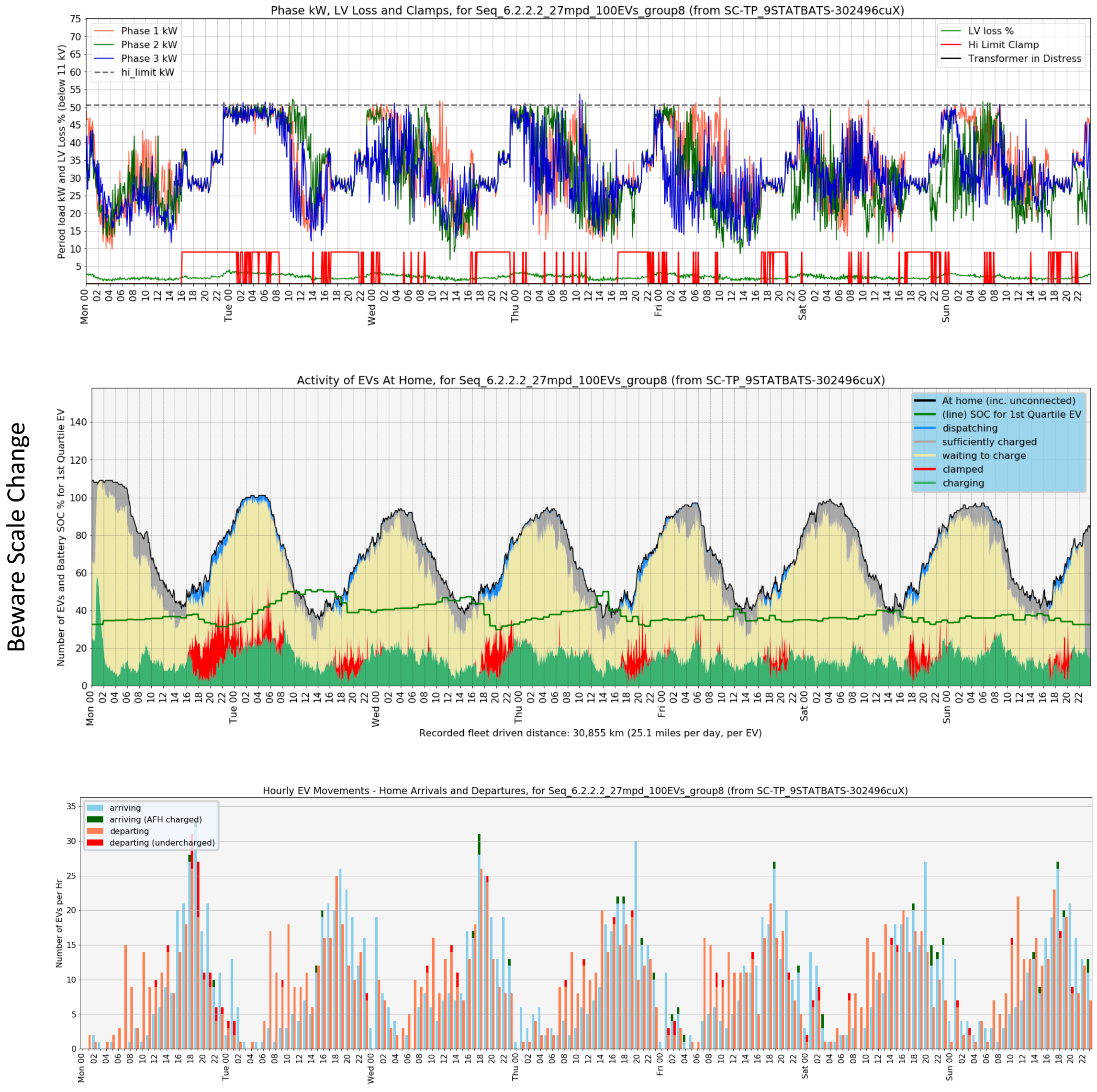
EoW stats: kWh[b] EV total: 2,563 Home: 2,253 AFH: 311 V2G: 239

Figure 2-18: Seq_6.2.2.2 27mpd 40EVs group 8 plots. Weekly km: 12,227

Notes re above plots:

- the Feeder plot is lower than usual (NB this is busbar load, not delivered kW)
- (CICD) EVs have acceptable SOC. All EVs are plugged-in
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.24.2 Seq_6.2.2.2: 27mpd 100EVs



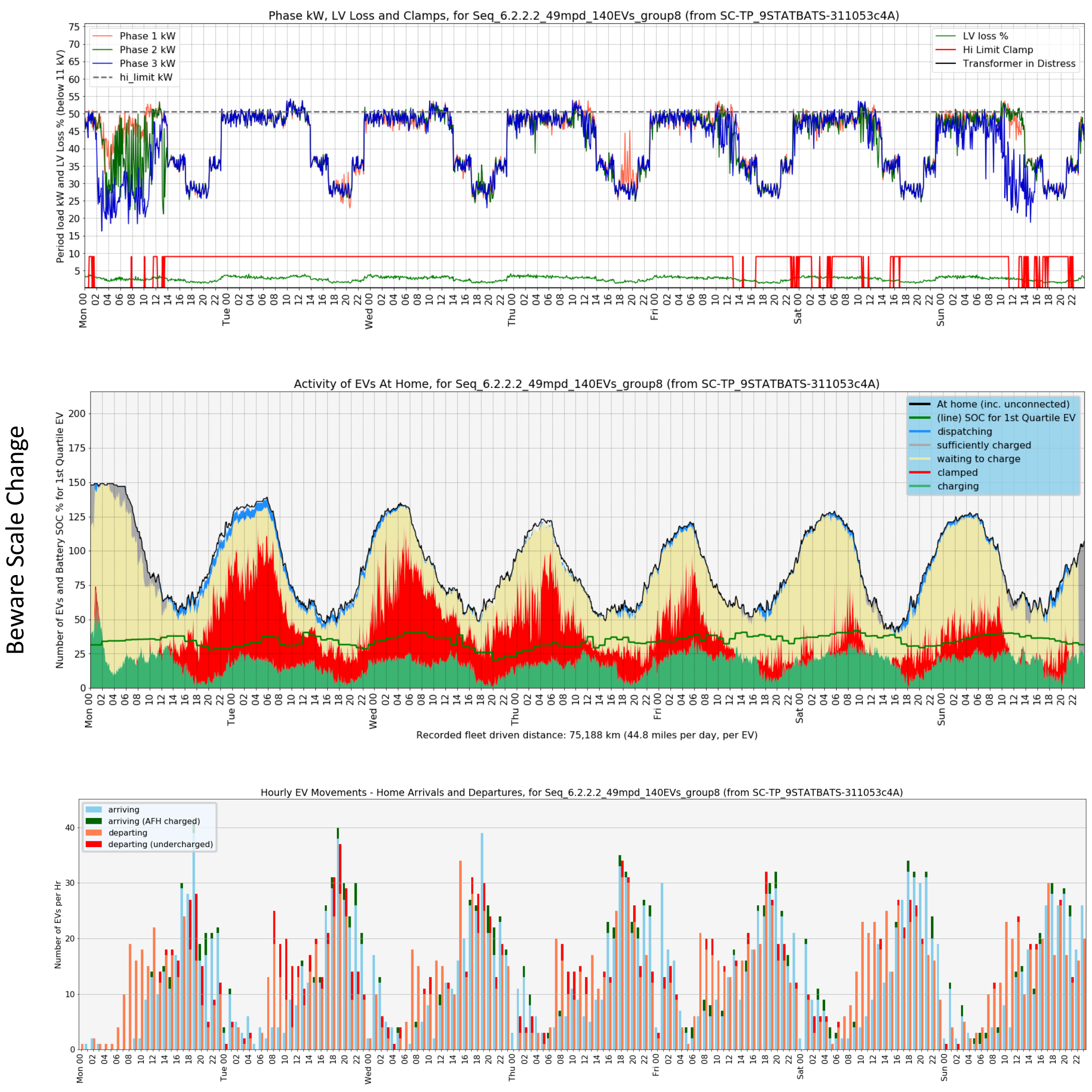
EoW stats: kWh[b] EV total: 6,634 Home: 5,782 AFH: 852 V2G: 756

Figure 2-19: Seq_6.2.2.2 27mpd 100EVs group 8 plots. Weekly km: 30,877

Notes re above plots:

- the Feeder plot shows the DR/FFR pattern, enforced predominantly by clamps
- (CICD) SOC is down slightly; all EVs are plugged-in and there is scattered V2G plus clamps
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.24.3 Seq_6.2.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,798 Home: 9,979 AFH: 4,819 V2G: 1,267

Figure 2-20: Seq_6.2.2.2 49mpd 140EVs group 8 plots. Fleet drives 77,340 km

Notes re above plots:

- the Feeder plot has long periods of clamping
- (CICD) V2G in blue strives to limit the high degree of clamping
- undercharging and AFH charging has clearly risen but do not seem extreme.

V4-2.25 Data Tables Seq_6.2.2.2

***Table 2-45:** 6.2.2.2 Unused kWh (weekly averages)*

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	16,879	16,182	14,793	13,403	12,040	10,667	9,355	7,980
	27mpd	16,768	15,944	14,317	12,694	11,112	9,537	7,992	6,417
	38mpd	16,678	15,767	13,913	12,061	10,274	8,442	6,752	5,264
	49mpd	16,597	15,618	13,600	11,599	9,699	7,735	6,006	4,832

6.2.2 span: [10,098] => [4,763]

Note that DRFFR "B" makes 1,134 kWh capacity unutilised, which cools the transformer.

Table 2-46: 6.2.2.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.7	3.2	3.3	3.3	3.4	3.6	3.6	3.6
	27mpd	6.7	7.8	7.8	8.1	8.5	8.5	8.4	8.3
	38mpd	17.6	17.6	17.9	18.7	18.4	18.8	18.8	19.2
	49mpd	35.7	33.4	32.0	31.7	31.5	31.6	32.4	34.4

6.2.2 span: [8.0] => [34.2]

AFH is slightly up, which may be expected if less charge is available at home.

Table 2-47: 6.2.2.2 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	0.13	0.14	0.15	0.15	0.15
	27mpd	0.30	0.31	0.30	0.31	0.33	0.32	0.32	0.32
	38mpd	0.63	0.61	0.61	0.62	0.62	0.63	0.64	0.66
	49mpd	1.15	1.04	0.97	0.96	0.97	0.97	1.00	1.07

6.2.2 span: [0.3] => [1.05]

There is a slight increase in need to AFH charge.

Table 2-48: 6.2.2.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4
	27mpd	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0
	38mpd	2.4	2.5	2.6	2.6	2.6	2.6	2.7	3.1
	49mpd	3.0	3.0	3.1	3.1	3.1	3.2	3.5	4.9

6.2.2 span: [1.4] => [5.0]

An increase is seen, other than for the 140 EV case.

Table 2-49: 6.2.2.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0002	0.0005	0.0004	0.0004	0.0006	0.0007	0.0006
	27mpd	0.0004	0.0004	0.0007	0.0012	0.0013	0.0018	0.0015	0.0018
	38mpd	0.0018	0.0039	0.0049	0.0053	0.0056	0.0058	0.0074	0.0268
	49mpd	0.0048	0.0047	0.0064	0.0065	0.0089	0.0120	0.0286	0.1299

6.2.2 span: [0.0015] => [0.1631] (limit: < 0.007)

All plies are slightly worse vs. 6.2.2, but one further cell (red) falls below the limit.

Table 2-50: 6.2.2.2 Static Battery kWh dispatch per Battery (weekly averages)

6. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12.5	15.9	24.9	35.8	49.3	67.1	88.2	115.6
	27mpd	12.8	16.6	26.5	40.0	58.5	84.1	117.1	158.0
	38mpd	13.1	17.4	29.1	46.0	70.9	108.0	150.8	167.1
	49mpd	13.4	17.8	30.4	50.5	81.5	125.7	161.5	140.7

6.2.2 span: [7.9] => [27.0]

The Static Batteries are clearly dispatching more vs. V2G in 6.2.2.

Table 2-51: ***6.2.2.2 MCS Clamps (weekly averages)***

7. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	68	114	222	350	503	697	923	1226
	27mpd	74	129	258	421	635	922	1297	1781
	38mpd	79	145	305	516	810	1259	1798	2652
	49mpd	85	153	331	587	975	1537	2253	3281

6.2.2 span: [366] => [2,985] (limit: < 420)

An extra 10 plies are lost vs. 6.2.2. These values also reflect that the EVs are dumb; they may only be controlled by clamps.

Table 2-52: ***6.2.2.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	34.5%	35.7%	36.9%	41.1%	46.4%	55.4%	65.5%	74.4%
	27mpd	33.3%	35.7%	39.9%	45.2%	52.4%	64.3%	73.8%	83.3%
	38mpd	32.7%	36.9%	41.1%	47.6%	59.5%	72.6%	82.7%	91.7%
	49mpd	34.5%	35.7%	43.5%	48.2%	60.1%	78.0%	88.1%	96.4%

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

The DR/FFR response metric is down vs. 6.2.2.

V4-2.26 Seq_6.2.2.2 Results Summary

Seq_6.2.2.2 has removed both SV1G and V2G EVs, substituting V2G with 3 static batteries per phase, which frankly are under-powered in terms of kW. However the Static Batteries have stood in for V2Gs effectively.

With all-dumb EVs, once Static Battery support becomes inadequate clamps are the only control, thus clamp counts raise. Re-running this experiment with SV1G EVs plus the standard number of dumb EVs may be useful. The network also has 9 extra units to charge (the Static Batteries) which has impacted under-charging.

A less aggressive DR protocol then DR-B may also help.

Table 2-53: ***6.2.2.2 Overall Usable EV Plies***

N EV	10	20	40	60	80	100	120	140
19mpd					C	C	C	C
27mpd				C	C	C	C	C
38mpd				C	C	C	SC	SC
49mpd				C	SC	SC	SC	SC

Key:

- clear: No observed issues
- green: gain vs. 6.2.2
- blue: clamp limits exceeded; dark blue: loss vs. 6.2.2
- red: both clamps and severe undercharging rates too high; dark red: loss vs. 6.2.2.

V4-2.27 Sequence 6.2.2.3

Sequence	**Simulation ID**	**Description**
Seq_6.2.2.3	(S_BD)	Variation vs. Seq_6.2.2: An alternative mixed V2G and clamping method, so to limit V2G pre-burn
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Sequence 6.2.2.1 illustrated that V2G pre-burn OFF greatly limited use of V2G, which is a cost and battery-ageing factor.

Seq_6.2.2.3 allocates a running “clamp budget” which is to be consumed before V2G Pre-burn is used. This is set to 500 instances across the week, allocated pro-rata over time.

The intent is to limit use of V2G whilst holding clamping to an acceptable level. The method employed was straightforward to implement.

Note that clamps remain the mechanism of last resort / will always be used if necessary.

V4-2.27.1 Seq_6.2.2.3 Outcomes

The method shows promise but in this form is a step backwards. V2G use was however reduced, offering an apparent uplift of V2G EV battery life of 3 weeks, vs. Seq_6.2.2.

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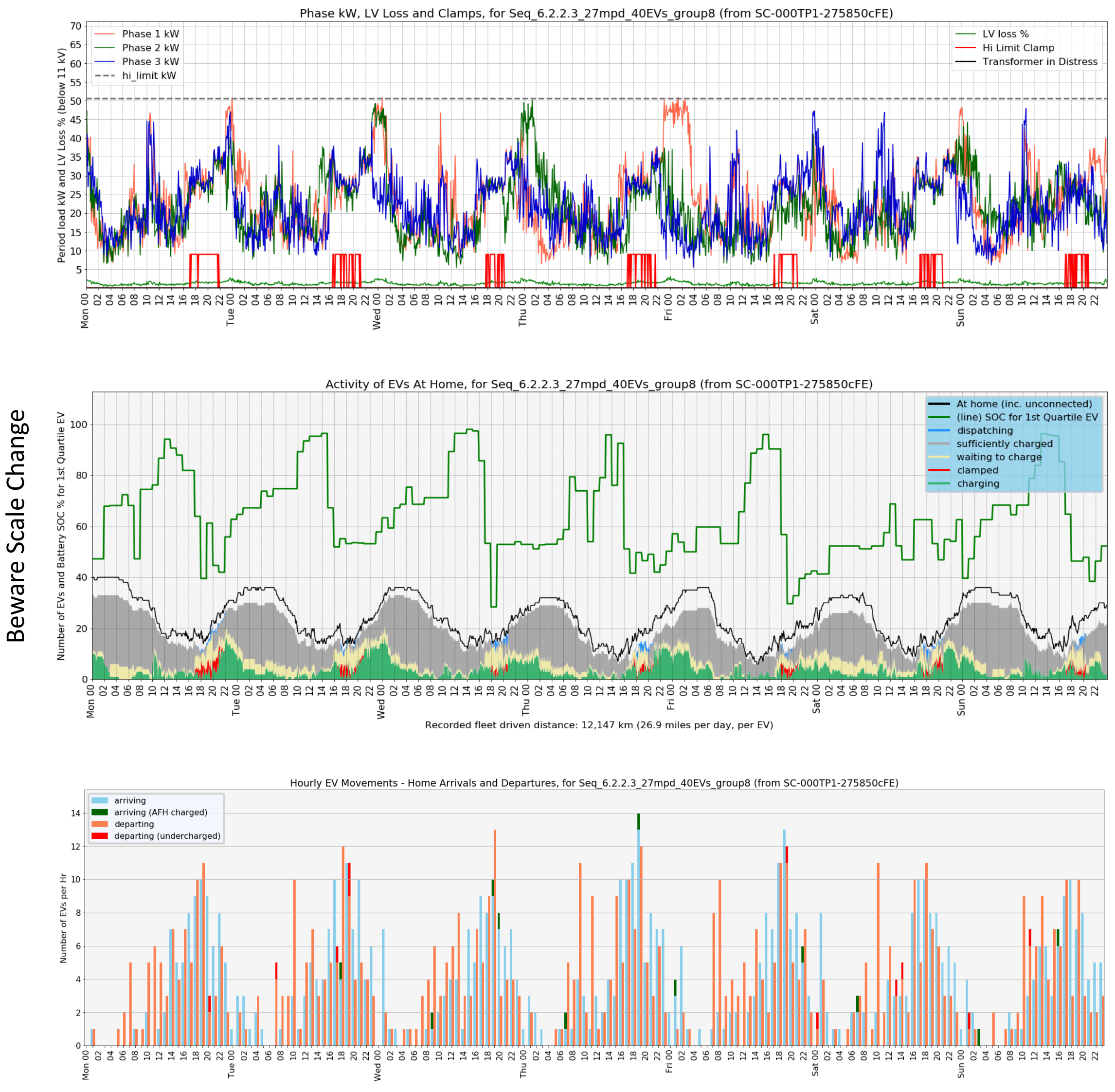
V4-2.28 Seq_6.2.2.3 Feeder and EV Plots

V4-2.28.1 Seq_6.2.2.3: 27mpd 40EVs



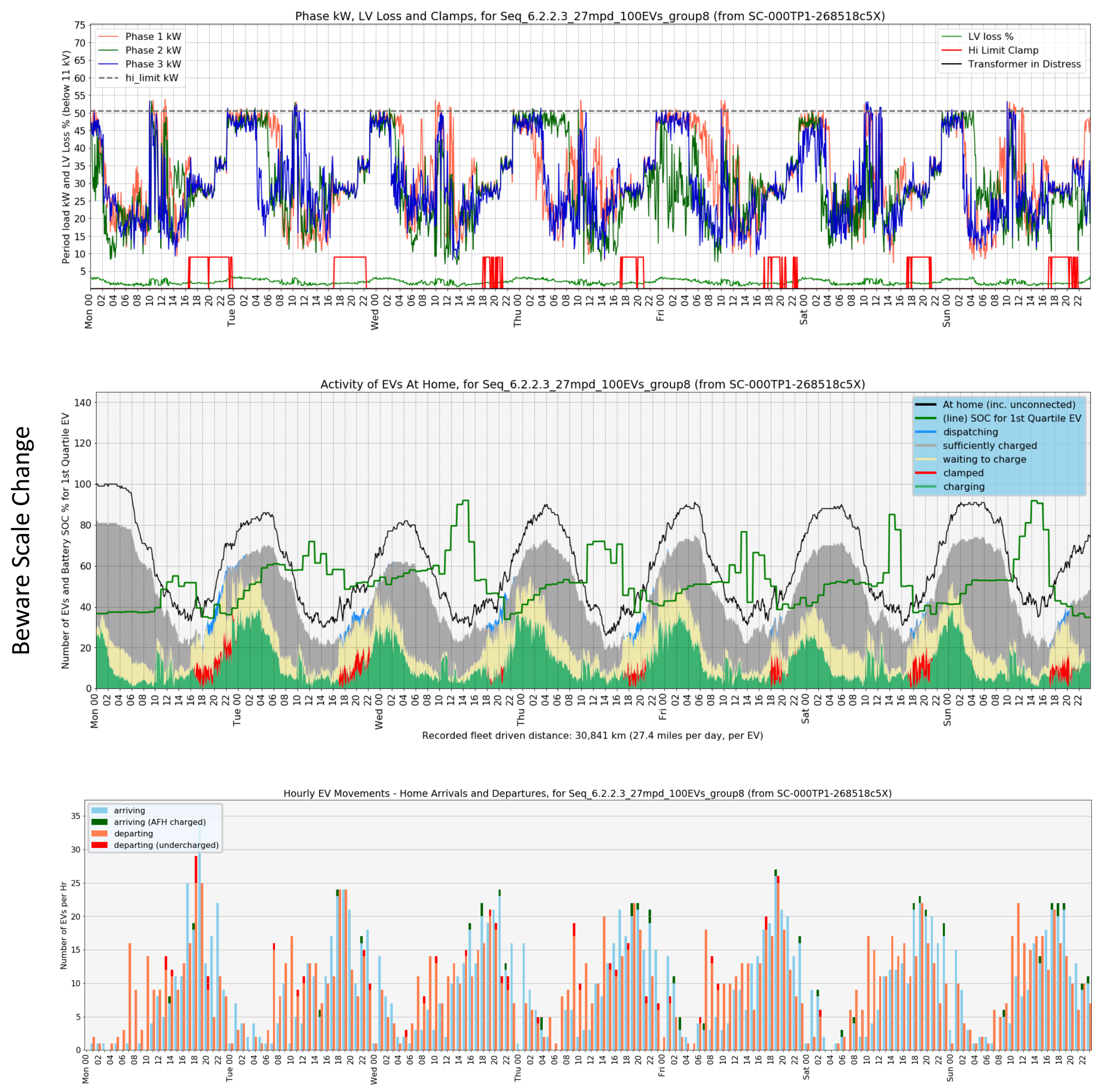
EoW stats: kWh[b] EV total: 2,375 Home: 2,082 AFH: 293 V2G: 60

Figure 2-21: Seq_6.2.2.3 27mpd 40EVs group 8 plots. Weekly km: 12,227

Compared to 6.2.2, AFH charging is up (was 289) and V2G is down (was 79). Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare
- all plots are very similar to 27mpd 40 EVs group 8 from 6.2.2

V4-2.28.2 Seq_6.2.2.3: 27mpd 100EVs



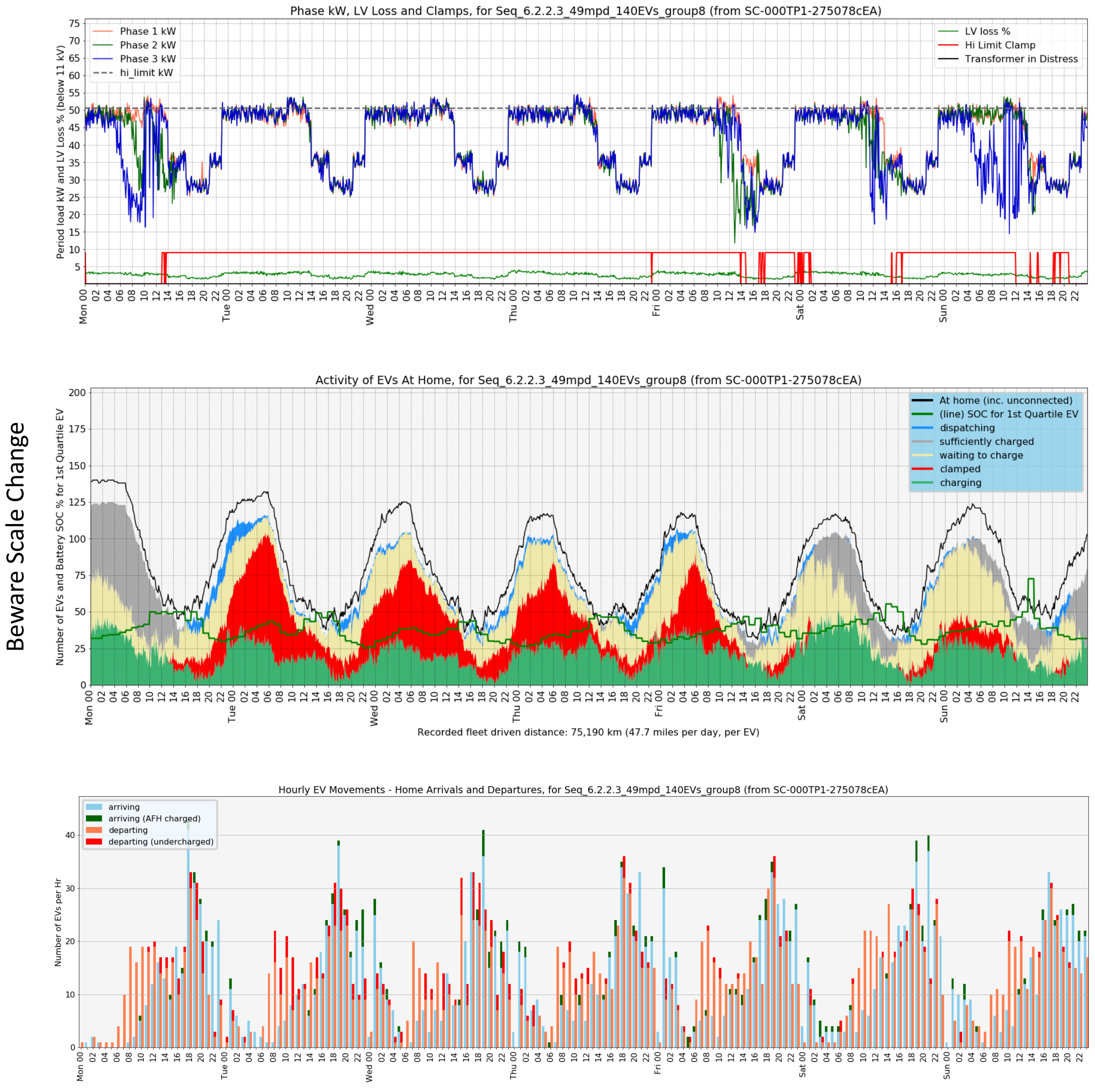
EoW stats: kWh[b] EV total: 6,120 Home: 5,302 AFH: 818 V2G: 215

Figure 2-22: Seq_6.2.2.3 27mpd 100EVs group 8 plots. Weekly km: 30,877

The corresponding plots for 6.2.2 show: AFH: 806, V2G: 260. V2G has fallen in 6.2.2.3.

These plots are indistinguishable by eye from 6.2.2.

V4-2.28.3 Seq_6.2.2.3: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,821 Home: 10,021 AFH: 4,800 V2G: 1,248

Figure 2-23: Seq_6.2.2.3 27mpd 40EVs group 8 plots. Weekly km: 77,340

The plots for 6.2.2 show: AFH: 4,787, V2G: 1,351. V2G has fallen again.

Although near indistinguishable by eye from 6.2.2, V2G blue and clamped red can be seen occasionally “trading places”.

V4-2.29 Data Tables Seq_6.2.2.3

Table 2-54: 6.2.2.3 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	17,106	16,478	15,238	13,980	12,710	11,416	10,118	8,776
	27mpd	16,992	16,223	14,718	13,192	11,668	10,091	8,455	6,713
	38mpd	16,895	16,029	14,274	12,471	10,679	8,779	6,910	5,240
	49mpd	16,813	15,863	13,915	11,935	9,995	7,960	6,060	4,758

6.2.2 span: [10,098] => [4,763]

Note that DRFFR "B" makes 1,134 kWh capacity unutilised, which cools the transformer.

Table 2-55: 6.2.2.3 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.1	3.2	3.1	3.2	3.5	3.4	3.4
	27mpd	6.4	7.4	7.3	7.7	8.2	8.2	8.0	7.9
	38mpd	16.6	16.7	17.3	17.8	17.7	18.2	18.0	18.8
	49mpd	34.5	32.0	30.9	30.6	30.4	30.7	31.5	34.3

6.2.2 span: [8.0] => [34.2]

Table 2-56: 6.2.2.3 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	0.12	0.13	0.13	0.13	0.14	0.15	0.14	0.14
	27mpd	0.28	0.29	0.28	0.29	0.31	0.31	0.30	0.30
	38mpd	0.58	0.58	0.58	0.58	0.59	0.60	0.60	0.63
	49mpd	1.09	0.97	0.92	0.91	0.92	0.93	0.95	1.05

6.2.2 span: [0.3] => [1.05]

There is a slight increase in need to AFH charge.

Table 2-57: ***6.2.2.3 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.9	1.0	1.0	1.0	1.0
	27mpd	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6
	38mpd	1.9	1.9	2.1	2.1	2.1	2.2	2.3	2.9
	49mpd	2.6	2.6	2.7	2.7	2.7	2.9	3.2	5.0

6.2.2 span: [1.4] => [5.0]

An increase is seen, other than for the 140 EV case.

Table 2-58: ***6.2.2.3 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0028	0.0020	0.0016	0.0011	0.0010	0.0011	0.0010	0.0008
	27mpd	0.0002	0.0007	0.0019	0.0023	0.0023	0.0018	0.0018	0.0014
	38mpd	0.0032	0.0037	0.0064	0.0068	0.0057	0.0066	0.0060	0.0341
	49mpd	0.0074	0.0052	0.0087	0.0080	0.0092	0.0125	0.0328	0.1589

6.2.2 span: [0.0015] => [0.1631] (limit: < 0.007)

All plies are slightly worse vs. 6.2.2, but one cell has degraded to below the limit.

Table 2-59: ***6.2.2.3 V2G kWh dispatch per EV (weekly averages)***

6. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7.5	4.8	3.6	2.8	3.0	3.6	4.0	5.1
	27mpd	6.8	4.6	3.5	3.2	4.4	6.5	8.5	14.2
	38mpd	6.7	4.4	3.7	4.2	7.3	12.2	18.0	23.8
	49mpd	6.5	4.4	4.0	5.5	9.9	16.4	22.4	25.0

6.2.2 span: [7.9] => [27.0]

V2G dispatch rates have indeed marginally dropped, by about 18%. Given 6.2.2 was anticipating loosing 100 days battery life for the parity case, this is a useful step forward but not major. The higher V2G duties are only slightly improved.

Table 2-60: ***6.2.2.3 MCS Clamps (weekly averages)***

7. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	108	160	273	349	418	466	479	489
	27mpd	115	182	309	399	458	487	492	677
	38mpd	131	208	358	447	493	659	1018	2185
	49mpd	141	228	390	473	590	1094	1833	3033

6.2.2 span: [366] => [2,985] (limit: < 420)

Several values are just over the 420 limit, suggesting the choice of 500 was too high; a better value may have been 380, to give some count headroom.

Table 2-61: ***6.2.2.3 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	33.9%	35.1%	42.3%	48.8%	56.0%	66.1%	72.6%	79.2%
	27mpd	32.7%	36.9%	45.2%	54.8%	67.3%	73.8%	80.4%	88.1%
	38mpd	31.0%	36.3%	44.0%	58.3%	72.6%	79.8%	86.3%	95.2%
	49mpd	32.1%	37.5%	48.8%	64.3%	75.6%	82.1%	91.1%	98.2%

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

The DR/FFR response metric broadly matches 6.2.2.

Table 2-62: ***6.2.2.3 Overall Usable EV Plies***

N EV	10	20	40	60	80	100	120	140
19mpd						C	C	C
27mpd					C	C	C	C
38mpd				C	C	C	C	SC
49mpd	S		SC	SC	SC	SC	SC	SC

Yellow: Severe undercharging too high, blue: Clamp limits exceeded, red: both too high

Darker colours indicate losses vs. 6.2.2

V4-2.30 Seq_6.2.2.3 Results Summary

Seq_6.2.2.3 has assisted V2G battery wear, but overall appears a step backwards; the use of early clamps over V2G caused more problems then it solved. Adjusting (down) the clamp count and / or moderating the DR from “B” to “C” (which is less arduous) may help.

Seq_6.2.2.3 offers similar overall capability with reduced V2G, for a modest clamp increase. Estimated battery life loss for 27mpd 100 EVs in 6.2.2 was c. 100 days, and is now improved by c. 18 days, provided by no more than an algorithm change.

The author considers that clamps need more investigation, from both EV and Ofgem viewpoints. For this, FPB/MCS needs be improved to give a clear EV owner view of:

- what clamps are doing
- for how long they operate, and
- how often each EV is clamped.

Recommendation:

- further testing or
- abandon the method.

V4-2.31 Results for Seq_6.2.2.4

Sequence	Simulation ID	Description
Seq_6.2.2.4	(S_B1)	Variation vs. Seq_6.1.2: Alternative Week in Winter. Uses DR-B/FFR hi_limit modulation.
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

The purpose of this sequence is to consider if the author's approach of not varying the residential load data source is unconsciously cherry-picking a positive situation.

Sequence 6.2.2.4 uses data for the week following the usual dataset (i.e. from 18th March 2013) which is scaled down slightly, so to match the total kWh consumption.

What differences arise? The author suspects (hopes) less than a few percent.

Data originate from MetaMeta spreadsheets (online) for Seq_6.2.2.4.

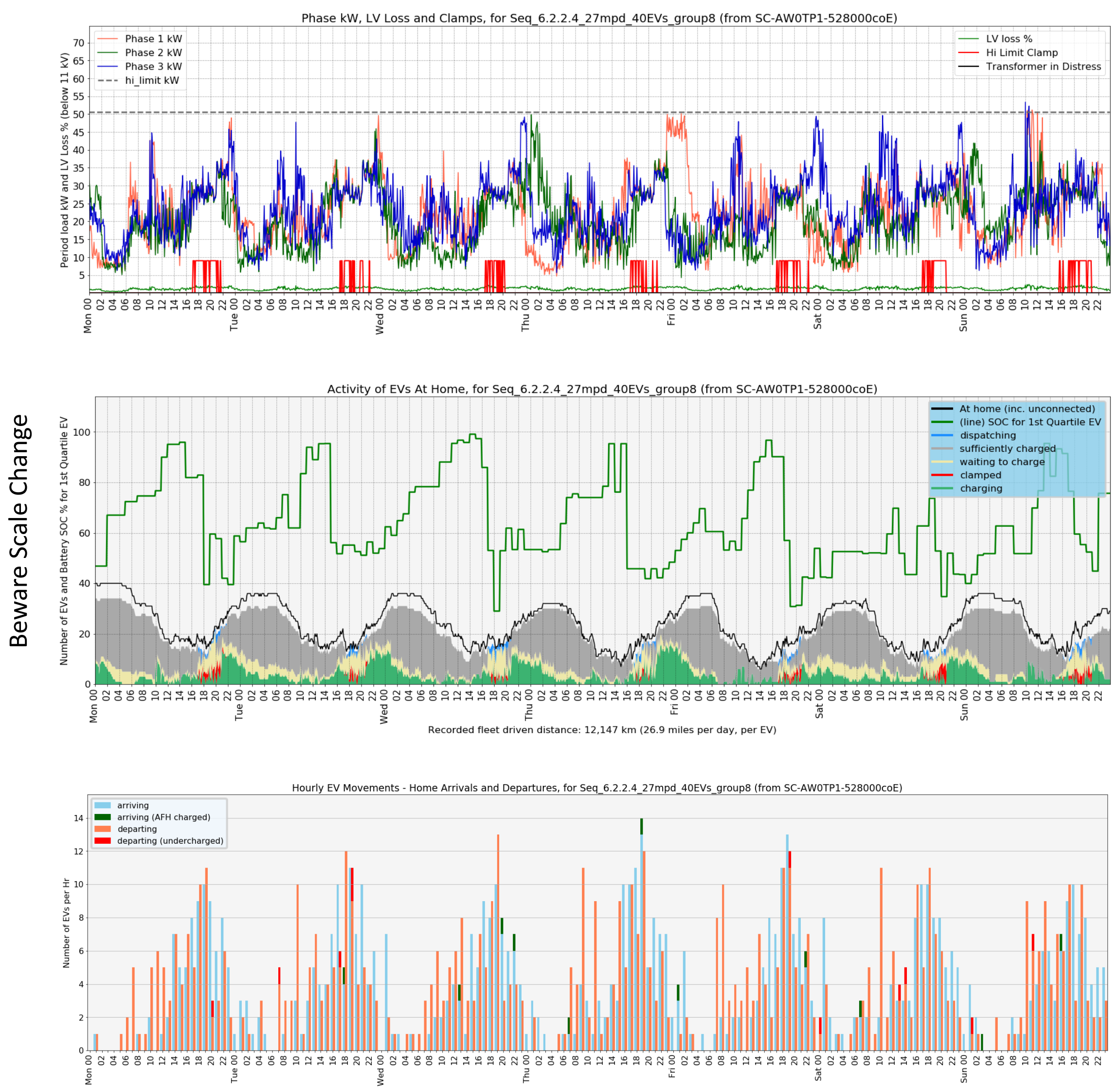
V4-2.31.1 Seq_6.2.2.4 Outcomes

There were changes (degradation) of results at near edge-cases, however not a sea-change. It is not shown that changing the residential loads makes major difference; however what is shown is a need for margin in any real-world system simply as what is worst-case is not known.

A caveat: the new residential load was from the same estate of houses. Moving to another estate with a different set of houses and occupants has **not** been tested; this would certainly need assessing if the methods were applied to a real-world situation.

V4-2.32 Seq_6.2.2.4 Feeder and EV Plots

V4-2.32.1 Seq_6.2.2.4: 27mpd 40EVs



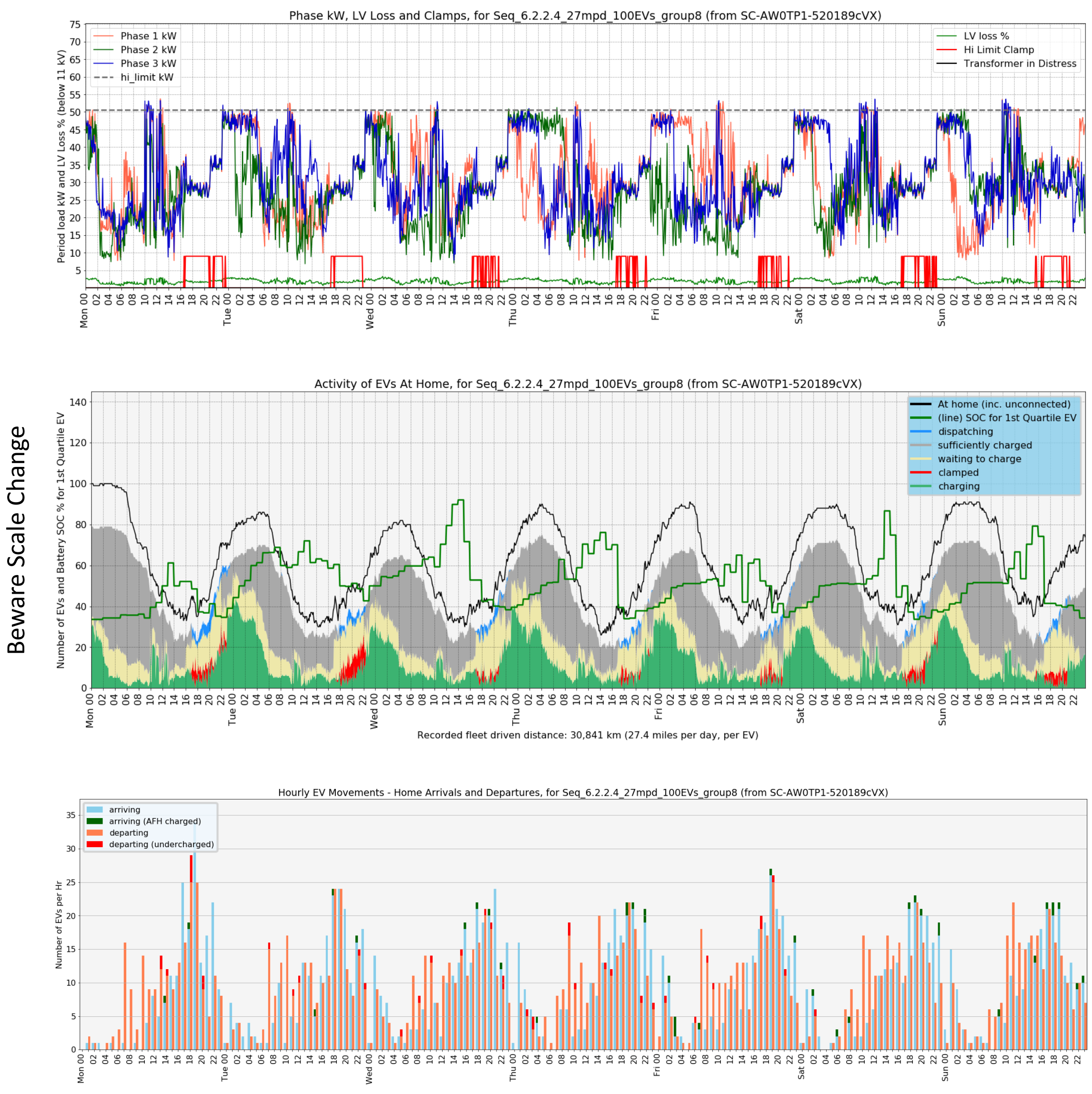
EoW stats: kWh[b]	EV total: 2,411	Home: 2,118	AFH: 293	V2G: 98
cf. 6.2.2:	*EV total: 2,394*	*Home: 2,105*	*AFH: 289*	*V2G: 79*

Figure 2-24: Seq_6.2.2.4 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC; V2G and clamps are occasionally used
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.32.2 Seq_6.2.2.4: 27mpd 100EVs



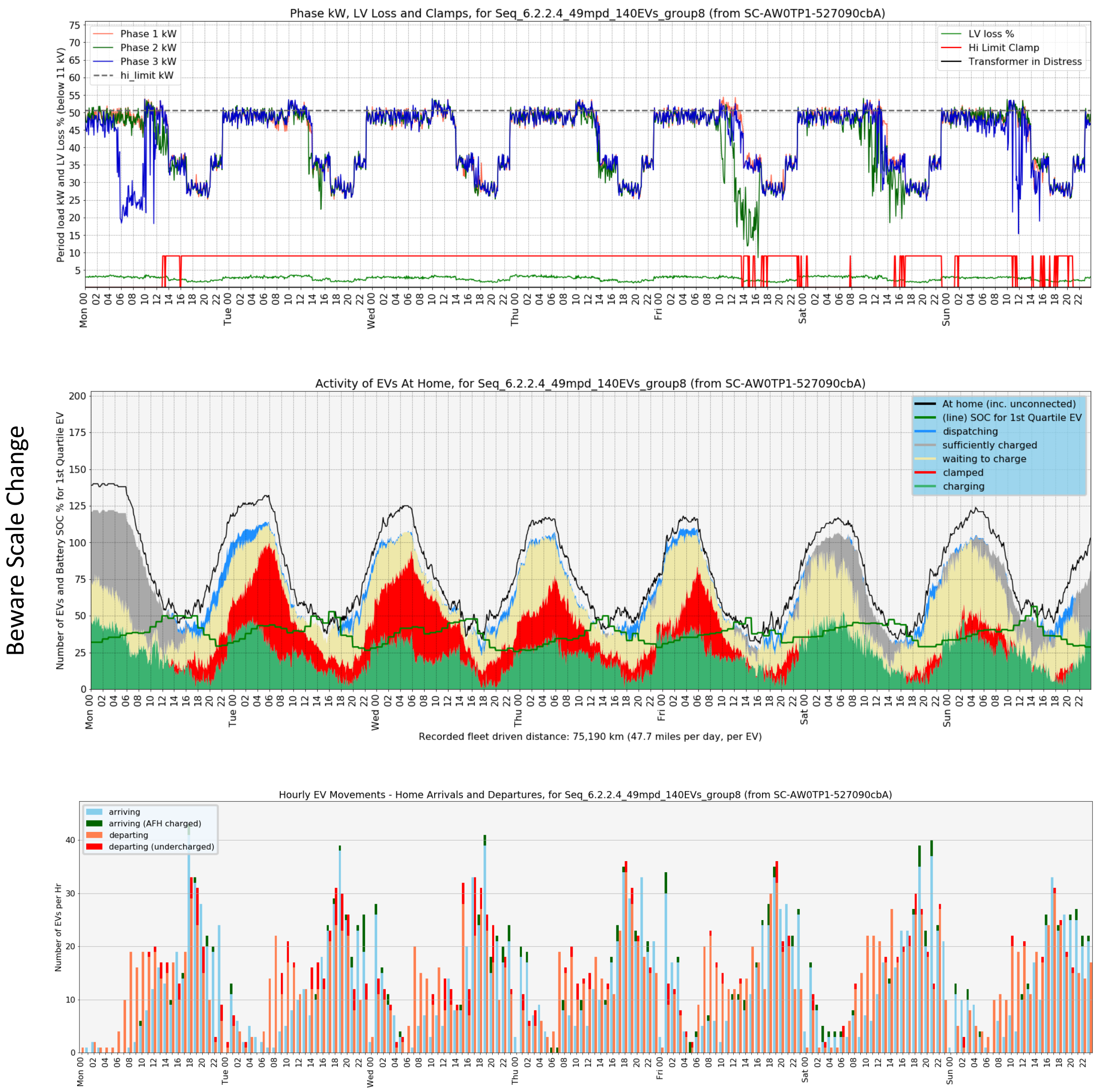
EoW stats: kWh[b]	EV total: 6,207	Home: 5,390	AFH: 817	V2G: 301
cf. 6.2.2:	*EV total: 6,165*	*Home: 5,359*	*AFH: 806*	*V2G: 260*

Figure 2-25: Seq_6.2.2.4 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows an increase in clamps and the DR/FFR signal
- (CICD) SOC is similar with significant numbers of EVs ready to depart; V2G blue and clamps are similar to 6.2.2
- (Arrive/Depart) is by eye identical to 6.2.2.

V4-2.32.3 Seq_6.2.2.4: 49mpd 140EVs



EoW stats: kWh[b]	EV total: 14,865	Home: 10,088	AFH: 4,777	V2G: 1,282
cf. 6.2.2:	*EV total: 14,920*	*Home: 10,133*	*AFH: 4,787*	*V2G: 1,351*

Figure 2-26: Seq_6.2.2.4 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows DR/FFR clearly with many clamps, but no transformer distress. This is attributed to DR allowing the transformer to cool
- (CICD) arguably less EVs are ready to depart vs. 6.2.2; the difference is trivial
- (Arrive/Depart) by eye 6.2.2.4 has slightly less undercharged departs on Tuesday am, but is otherwise identical to 6.2.2.

V4-2.33 Data Tables Seq_6.2.2.4

Table 2-63: ***6.2.2.4 Unused kWh (weekly averages)***

Seq_6.2.2	1. A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,107	16,476	15,231	13,973	12,694	11,390	10,075	8,760
		27mpd	16,992	16,221	14,711	13,175	11,654	10,098	8,470	6,805
		38mpd	16,895	16,026	14,258	12,452	10,690	8,822	6,969	5,279
		49mpd	16,813	15,858	13,895	11,925	10,012	7,990	6,087	4,763
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,211	16,579	15,326	14,063	12,778	11,469	10,115	8,774
		27mpd	17,097	16,323	14,811	13,273	11,747	10,177	8,497	6,817
		38mpd	17,003	16,132	14,363	12,560	10,788	8,900	7,013	5,319
		49mpd	16,919	15,964	14,004	12,036	10,116	8,079	6,119	4,743
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	104	102	95	89	83	79	40	13
		27mpd	105	102	100	98	92	78	27	12
		38mpd	108	106	105	108	98	78	45	41
		49mpd	107	106	110	110	104	89	31	-20

Average Weekly Unutilised Network kWh: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

Differences are under 1%.

Table 2-64: 6.2.2.4 Per EV AFH kWh Uptake (weekly averages)

Seq_6.2.2	2. A	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	3.0	3.1	3.0	3.2	3.4	3.3	3.3
		27mpd	6.3	7.3	7.2	7.5	8.0	8.0	7.9	7.8
		38mpd	16.5	16.6	17.0	17.6	17.6	18.0	17.8	18.7
		49mpd	34.4	31.8	30.6	30.4	30.2	30.4	31.3	34.2
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	2.5	3.1	3.2	3.1	3.2	3.5	3.3	3.3
		27mpd	6.5	7.4	7.3	7.6	8.1	8.2	8.0	7.9
		38mpd	16.8	16.8	17.2	17.8	17.7	18.2	18.0	18.9
		49mpd	34.6	32.0	30.8	30.6	30.5	30.7	31.5	34.1
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.03	0.02	0.05	0.04	0.05	0.06	0.04	0.05
		27mpd	0.11	0.11	0.10	0.10	0.10	0.11	0.09	0.09
		38mpd	0.28	0.22	0.19	0.18	0.17	0.17	0.16	0.19
		49mpd	0.26	0.23	0.24	0.24	0.27	0.27	0.22	-0.07

Averaged Weekly Per EV AFH kWh Uptake: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

Differences are under 3%.

Table 2-65: 6.2.2.4 Per EV AFH N events (count of away connects, weekly averages)

Seq_6.2.2	3. EV N AFH A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.59
		49mpd	1.06	0.96	0.90	0.89	0.91	0.90	0.92	0.96
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.12	0.13	0.13	0.13	0.13	0.15	0.14	0.14
		27mpd	0.28	0.29	0.28	0.28	0.31	0.31	0.30	0.30
		38mpd	0.59	0.58	0.58	0.58	0.59	0.60	0.60	0.63
		49mpd	1.09	0.97	0.92	0.91	0.92	0.93	0.95	1.05
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
		27mpd	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01
		38mpd	0.03	0.03	0.02	0.01	0.01	0.02	0.02	0.05
		49mpd	0.03	0.01	0.02	0.01	0.01	0.02	0.03	0.09

Averaged Weekly Per EV AFH N Connects: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

There is a slight increase in need to AFH charge.

Table 2-66: 6.2.2.4 Counts of Undercharging events per EV (weekly averages)

		N EV	10	20	40	60	80	100	120	140
Seq_6.2.2	4. A	19mpd	0.6	0.8	0.8	0.9	0.9	1.0	0.9	1.0
		27mpd	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.4
		38mpd	1.7	1.8	1.9	1.9	2.0	2.0	2.0	2.1
		49mpd	2.3	2.3	2.4	2.4	2.4	2.4	2.5	3.5
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.7	0.8	0.8	0.9	0.9	1.0	0.9	1.0
		27mpd	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6
		38mpd	1.9	2.0	2.1	2.1	2.1	2.2	2.2	2.9
		49mpd	2.7	2.6	2.7	2.7	2.7	2.9	3.2	4.8
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.07	0.02	-0.01	0.00	-0.01	0.01	0.00	0.02
		27mpd	0.12	0.10	0.05	0.05	0.06	0.08	0.08	0.16
		38mpd	0.25	0.20	0.16	0.17	0.18	0.24	0.29	0.84
		49mpd	0.39	0.34	0.30	0.31	0.33	0.45	0.71	1.31

Counts of Undercharging events per EV in Week: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

A small increase is seen.

Table 2-67: 6.2.2.4 Counts of Severely Undercharged EVs in Week, per EV

		N EV	10	20	40	60	80	100	120	140
Seq_6.2.2	5. A	19mpd	0.0022	0.0013	0.0010	0.0008	0.0005	0.0007	0.0006	0.0005
		27mpd	0.0002	0.0006	0.0012	0.0015	0.0016	0.0015	0.0010	0.0014
		38mpd	0.0038	0.0039	0.0048	0.0052	0.0049	0.0062	0.0060	0.0350
		49mpd	0.0070	0.0045	0.0071	0.0065	0.0087	0.0115	0.0336	0.1631
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0004	0.0005	0.0010	0.0009	0.0008	0.0012	0.0007	0.0007
		27mpd	0.0002	0.0015	0.0020	0.0026	0.0026	0.0024	0.0017	0.0018
		38mpd	0.0048	0.0040	0.0067	0.0067	0.0057	0.0074	0.0066	0.0367
		49mpd	0.0064	0.0060	0.0085	0.0079	0.0102	0.0133	0.0342	0.1437
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.0018	-0.0008	0.0000	0.0001	0.0003	0.0005	0.0001	0.0002
		27mpd	0.0000	0.0009	0.0009	0.0010	0.0011	0.0009	0.0008	0.0005
		38mpd	0.0010	0.0001	0.0019	0.0015	0.0008	0.0012	0.0007	0.0018
		49mpd	-0.0006	0.0015	0.0014	0.0013	0.0015	0.0018	0.0006	-0.0194

Averaged Weekly Per EV Severe Undercharges: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

These show a noticeable but varied increase in severe undercharging, with one extra ply becoming unacceptable. The only modifier here is residential load pattern and shows that the uncontrollable load pattern vs. EV movements do interact. The degree of severity of this interaction is not sensibly determinable from two trials; these could have been worst case or best case combinations; without more trials this cannot be determined. The author suggests about 30 more trials, but that is 30 * 1.5 days effort which for brevities sake is not undertaken.

The worst outcomes would be that there is a linkage which the MCS cannot remove; what to do about that is not apparent, simply as MCS cannot affect residential loads.

Table 2-68: 6.2.2.4 Clamps (weekly averages)

Seq_6.2.2	6. A	N EV	10	20	40	60	80	100	120	140
		19mpd	91.4	119.6	168.3	205.3	243.5	269.8	208.6	248.9
		27mpd	98.6	139.1	203.6	252.6	308.6	366.3	340.2	582.4
		38mpd	115.7	163.6	248.1	321.8	419.5	606.6	932.5	2,091.9
		49mpd	124.1	183.3	286.7	380.3	548.7	1,032.0	1,757.8	2,985.2
Seq_6.2.2.4	B	N EV	10	20	40	60	80	100	120	140
		19mpd	143	180	233	270	318	352	268	311
		27mpd	151	201	271	325	393	458	410	618
		38mpd	172	232	324	401	505	667	891	1,948
		49mpd	176	254	366	461	619	986	1,606	2,886
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	51.1	60.2	64.9	64.6	74.0	82.2	59.3	61.7
		27mpd	52.0	62.0	67.9	72.2	84.0	91.9	69.3	35.6
		38mpd	56.2	68.7	76.2	78.7	85.9	60.9	-41.9	-143.6
		49mpd	51.6	71.2	79.0	80.3	70.1	-45.7	-151.9	-99.2

Averaged Weekly Clamping Counts: Seq_6.2.2.4 (B) vs. Baseline 6.2.2 (A)

Clamping counts have in general risen with two ply cells no longer acceptable.

Table 2-69: ***6.2.2.4 Difference in LV Losses kWh (weekly averages)***

7. C. Diff. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	-1.1	-9.0	-2.5	-8.4	-9.8	-15.4	-14.8	-14.0
	27mpd	-1.2	-8.9	-6.2	-11.6	-13.0	-13.0	-14.6	-15.6
	38mpd	-1.2	-5.6	-12.5	-10.3	-12.8	-15.4	-17.0	-16.8
	49mpd	-1.2	-3.7	-9.6	-14.6	-15.3	-15.6	-11.1	-13.0

Network losses are slightly down, which is interesting as net kWh throughput (see 1.) is up. It is reasonable to suppose the levels now experienced are “less peaky” as losses, being a square-law phenomena, predominantly arise from load peaks.

Table 2-70: ***6.2.2.4 Difference in DRFFR Percent Effective Hours (weekly averages)***

8. C. Diff. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	-7.10%	-4.70%	2.30%	1.20%	0.60%	0.00%	5.40%	3.00%
	27mpd	-4.70%	-4.70%	1.80%	1.20%	-1.80%	1.20%	1.70%	1.80%
	38mpd	-5.30%	-4.80%	1.80%	-0.60%	-1.20%	1.80%	1.20%	1.80%
	49mpd	-4.70%	-5.40%	-2.40%	0.60%	-1.80%	0.60%	3.00%	0.60%

6.2.2.4 span: [75.0%] => [98.8%]

High-end DRFFR response is better; however there is no clear pattern.

V4-2.34 Seq_6.2.2.4 Results Summary

Is using the same residential load “cherry-picking”?

Network loads and unutilised kWh are similar; only trivial differences are found => **No**.

However some “near edge” cases i.e. just below the 420 clamp count limit - now exceed the limit. This suggests that limits, where ever they are set, need a suitable margin.

This in turn suggests the need for a new set of simulations, in which the same trips are repeated with many varied residential load weeks, so to discover a scatter distribution.

But in reality these loads are unconstrained and can become (for whatever reasons) different. Residential demand comes first; MCS sees these as uncontrollable. The vagaries of demand cannot be stopped from causing EV charging shortages.

By imposing a clamping system, the system restricts overloads - but has not increased power throughput nor freed any party from the vagaries of chance. A major load will cause EVs to starve; EVs are never guaranteed to be adequately charged when the network is congested (constrained).

The author is plotting a scatter graph of severe undercharging vs. undercharging hoping for a good correlation, however:

- by eye, there are cases pro and con so not a consistent correction
- popcorn noise dominates: There are no consistent:
    - residential load profiles or
    - driving load demand profiles, hence
    - forecasts cannot be reliable.
- Even with good correlation (thus a predictor) there is nothing the home network can do, even with perfect knowing of severe undercharging - these vehicles are already “first to be served”. When throughput is already maximised by definition there are no further options.

The only useful interventions revolve about getting more charge into the EVs:

- by upping the hi_limit, so stressing the assets more
- by withdrawing DR/FFR services
- by modifying driver habits to charge elsewhere e.g. subsidised AFH charging
- by injecting current e.g. 3rd party DG midway along the cable
- by remedial works to lift any constraint e.g. add a rho section (~X$) to the feeder.

These must be conscious on behalf of the DNO. The author sees no further programmable real-time intervention which would assist the local network, which are not already in use.

It may be useful to map the departure times and identity of severely undercharged EVs.

V4-2.35 Sequence 6.2.2.5

Sequence	Simulation ID	Description
Seq_6.2.2.5	(S_BH)	Variation vs. Seq_6.2.2: EVs include preheat of cabin plus adds battery heaters, so to reduce thermal C shrinkage. This will increase general load, and allow the batteries to take more charge so effecting diversity. Method: idle load increased to 400 W, preheat cabin at 800 W for 40 mins before departure time, raise calculations for ambient to 8°C (giving *C* = 0.88 *C-rated*, vs. *C* = 0.57*C-rated* @ 1°C, a relative uplift of +54% C)
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

These changes revolve about the characteristics of Lithium-ion batteries, so may not apply if battery technology changes.

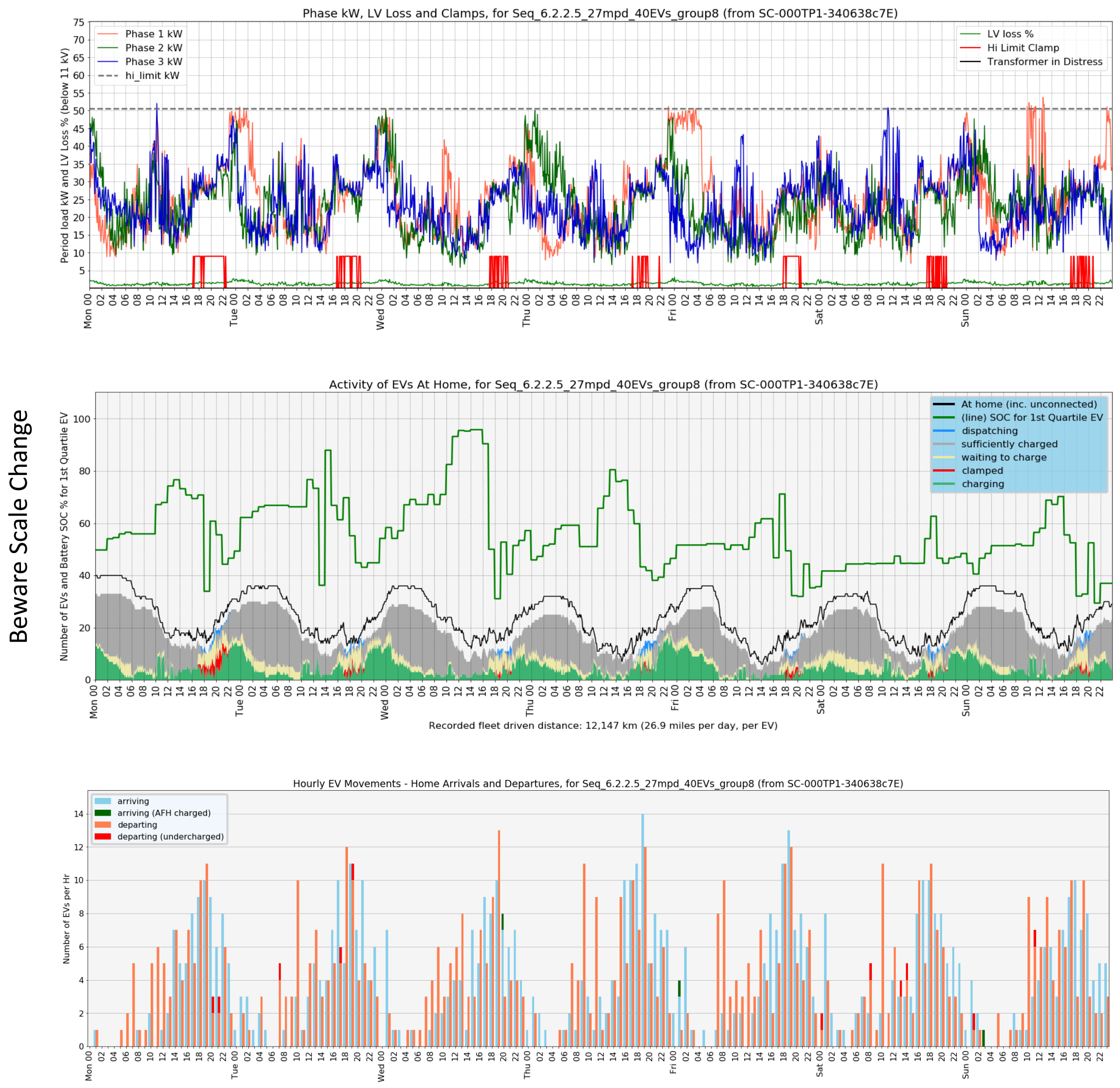
The anticipated effect is to noticeably rise local load, and decrease AFH charging.

V4-2.35.1 Seq_6.2.2.5 Outcomes

For the lower tier plies (say up to parity) heated EV batteries allow individual EVs to be better charged. Yet the higher duty plies suffer excess clamps and undercharging; the network goes into saturation earlier.

V4-2.36 Seq_6.2.2.5 Feeder and EV Plots

V4-2.36.1 Seq_6.2.2.5: 27mpd 40EVs



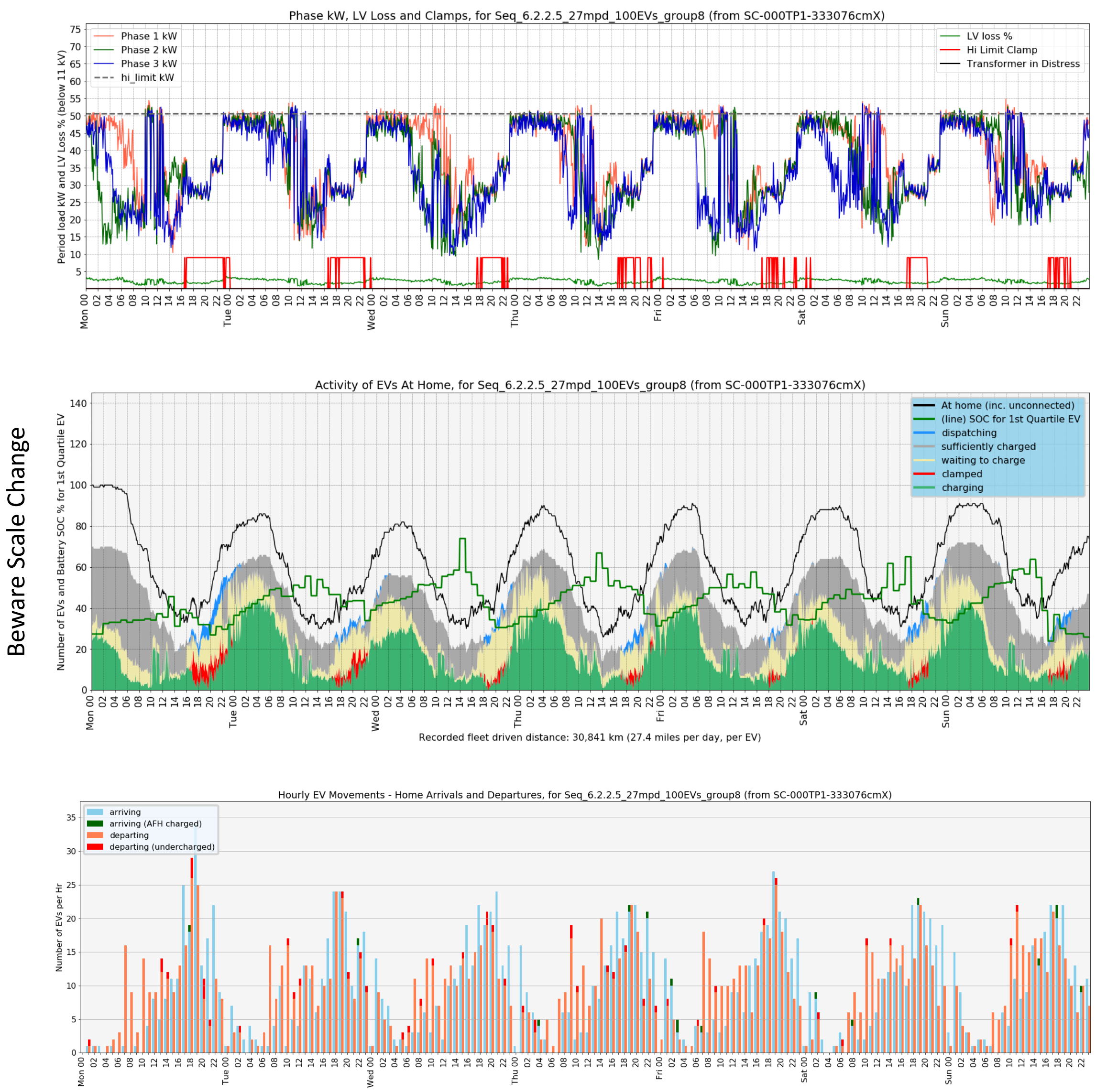
EoW stats: kWh[b]	EV total: 2,571	Home: 2,426	AFH: 63	V2G: 96
cf. 6.2.2:	*EV total: 2,394*	*Home: 2,105*	*AFH: 289*	*V2G: 79*

Figure 2-27: Seq_6.2.2.5 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable and similar to 6.2.2. Clamping is more persistent
- (CICD) EVs have good SOC; V2G and clamps are occasionally used. Similar to 6.2.2
- (Arrive/Depart) cf. 6.2.2, there are less prevalent undercharged departs; AFH charging is very rare.

V4-2.36.2 Seq_6.2.2.5: 27mpd 100EVs



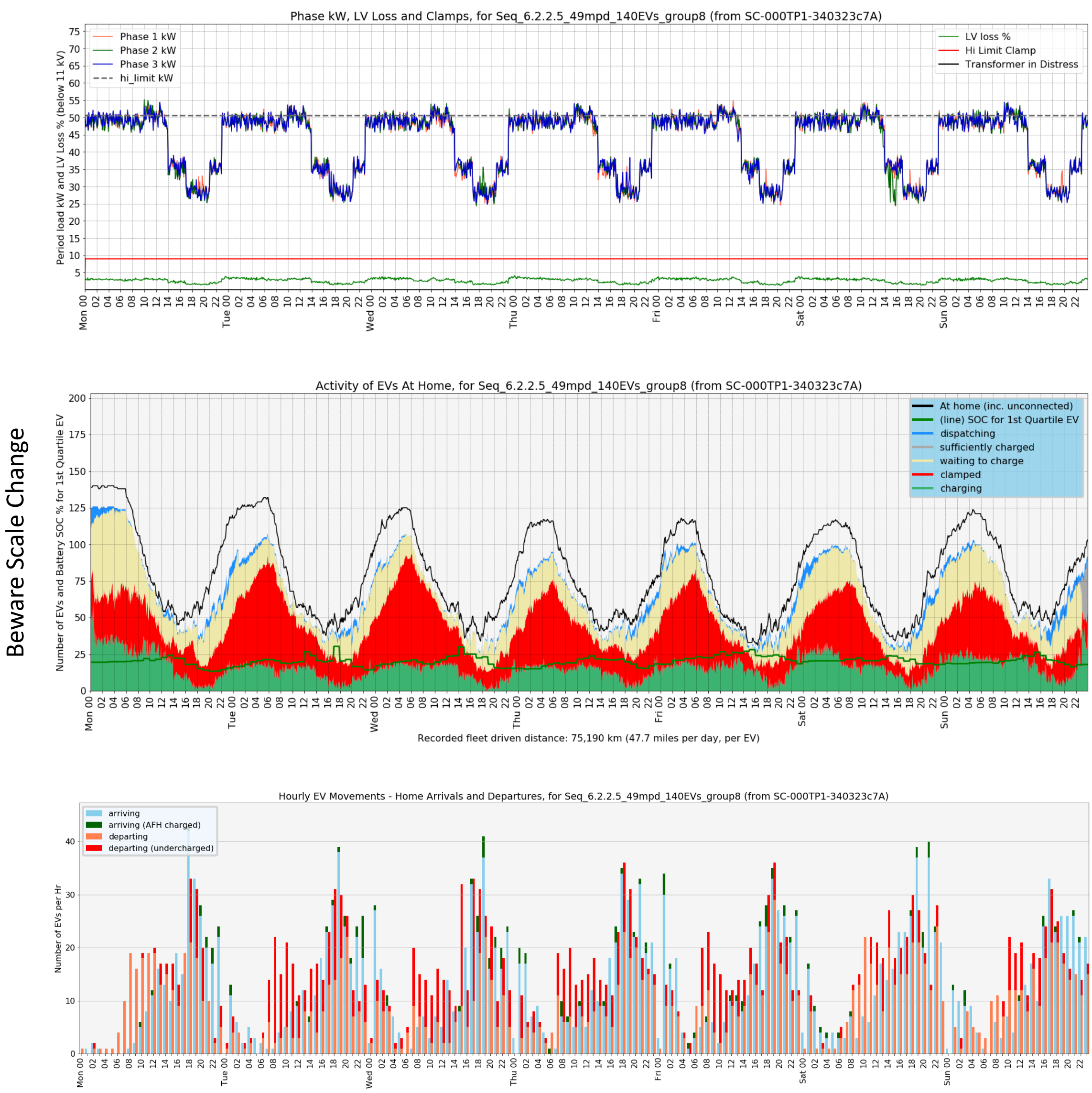
EoW stats: kWh[b]	EV total: 6,725	Home: 6,281	AFH: 444	V2G: 429
cf. 6.2.2:	*EV total: 6,165*	*Home: 5,359*	*AFH: 806*	*V2G: 260*

Figure 2-28: Seq_6.2.2.5 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot is broadly similar to 6.2.2
- (CICD) however SOC is down, implying that energy is going to other places that the battery. However the vertical scale is SOC not kWh; the scale changes as the temperature changes. This needs to be improved.
- (Arrive/Depart) shows AFH charging substantively down vs.6.2.2.

V4-2.36.3 Seq_6.2.2.5: 49mpd 140EVs



EoW stats: kWh[b]	EV total: 15,097	Home: 9,611	AFH: 5,487	V2G: 1,282
cf. 6.2.2:	*EV total: 14,920*	*Home: 10,133*	*AFH: 4,787*	*V2G: 1,106*

Figure 2-29: Seq_6.2.2.5 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows DR/FFR clearly with 100% persistent clamps, but no transformer distress, as the DR allows the transformer to cool
- (CICD) by eye nearly no EVs ready to depart vs. 6.2.2; plus the SOC drop is by c. 1/2 SOC which is more than the +54% C uplift would suggest. The EVs are getting less charge to the batteries.
- (Arrive/Depart) now shows clear depart undercharged vs. 6.2.2.

V4-2.37 Data Tables Seq_6.2.2.5

Table 2-71: 6.2.2.5 Unused kWh (weekly averages)

Seq_6.2.2	1. A	N EV	10	20	40	60	80	100	120	140
		19mpd	17,107	16,476	15,231	13,973	12,694	11,390	10,075	8,760
		27mpd	16,992	16,221	14,711	13,175	11,654	10,098	8,470	6,805
		38mpd	16,895	16,026	14,258	12,452	10,690	8,822	6,969	5,279
		49mpd	16,813	15,858	13,895	11,925	10,012	7,990	6,087	4,763
Seq_6.2.2.5	B	N EV	10	20	40	60	80	100	120	140
		19mpd	16,865	16,024	14,351	12,684	10,970	9,187	7,194	5,406
		27mpd	16,719	15,702	13,701	11,658	9,594	7,434	5,151	4,266
		38mpd	16,582	15,421	13,048	10,637	8,217	5,799	4,368	4,223
		49mpd	16,450	15,153	12,513	9,835	7,216	5,063	4,304	4,249
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-242	-452	-880	-1,289	-1,724	-2,204	-2,881	-3,354
		27mpd	-274	-519	-1,010	-1,518	-2,060	-2,665	-3,319	-2,539
		38mpd	-312	-605	-1,209	-1,815	-2,472	-3,023	-2,601	-1,056
		49mpd	-363	-705	-1,382	-2,091	-2,796	-2,928	-1,783	-515

Average Weekly Unutilised Network kWh: Seq_6.2.2.5 (B) vs. Baseline 6.2.2 (A)

6.2.2.5 places significantly more burden as the lowered kWh headroom shows.

Table 2-72: 6.2.2.5 Per EV AFH kWh Uptake (weekly averages)

Seq_6.2.2	2. A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	2.5	3.0	3.1	3.0	3.2	3.4	3.3	3.3
		27mpd	6.3	7.3	7.2	7.5	8.0	8.0	7.9	7.8
		38mpd	16.5	16.6	17.0	17.6	17.6	18.0	17.8	18.7
		49mpd	34.4	31.8	30.6	30.4	30.2	30.4	31.3	34.2
Seq_6.2.2.5	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	1.0	1.4	1.5	1.4	1.5	1.6	1.5	1.7
		27mpd	2.7	3.6	3.6	3.9	4.3	4.4	4.6	6.3
		38mpd	9.9	9.9	10.3	11.0	11.1	12.0	14.1	21.3
		49mpd	23.7	21.5	21.0	20.8	21.2	23.1	30.0	39.2
Difference B - A	C	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-1.5	-1.7	-1.7	-1.7	-1.7	-1.9	-1.8	-1.6
		27mpd	-3.6	-3.8	-3.6	-3.6	-3.7	-3.6	-3.3	-1.5
		38mpd	-6.7	-6.6	-6.7	-6.6	-6.5	-6.1	-3.7	2.6
		49mpd	-10.7	-10.4	-9.6	-9.6	-9.1	-7.4	-1.3	5.0

Averaged Weekly Per EV AFH kWh Uptake: Seq_6.2.2.5 (B) vs. Baseline 6.2.2 (A)

Interestingly, AFH use has fallen other than in extremis, from 120 and 140 EVs, both of which show rising use of AFH.

Table 2-73: 6.2.2.5 Per EV AFH N events (count of away connects, weekly averages)

		N EV	10	20	40	60	80	100	120	140
Seq_6.2.2	3. EV N AFH A	19mpd	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
		27mpd	0.27	0.28	0.27	0.28	0.31	0.30	0.30	0.29
		38mpd	0.56	0.55	0.56	0.57	0.58	0.59	0.58	0.59
		49mpd	1.06	0.96	0.90	0.89	0.91	0.90	0.92	0.96
Seq_6.2.2.5	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.04	0.05	0.04	0.04	0.04	0.05	0.05	0.05
		27mpd	0.09	0.11	0.10	0.11	0.12	0.13	0.13	0.19
		38mpd	0.27	0.27	0.26	0.28	0.28	0.30	0.37	0.60
		49mpd	0.59	0.51	0.49	0.48	0.50	0.55	0.75	1.02
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.08	-0.09	-0.08	-0.08	-0.09	-0.10	-0.09	-0.08
		27mpd	-0.18	-0.18	-0.17	-0.17	-0.18	-0.18	-0.16	-0.10
		38mpd	-0.31	-0.30	-0.31	-0.30	-0.30	-0.29	-0.22	-0.02
		49mpd	-0.49	-0.45	-0.42	-0.42	-0.41	-0.37	-0.19	-0.03

Averaged Weekly Per EV AFH N Connects: Seq_6.2.2.5 (B) vs. Baseline 6.2.2 (A)

There is a decrease in need to AFH charge, other than for 120 and 140 EVs. Does heating the battery effect the Winter : Summer AFH connect rate?

Table 2-74: Ratio 6.2.2.5 vs. Summer 1.1.2.2 EV AFH N events (weekly averages)

	N EV	10	20	40	60	80	100	120	140
EV N AFH Winter / Summer Ratio	19mpd	6.6	5.8	3.2	3.5	3.7	4.4	4.2	4.2
	27mpd	3.4	3.6	3.1	3.1	3.0	3.3	3.5	5.0
	38mpd	2.6	2.5	2.5	2.4	2.5	2.7	3.3	5.4
	49mpd	2.4	2.3	2.3	2.2	2.3	2.5	3.4	4.7

Yes; ratio has better than halved. The parity case without heaters was 8.11 (see ~!X) with a least:worst span of: 22.3 : 4.4, which with heated batteries becomes: 6.6 : 4.7.

Table 2-75: 6.2.2.5 Counts of Undercharging events per EV (weekly averages)

Seq_6.2.2	4. A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.6	0.8	0.8	0.9	0.9	1.0	0.9	1.0
		27mpd	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.4
		38mpd	1.7	1.8	1.9	1.9	2.0	2.0	2.0	2.1
		49mpd	2.3	2.3	2.4	2.4	2.4	2.4	2.5	3.5
Seq_6.2.2.5	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.5	0.6	0.6	0.6	0.7	0.8	0.8	1.1
		27mpd	0.9	0.9	1.0	1.1	1.2	1.3	1.6	3.8
		38mpd	1.4	1.5	1.6	1.7	1.8	2.2	4.2	8.0
		49mpd	2.1	2.1	2.2	2.3	2.5	3.7	7.0	9.8
Difference B - A	C	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-0.18	-0.21	-0.19	-0.18	-0.17	-0.14	-0.09	0.12
		27mpd	-0.30	-0.31	-0.26	-0.23	-0.19	-0.12	0.17	2.26
		38mpd	-0.44	-0.41	-0.38	-0.33	-0.25	0.08	2.01	5.14
		49mpd	-0.47	-0.42	-0.41	-0.33	-0.15	0.90	3.83	4.82

Counts of Undercharging events per EV in Week: Seq_6.2.2.5 (B) vs. Baseline 6.2.2 (A)

A reduction is seen other than for both 120, 140 EVs and for 38, 49mpd of 100 EVs.

Table 2-76: 6.2.2.5 Counts of Severely Undercharged EVs in Week, per EV

Seq_6.2.2	5. A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0022	0.0013	0.0010	0.0008	0.0005	0.0007	0.0006	0.0005
		27mpd	0.0002	0.0006	0.0012	0.0015	0.0016	0.0015	0.0010	0.0014
		38mpd	0.0038	0.0039	0.0048	0.0052	0.0049	0.0062	0.0060	0.0350
		49mpd	0.0070	0.0045	0.0071	0.0065	0.0087	0.0115	0.0336	0.1631
Seq_6.2.2.5	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0004	0.0004	0.0008	0.0005	0.0006	0.0004	0.0003	0.0007
		27mpd	0.0004	0.0012	0.0014	0.0019	0.0018	0.0017	0.0027	0.0389
		38mpd	0.0028	0.0028	0.0042	0.0050	0.0061	0.0105	0.0652	0.2342
		49mpd	0.0092	0.0094	0.0113	0.0117	0.0141	0.0516	0.2210	0.4326
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.0018	-0.0009	-0.0003	-0.0003	0.0001	-0.0002	-0.0003	0.0002
		27mpd	0.0002	0.0006	0.0003	0.0004	0.0003	0.0001	0.0017	0.0375
		38mpd	-0.0010	-0.0011	-0.0006	-0.0002	0.0012	0.0042	0.0592	0.1993
		49mpd	0.0022	0.0049	0.0042	0.0051	0.0054	0.0401	0.1875	0.2696

Averaged Weekly Per EV Severe Undercharges: Seq_6.2.2.5 (B) vs. Baseline 6.2.2 (A)

These show great degradation from 80 EVs up for 19 and 27mpd, but failing completely for 49mpd vehicles.

Table 2-77: 6.2.2.5 Clamps (weekly averages)

Seq_6.2.2	6. A	N EV	10	20	40	60	80	100	120	140
		19mpd	91.4	119.6	168.3	205.3	243.5	269.8	208.6	248.9
		27mpd	98.6	139.1	203.6	252.6	308.6	366.3	340.2	582.4
		38mpd	115.7	163.6	248.1	321.8	419.5	606.6	932.5	2,091.9
		49mpd	124.1	183.3	286.7	380.3	548.7	1,032.0	1,757.8	2,985.2
Seq_6.2.2.5	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	99.0	130.0	199.6	259.5	319.0	382.6	333.4	915.1
		27mpd	101.4	143.1	230.8	313.6	406.2	576.4	1,268.4	3,622.2
		38mpd	119.7	173.3	279.4	394.0	608.5	1,559.9	3,416.7	4,491.2
		49mpd	127.2	192.7	324.6	500.5	1,007.4	2,528.1	4,069.0	4,664.5
Difference B - A	**C**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	7.6	10.4	31.3	54.3	75.5	112.8	124.8	666.2
		27mpd	2.9	4.1	27.2	61.0	97.6	210.1	928.2	3,039.8
		38mpd	4.0	9.7	31.3	72.2	189.0	953.3	2,484.2	2,399.2
		49mpd	3.1	9.4	37.9	120.2	458.6	1,496.1	2,311.3	1,679.3

Six further plies have been lost to excessive clamping.

Table 2-78: ***6.2.2.5 Difference in LV Losses kWh (weekly averages)***

7. C. Diff. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.7	5.4	12.8	29.9	49.8	76.6	114.6	140.5
	27mpd	3.0	6.2	19.9	37.1	63.3	98.0	134.1	107.5
	38mpd	3.4	7.3	19.4	48.3	78.3	113.1	106.5	47.4
	49mpd	4.0	8.5	30.0	55.3	91.8	108.5	79.5	26.5

6.2.2 parity loss: 336 kWh, 6.2.2.5: 434 kWh

Network losses are up by a minor amount.

Table 2-79: ***6.2.2.5 Difference in DRFFR Percent Effective Hours (weekly averages)***

8. C. Diff. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	0.60%	1.20%	2.90%	4.80%	9.60%	7.70%	13.70%	18.40%
	27mpd	0.60%	1.80%	0.60%	6.50%	7.10%	11.90%	16.00%	11.90%
	38mpd	0.60%	0.60%	3.00%	10.10%	7.20%	13.10%	13.10%	5.40%
	49mpd	0.60%	1.20%	2.40%	9.50%	10.70%	14.30%	10.10%	1.80%

6.2.2.5 span: [86%] => [100%] red : 100% for 6.2.2.5

High-end DRFFR response is better; the 5 plies in red are at 100% i.e. the network is fully loaded so there is complete DR/FFR response fidelity.

V4-2.38 Seq_6.2.2.5 Results Summary

For the lower tier plies (say up to parity) heated EV batteries allow individual EVs to be better charged. However, as numbers of EVs and mpd duties rise, the extra load imposed on the network induces earlier onset of severe undercharging, together with extensive use of clamps.

This implies that a DNO needs to know the characteristics of the EVs which are on their networks.

V4-2.39 Sequence 6.2.2.9

Sequence	**Simulation ID**	**Description**
Seq_6.2.2.9	(S_BJ)	Variation vs. Seq_6.2.2.5: Preheats cabin with battery heaters as 6.2.2.5, but N EV receives +10% uplift
Baseline Seq	***Description***	
Seq_6.2.2.5	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW. EVs include preheat of cabin plus battery heaters, to reduce thermal C shrinkage.*	

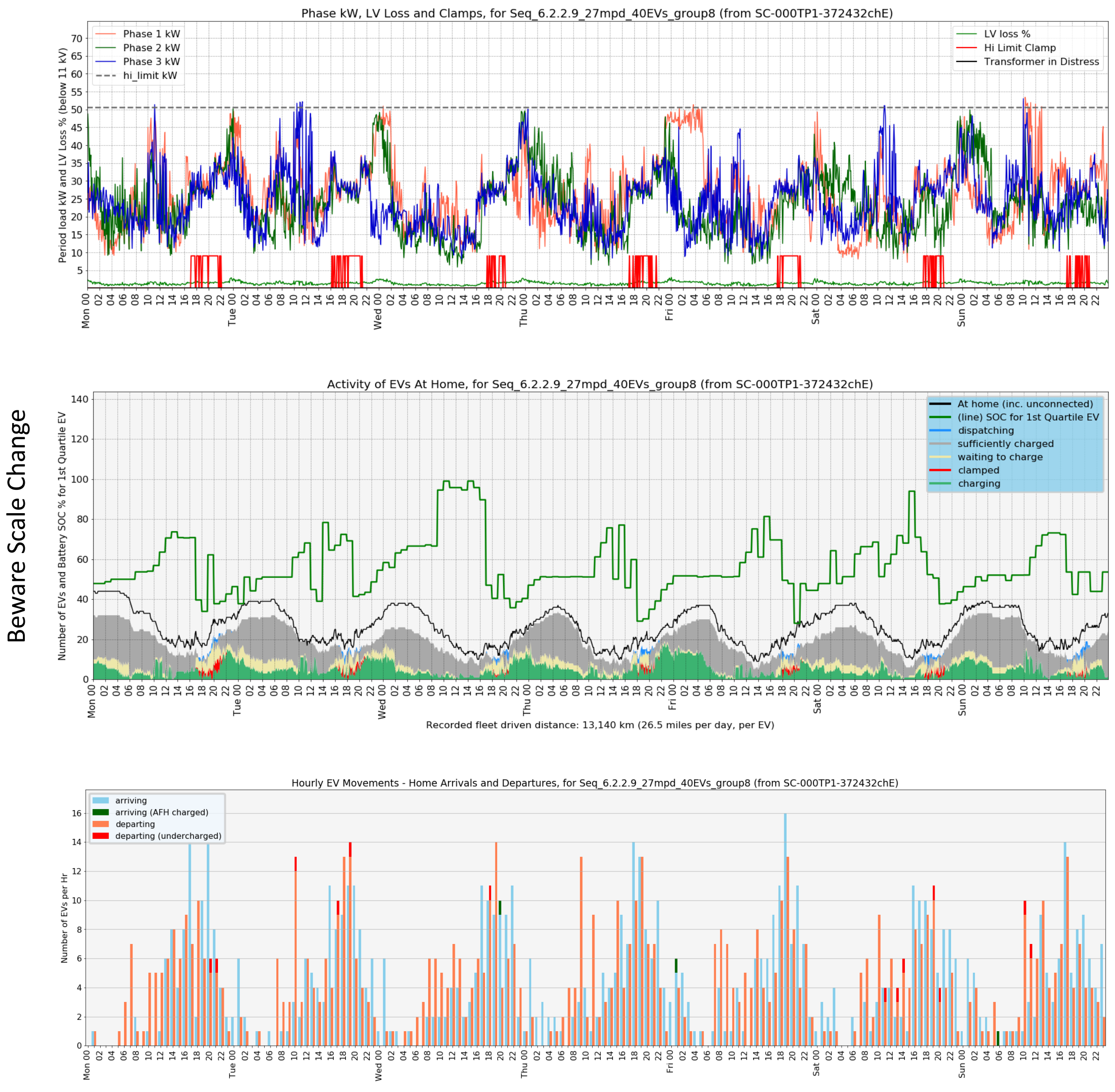
The motive for adding 10% extra EVs per N EV count is to counteract the mid-week drop of EVs overnighting at home, which the author sees justified in the synthesised trips, but suspects this is not always so.

V4-2.40 Seq_6.2.2.9 Outcomes

The presence of extra EVs lifts demand and the system is less able to cope.

V4-2.41 Seq_6.2.2.9 Feeder and EV Plots

V4-2.41.1 Seq_6.2.2.9: 27mpd 40EVs



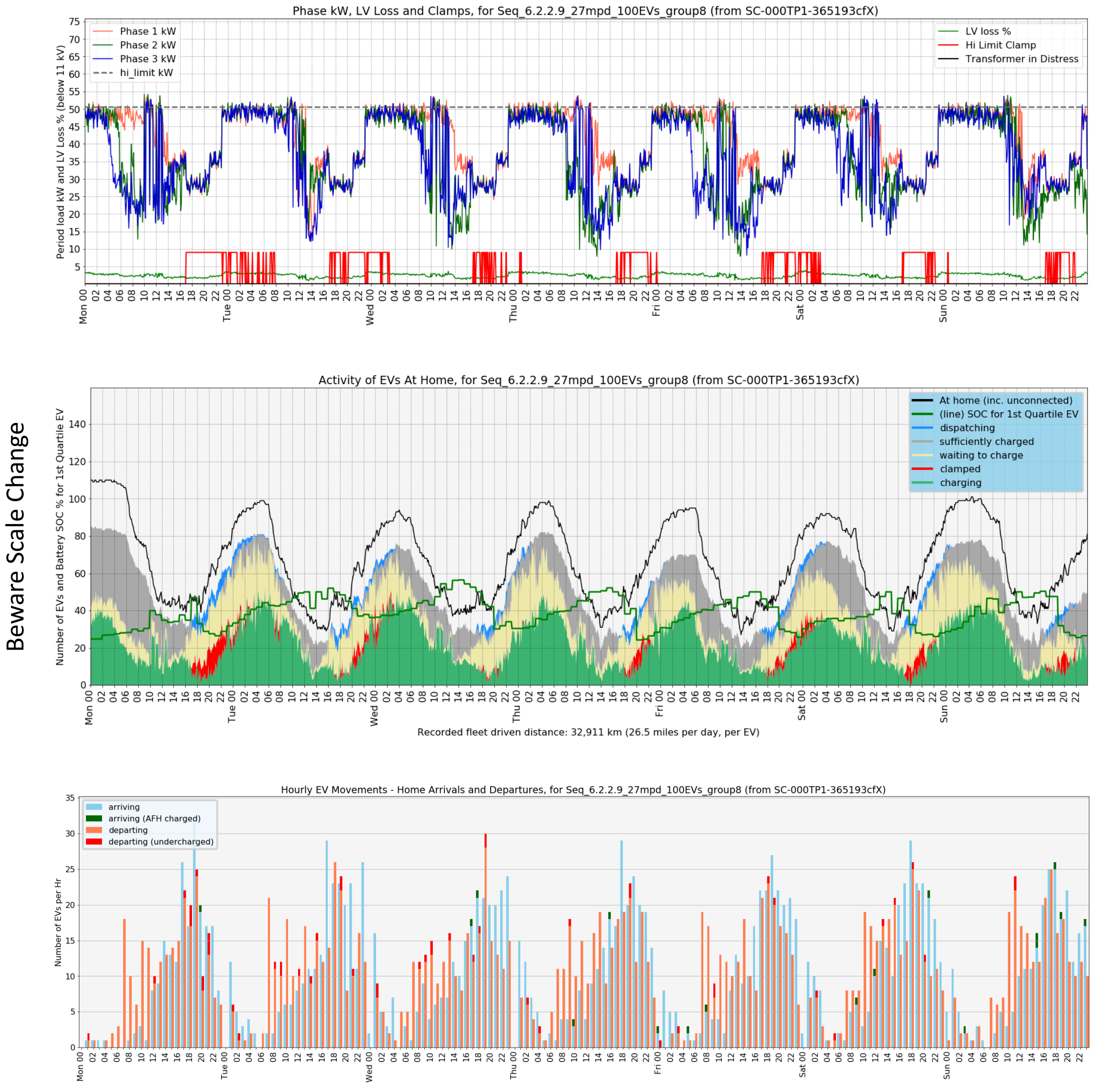
EoW stats: kWh[b]	EV total: 2,807	Home: 2,652	AFH: 155	V2G: 110
cf. 6.2.2.5:	*EV total: 2,571*	*Home: 2,426*	*AFH: 63*	*V2G: 96*

Figure 2-30: Seq_6.2.2.9 27mpd 40EVs group 8 plots. Weekly km: 13,307 (12,212)

Notes re above plots:

- here, each EV does the duty of 1.1; the values reflect this, other than AFH which has doubled rather than risen by 10%. This implies the home network is saturating
- (CICD) EVs have good SOC; V2G and clamps are occasionally used.
- (Arrive/Depart) very few AFH and undercharged depart events.

V4-2.41.2 Seq_6.2.2.9: 27mpd 100EVs



EoW stats: kWh**b**	EV total: 7,537	Home: 7,055	AFH: 482	V2G: 705
cf. 6.2.2.5:	*EV total: 6,725*	*Home: 6,281*	*AFH: 444*	*V2G: 429*

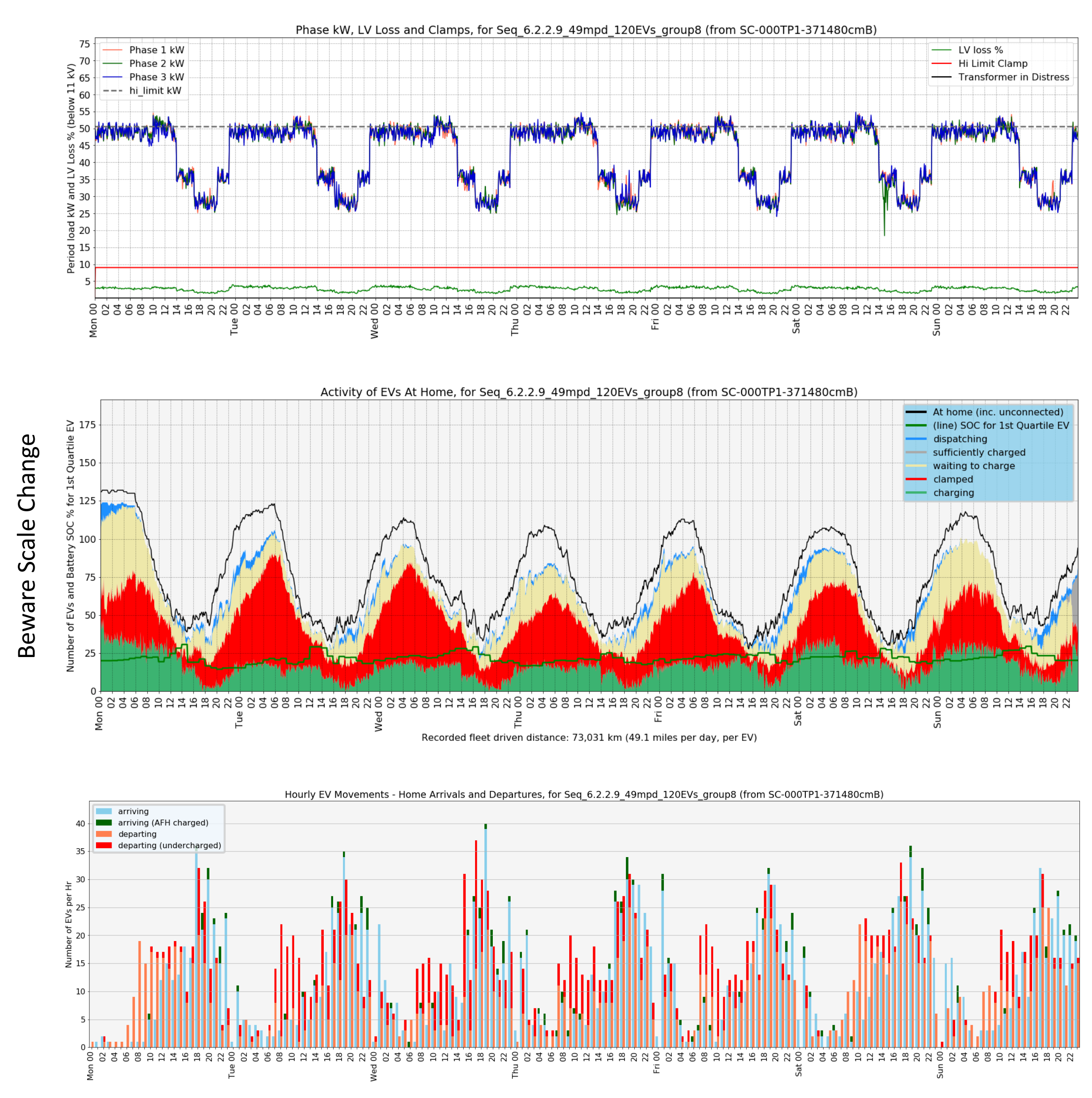
Figure 2-31: Seq_6.2.2.9 27mpd 100EVs group 8 plots. Weekly km: 33,839 (30,876)

Notes re above plots:

- Other than V2G, all values see a c. 10% uplift. V2G is however more active.
- it is noticeable that the red phase has more duty to perform.

V4-2.41.3 Seq_6.2.2.9: 49mpd 120EVs

These images needed a plot for 1.1 x 140 = 154 EVs; this does not exist, therefore the 120 EV plot will be shown:



EoW stats: kWh[b]	EV total: 14,340	Home: 9,597	AFH: 4,743	V2G: 1,098
cf. 6.2.2.5:	*EV total: 13,156*	*Home: 9,554*	*AFH: 3,602*	*V2G: 1,093*

Figure 2-32: Seq_6.2.2.9 49mpd 120EVs group 8 plots. Weekly km: 73,009 (66,335)

Notes re above plots:

- Total supply is struggling to meet the needs of the fleet; consumption has risen. Demand is clearly high as the network is perpetually clamped.

V4-2.42 Data Tables Seq_6.2.2.9

Note that this run omitted the 140 EV cells as 1.1 x 140 = 154 EV option does not exist.

Table 2-80: ***6.2.2.9 Unused kWh (weekly averages)***

Seq_6.2.2.5	1. A	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	16,865	16,024	14,351	12,684	10,970	9,187	7,194	5,406
		27mpd	16,719	15,702	13,701	11,658	9,594	7,434	5,151	4,266
		38mpd	16,582	15,421	13,048	10,637	8,217	5,799	4,368	4,223
		49mpd	16,450	15,153	12,513	9,835	7,216	5,063	4,304	4,249
Seq_6.2.2.9	B	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	16,795	15,858	14,004	12,144	10,249	8,219	6,034	
		27mpd	16,624	15,498	13,332	11,071	8,695	6,264	4,422	
		38mpd	16,480	15,169	12,588	9,898	7,154	4,860	4,238	
		49mpd	16,338	14,876	12,027	9,040	6,191	4,510	4,259	
Difference B - A	C	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-70	-167	-347	-541	-721	-968	-1,160	
		27mpd	-95	-203	-370	-587	-899	-1,170	-729	
		38mpd	-102	-253	-461	-738	-1,063	-939	-129	
		49mpd	-111	-277	-486	-795	-1,025	-553	-46	

Average Weekly Unutilised Network kWh: Seq_6.2.2.9 (B) vs. Baseline 6.2.2.5 (A)

6.2.2.9 places significantly more burden as the lowered kWh headroom shows.

Note that the DRB/FFR pattern displaces 4,196 kWh during the week vs. total suppliable (LV side) of 25,855 kWh. The residential load is c. 8,142 kWh. This leaves a maximum: 25,855 - 8,142 - 4,196 = 13,517 kWh to EVs at home, which after charging losses is about 11,354 kWh[b], assuming EVs are perpetually connected at home i.e. not driven.

From this, seeing the above values approach 4,196 kWh implies that near every practicable kWh is being extracted, likely with a steep rise in undercharging.

As this sequence is studying home numbers, the AFH tables will not be investigated.

Table 2-81: 6.2.2.9 Counts of Undercharging events per EV (weekly averages)

Seq_6.2.2.5	4. A	N EV	10	20	40	60	80	100	120	140
		19mpd	0.5	0.6	0.6	0.6	0.7	0.8	0.8	1.1
		27mpd	0.9	0.9	1.0	1.1	1.2	1.3	1.6	3.8
		38mpd	1.4	1.5	1.6	1.7	1.8	2.2	4.2	8.0
		49mpd	2.1	2.1	2.2	2.3	2.5	3.7	7.0	9.8
Seq_6.2.2.9	B	N EV	10	20	40	60	80	100	120	140
		19mpd	0.5	0.6	0.7	0.7	0.8	0.9	1.0	
		27mpd	1.0	1.1	1.1	1.2	1.4	1.5	2.7	
		38mpd	1.5	1.7	1.8	1.9	2.1	3.0	7.4	
		49mpd	2.2	2.4	2.3	2.5	3.0	5.5	9.9	
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.00	0.04	0.09	0.08	0.10	0.07	0.20	
		27mpd	0.07	0.12	0.07	0.12	0.15	0.20	1.15	
		38mpd	0.15	0.22	0.16	0.18	0.30	0.80	3.18	
		49mpd	0.15	0.30	0.17	0.25	0.54	1.84	2.89	

Counts of Undercharging events per EV in Week: Seq_6.2.2.9 (B) vs. Baseline 6.2.2.5 (A)

As may be expected, EVs are departing less well charged.

Table 2-82: 6.2.2.9 Counts of Severely Undercharged EVs in Week, per EV

Seq_6.2.2.5	**5. A**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.0004	0.0004	0.0008	0.0005	0.0006	0.0004	0.0003	0.0007
		27mpd	0.0004	0.0012	0.0014	0.0019	0.0018	0.0017	0.0027	0.0389
		38mpd	0.0028	0.0028	0.0042	0.0050	0.0061	0.0105	0.0652	0.2342
		49mpd	0.0092	0.0094	0.0113	0.0117	0.0141	0.0516	0.2210	0.4326
Seq_6.2.2.9	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.0004	0.0001	0.0006	0.0005	0.0005	0.0004	0.0004	
		27mpd	0.0012	0.0007	0.0011	0.0021	0.0021	0.0020	0.0140	
		38mpd	0.0022	0.0042	0.0045	0.0062	0.0072	0.0254	0.1791	
		49mpd	0.0082	0.0117	0.0110	0.0148	0.0217	0.1283	0.4005	
Difference B - A	**C**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	-0.0018	-0.0009	-0.0003	-0.0003	0.0001	-0.0002	-0.0003	
		27mpd	0.0002	0.0006	0.0003	0.0004	0.0003	0.0001	0.0017	
		38mpd	-0.0010	-0.0011	-0.0006	-0.0002	0.0012	0.0042	0.0592	
		49mpd	0.0022	0.0049	0.0042	0.0051	0.0054	0.0401	0.1875	

Averaged Weekly Per EV Severe Undercharges: Seq_6.2.2.9 (B) vs. Baseline 6.2.2.5 (A)

The darker red plies have been lost to excess severe undercharging.

Table 2-83: 6.2.2.9 Clamps (weekly averages)

Seq_6.2.2.5	6. A	N EV	10	20	40	60	80	100	120	140
		19mpd	99.0	130.0	199.6	259.5	319.0	382.6	333.4	915.1
		27mpd	101.4	143.1	230.8	313.6	406.2	576.4	1,268.4	3,622.2
		38mpd	119.7	173.3	279.4	394.0	608.5	1,559.9	3,416.7	4,491.2
		49mpd	127.2	192.7	324.6	500.5	1,007.4	2,528.1	4,069.0	4,664.5
Seq_6.2.2.9	B	N EV	10	20	40	60	80	100	120	140
		19mpd	97.8	145.4	211.7	269.4	352.7	332.0	487.3	
		27mpd	102.0	160.5	244.4	329.0	479.3	684.7	2,754.9	
		38mpd	119.7	192.5	293.7	427.7	849.6	2,340.5	4,255.5	
		49mpd	130.1	218.2	342.2	574.5	1,506.7	3,330.1	4,511.3	
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-1.2	15.4	12.1	9.9	33.6	-50.6	153.9	
		27mpd	0.5	17.4	13.5	15.4	73.1	108.3	1,486.4	
		38mpd	0.0	19.2	14.3	33.7	241.1	780.6	838.8	
		49mpd	2.9	25.5	17.6	74.0	499.3	802.0	442.2	

Three further plies have been lost to excessive clamping.

Table 2-84: 6.2.2.9 DRFFR Percent Effective Hours (weekly averages)

8. A	N EV	10	20	40	60	80	100	120	140
	19mpd	33.3%	38.1%	45.8%	58.3%	70.2%	80.4%	90.5%	
	27mpd	32.7%	39.3%	47.0%	66.7%	78.0%	89.3%	100.0%	
	38mpd	33.3%	39.3%	51.8%	73.2%	87.5%	98.2%	100.0%	
	49mpd	32.1%	38.1%	54.8%	76.8%	91.1%	99.4%	100.0%	

6.2.2.5 span: [33%] => [100%] red : 100% for 6.2.2.5

High-end DRFFR response is better; the 5 plies in red are at 100% i.e. the network is fully loaded so there is complete DR/FFR response fidelity.

V4-2.43 Seq_6.2.2.9 Results Summary

The sequence posits a characteristic of the simulation in that EVs are away from home overnight during the week. The addition of 10% extra EVs to add missing mid-week numbers approximates home overnight stays.

This is a somewhat imprecise approximation but does show that the Typical network is overtaxed when everyone overnights at home; sociological habits will impact charging.

For instance, a locality near a major city will likely experience return home overnight, yet an apparently similar situation in which residents commute for a weekly period, departing Sunday and returning Friday, would be different.

This is an area needing more study with some form of overnight away ratio or factor, which may be adjusted.

V4-2.44 Sequence 6.3.2

Sequence	**Simulation ID**	**Description**
Seq_6.3.2	(S_67)	Variation vs. Seq_6.2.2: with Aggregator issuing Agg-B commands to mimic national-DSR (peak shaving)
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Sequence 6.3.2 simultaneously applies Aggregator control "B" pattern to the existing DR/FFR "B" hi_limit modulation.

This is plausible; the MCS is managing the local network and the Aggregator is looking at National level issues.

All EVs are Aggregator controlled, using the following daily pattern:

- from 1pm: make EVs idle (cease charging and dispatching)
- from 6pm: allow charging if SOC < 30%, also enable V2G dispatch
- from 11pm: unrestricted / normal operation.

This is performed as such joint control is possible; is there useful impact?

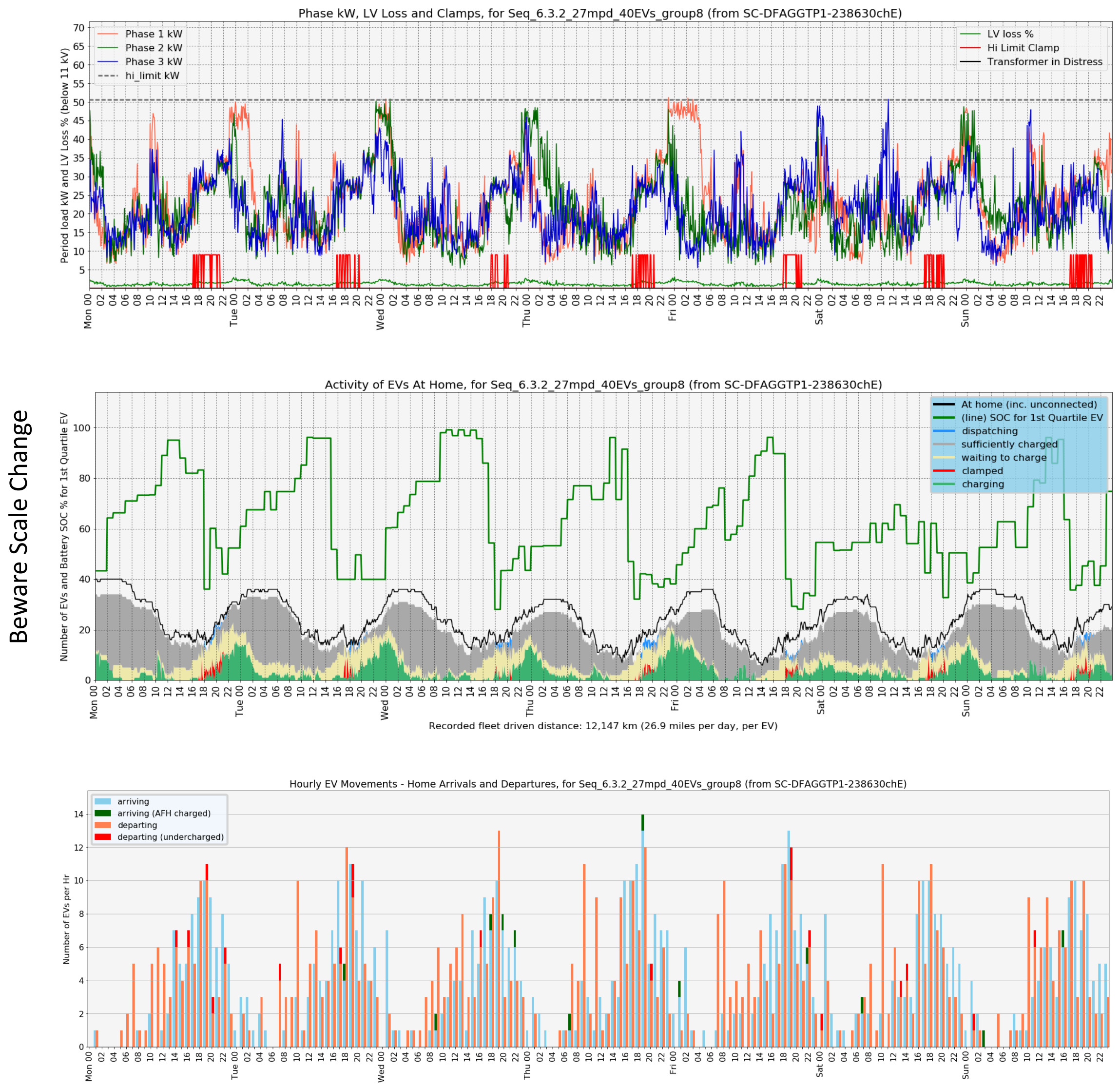
Data is from MetaMeta spreadsheets for Seq_6.3.2.

V4-2.44.1 Seq_6.3.2 Outcomes

Due to clamps, there are now no broaches caused by EVs en-masse rushing to charge following DSR constraint release. However undercharging is endemic with **all** plies failing.

V4-2.45 Seq_6.3.2 Feeder and EV Plots

V4-2.45.1 Seq_6.3.2: 27mpd 40EVs



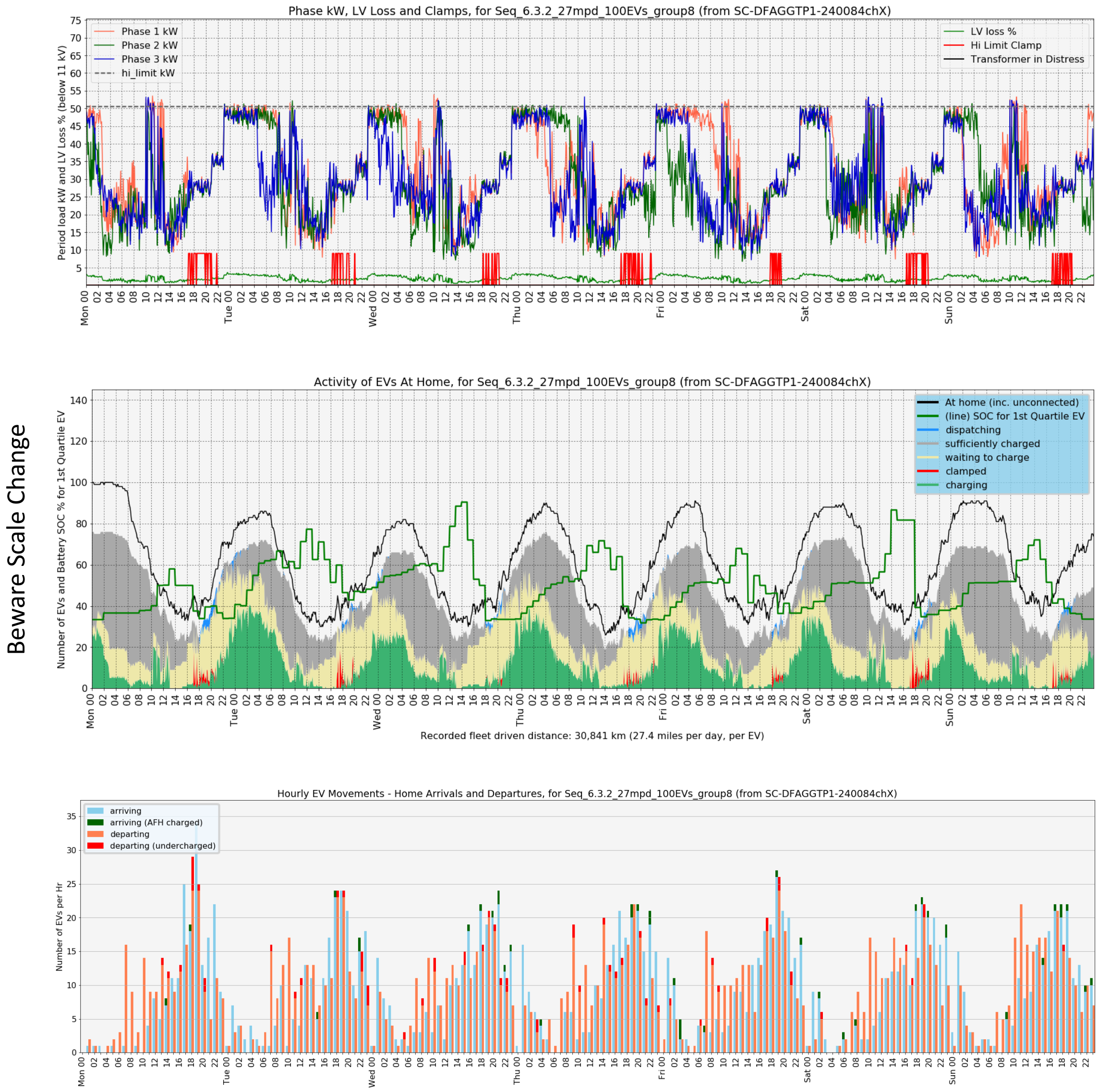
EoW stats: kWh[b] EV total: 2,384 Home: 2,072 AFH: 311 V2G: 65

Figure 2-33: Seq_6.3.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is showing clamps during the evening
- (CICD) EVs have good SOC; there is some V2G visible. Most EVs are ready to depart
- (Arrive/Depart) a few, scattered undercharged departs and AFH charging.

V4-2.45.2 Seq_6.3.2: 27mpd 100EVs



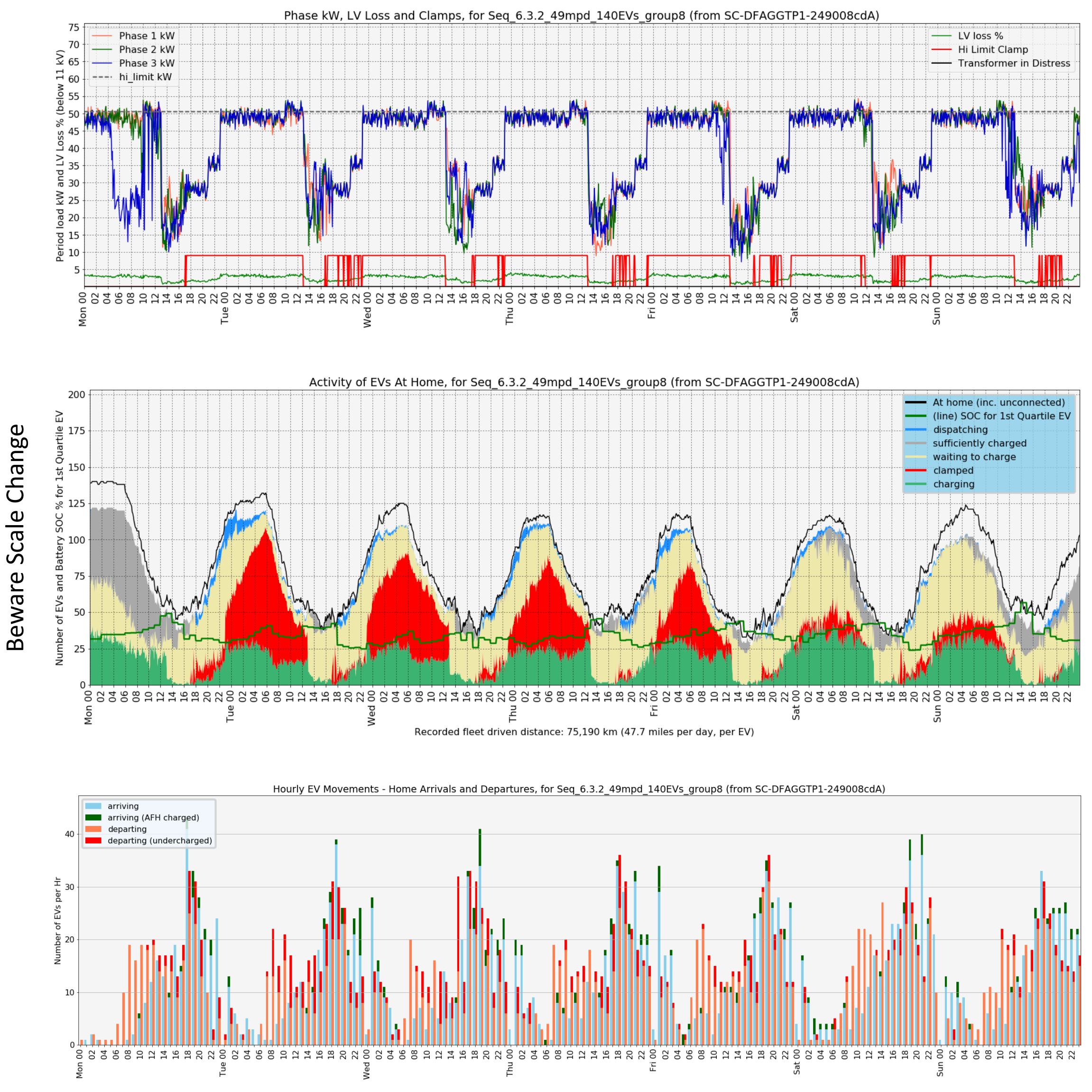
EoW stats: kWh[b] EV total: 6,091 Home: 5,218 AFH: 873 V2G: 181

Figure 2-34: Seq_6.3.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows apparently just one broach
- (CICD) SOC is similar with many EVs ready to depart; slight visible V2G blue
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. Both remain low.

V4-2.45.3 Seq_6.3.2: 49mpd 140EVs



EoW stats: kWh**b** EV total: 14,655 Home: 9,166 AFH: 5,490 V2G:1,093

Figure 2-35: Seq_6.3.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows that the Aggregator control (EVs must cease to be a load) is over-riding the hi_limit modulation during the afternoon
- (CICD) V2G in blue strives to limit clamping, which becomes extreme overnight
- undercharging and AFH charging have risen but do not seem extreme.

V4-2.46 Data Tables

Table 2-85: 6.3.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	17,118	16,497	15,267	14,022	12,762	11,484	10,192	8,888
	27mpd	17,009	16,246	14,763	13,252	11,756	10,239	8,658	7,064
	38mpd	16,915	16,061	14,330	12,560	10,840	9,033	7,299	6,038
	49mpd	16,838	15,900	13,987	12,067	10,218	8,320	6,677	5,747

6.2.2 span: [10,098] => [4,763]

Aggregators inhibit afternoon charging, thus unutilised kWh increases vs. 6.2.2.

Table 2-86: 6.3.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.6	3.3	3.3	3.3	3.4	3.8	3.6	3.7
	27mpd	7.0	7.9	7.8	8.1	8.6	8.7	8.6	8.8
	38mpd	17.4	17.4	18.0	18.6	18.6	19.2	19.3	22.3
	49mpd	35.7	33.0	31.9	31.7	31.7	32.4	34.3	39.2

6.2.2 span: [8.0] => [34.2]

Given the reduced kWh drawn at home, the EVs are charging elsewhere.

Table 2-87: 6.3.2 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	0.12	0.14	0.14	0.14	0.15	0.16	0.16	0.16
	27mpd	0.32	0.32	0.30	0.31	0.34	0.34	0.33	0.34
	38mpd	0.63	0.61	0.62	0.62	0.63	0.65	0.66	0.78
	49mpd	1.15	1.02	0.97	0.96	0.98	1.00	1.07	1.26

6.2.2 span: [0.3] => [1.05]

As the need for AFH charging rises, so drivers must find more connects.

Table 2-88: ***6.3.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.0	1.0	1.1	1.2	1.2	1.3	1.3	1.4
	27mpd	1.7	1.7	1.7	1.8	1.9	2.0	2.0	2.3
	38mpd	2.5	2.4	2.6	2.6	2.7	2.9	3.2	4.8
	49mpd	3.3	3.2	3.2	3.3	3.3	3.8	4.7	6.6

6.2.2 span: [1.4] => [5.0]

A small increase is seen.

Table 2-89: ***6.3.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0096	0.0083	0.0087	0.0074	0.0076	0.0104	0.0102	0.0107
	27mpd	0.0156	0.0136	0.0139	0.0161	0.0182	0.0209	0.0217	0.0297
	38mpd	0.0396	0.0366	0.0364	0.0385	0.0370	0.0438	0.0535	0.1473
	49mpd	0.0550	0.0571	0.0591	0.0560	0.0590	0.0817	0.1463	0.3175

6.2.2 span: [0.0015] => [0.1631] (limit: < 0.007)

This is a first for Seq_6. Every ply fails with too high a chance of severe undercharging, however the rates here are better then Seq_4.3.2 (Volume 3, Table 26).

Table 2-90: ***6.3.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	92.3	115.2	152.6	174.5	191.8	204.0	155.6	180.4
	27mpd	95.1	122.3	164.8	188.1	212.9	244.3	236.0	732.8
	38mpd	101.1	130.2	179.5	212.1	258.3	447.5	872.7	1,979.4
	49mpd	96.9	134.8	187.5	227.6	348.0	812.3	1,478.5	2,370.1

6.2.2 span: [366] => [2,985] (limit: < 420)

These values are down apparently as Aggregators, by overriding the EV’s desire to charge, reduce the need of the MCS to intervene with clamps.

***Table 2-91:** 6.3.2 V2G kWh dispatch per EV (weekly averages)*

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7.5	4.8	3.8	3.3	3.8	4.2	4.6	5.2
	27mpd	6.8	4.6	3.8	3.6	4.3	5.5	7.2	12.9
	38mpd	6.7	4.5	4.0	4.0	5.3	9.3	14.7	21.3
	49mpd	6.7	4.5	4.1	4.4	6.8	12.7	18.0	21.9

6.2.2 span: [7.9] => [27.0]

The V2G EVs have reduced duties, presumably because the Aggregator signal is dissuading them from:

- being active in the afternoons, and
- acquiring enough charge to permit V2G.

***Table 2-92:** 6.3.2 DRFFR Percent Effective Hours (weekly averages)*

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	31.5%	32.7%	41.1%	48.8%	59.5%	65.5%	69.0%	72.0%
	27mpd	31.5%	34.5%	41.1%	54.8%	64.3%	68.5%	77.4%	80.4%
	38mpd	33.9%	35.1%	45.2%	60.7%	67.9%	74.4%	79.2%	82.7%
	49mpd	31.0%	35.7%	47.0%	60.1%	69.6%	76.8%	81.0%	85.1%

6.3.2 span: [47.0%] => [85.7%]

By eliminating periods of load duty, the effective time per week has dropped by c. 5% i.e. 8.2 hours. The daily prohibition on charging amounts to 7 x 5 = 35 hours; hence the EVs (being hungry) are causing other times to possess a more effective response. This has been seen elsewhere (see hi_limit reduction in ~X$); hi_limit modulation is more effective when loads are high.

V4-2.47 Seq_6.3.2 Results Summary

The combination of DR/FFR and Aggregator control is seen as:

- technically possible, but
- potentially clashing with EV use as cars.

This does not prohibit such use; rather, it suggests that the combination needs be investigated not applied blithely, lest EVs experience severe undercharging.

In a parity week, the fleet in 6.2.2 experienced 0.15 severe undercharges (likely no more than once a winter) whereas in 6.3.2 the fleet experienced 2 a week (approaching 20 in the winter months).

Severe undercharging leads to stranding. Given the negativity repeated stranding engenders (and a tendency for such events to cluster upon the same people) this is far too high. Pushback in some form is expected.

As the 6.3.2 situation is not tolerable in the field, data from the sequence is not collated to the undercharging => severe undercharging correlation dataset.

V4-2.48 Sequence 6.3.2.1

Sequence	Simulation ID	Description
Seq_6.3.2.1	(S_AD)	Variation vs. Seq_6.2.2: a week in Summer with ambient temp of 18 °C. Residential loads scaled from 1.3 to 1.1 kW per house (to reflect use of LED lighting); there are no Aggregator controlled EVs. Residential load data is from SSE's NTVV project, for the week starting 15 July 2013.
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Household Summer loads are lower and EVs benefit from both no auxiliary loads and better battery capacity, due to raised ambient temperatures. There is DR/FFR "B" modulation of the hi_limit, which will be near 49 kW as the transformer is not allowed "cold weather cooling".

Note that DNOs who gather data away from winter must expect:

- what they see might be like this sequence; however the winter sequence may be different.

How much is the difference? How might the data found in summer need to be adjusted to assess a winter situation?

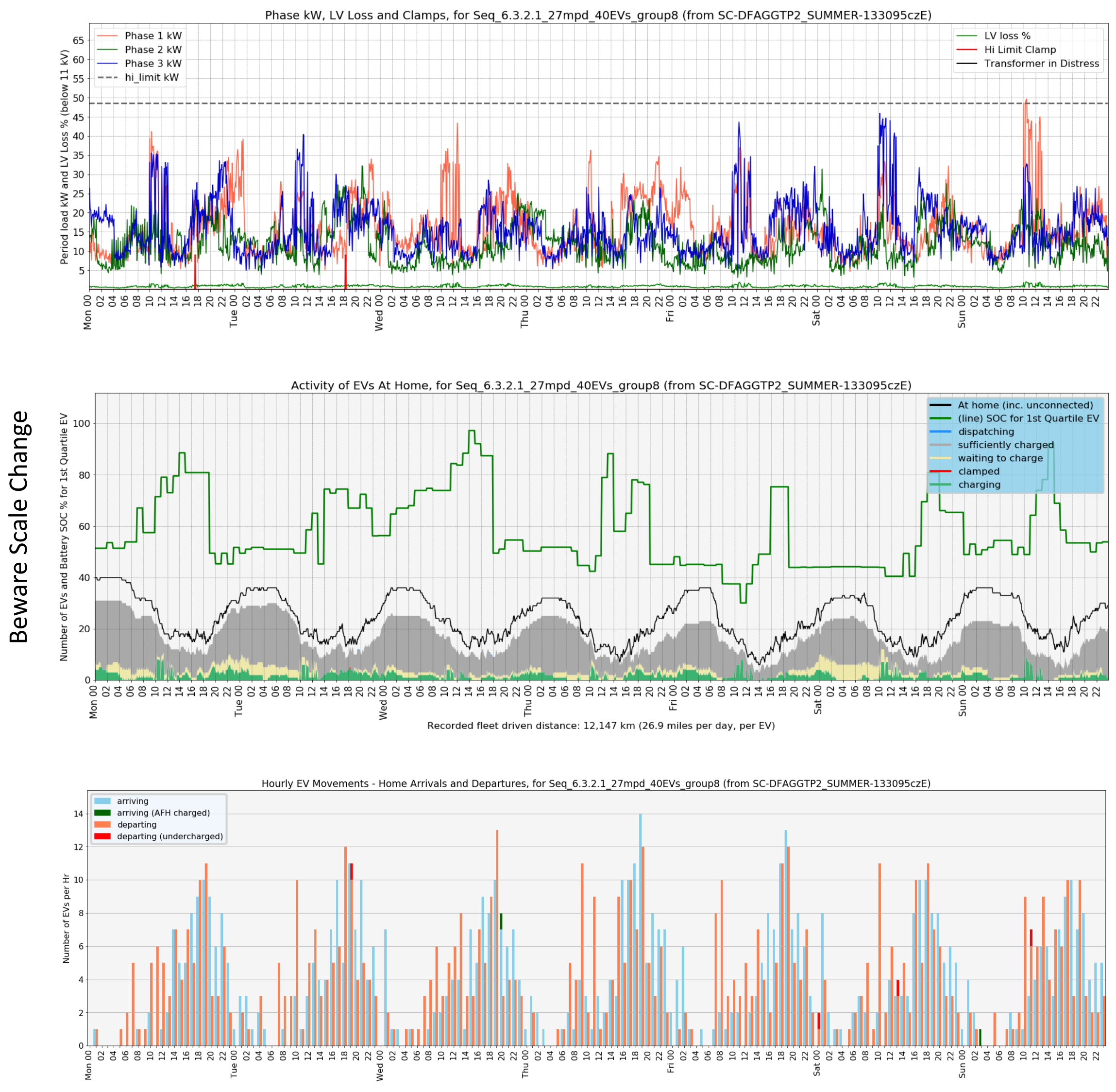
Data originate from MetaMeta spreadsheets for Seq_6.3.2.1.

V4-2.48.1 Seq_6.3.2.1 Outcomes

EV demand is lower thus ability to support N EVs is much better, successfully covering all cases. DRFFR PEH metric shows a noticeable drop, likely due to there being less EVs charging at any given time.

V4-2.49 Seq_6.3.2.1 Feeder and EV Plots

V4-2.49.1 Seq_6.3.2.1: 27mpd 40EVs



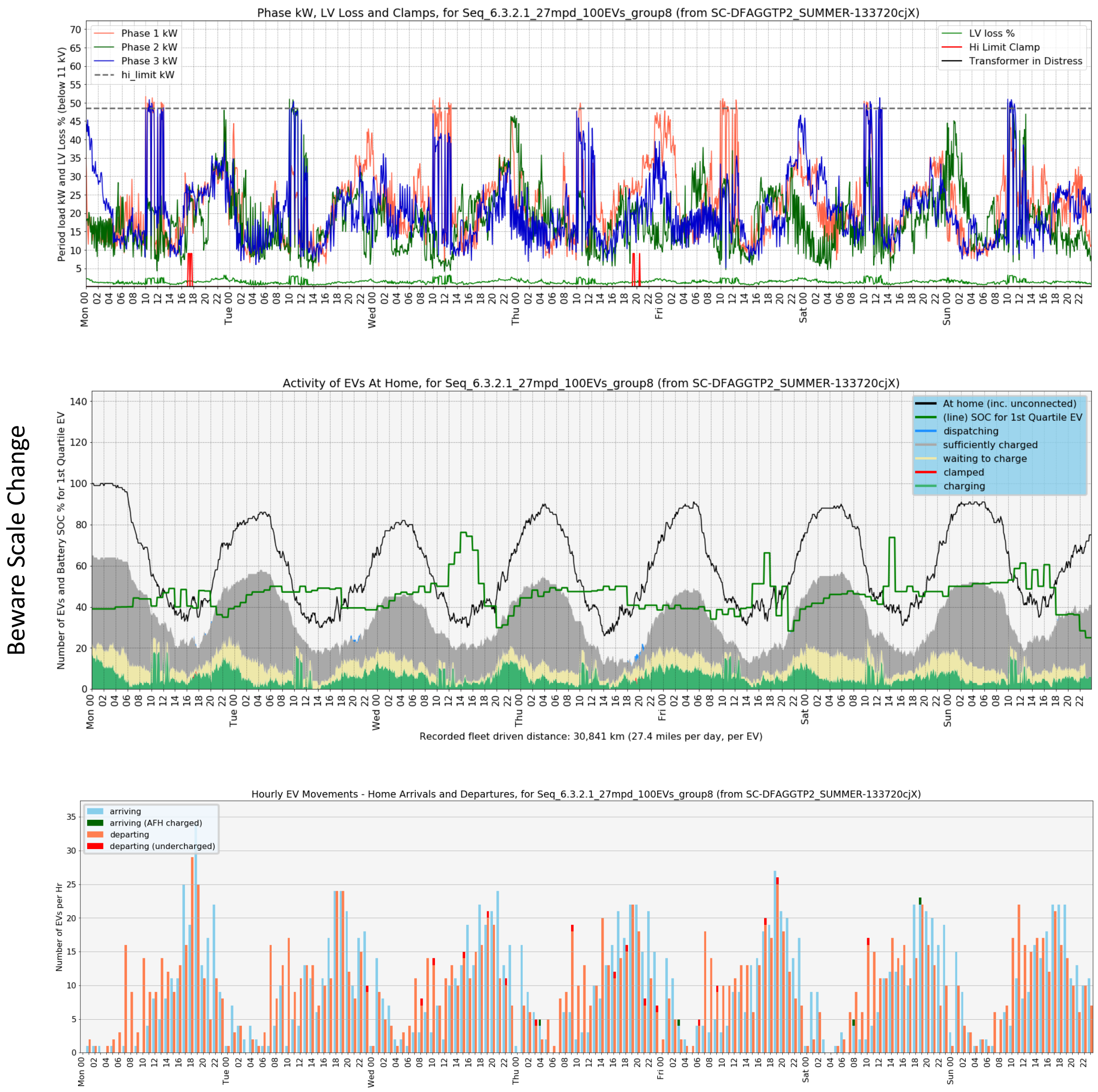
EoW stats: kWh[b] EV total: 1,425 Home: 1,385 AFH: 39 V2G: 1

Figure 2-36: Seq_6.3.2.1 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is low but otherwise unremarkable
- (CICD) EVs have good SOC; many ready to depart
- (Arrive/Depart) there are very few undercharged departs or AFH charging.

V4-2.49.2 Seq_6.3.2.1: 27mpd 100EVs



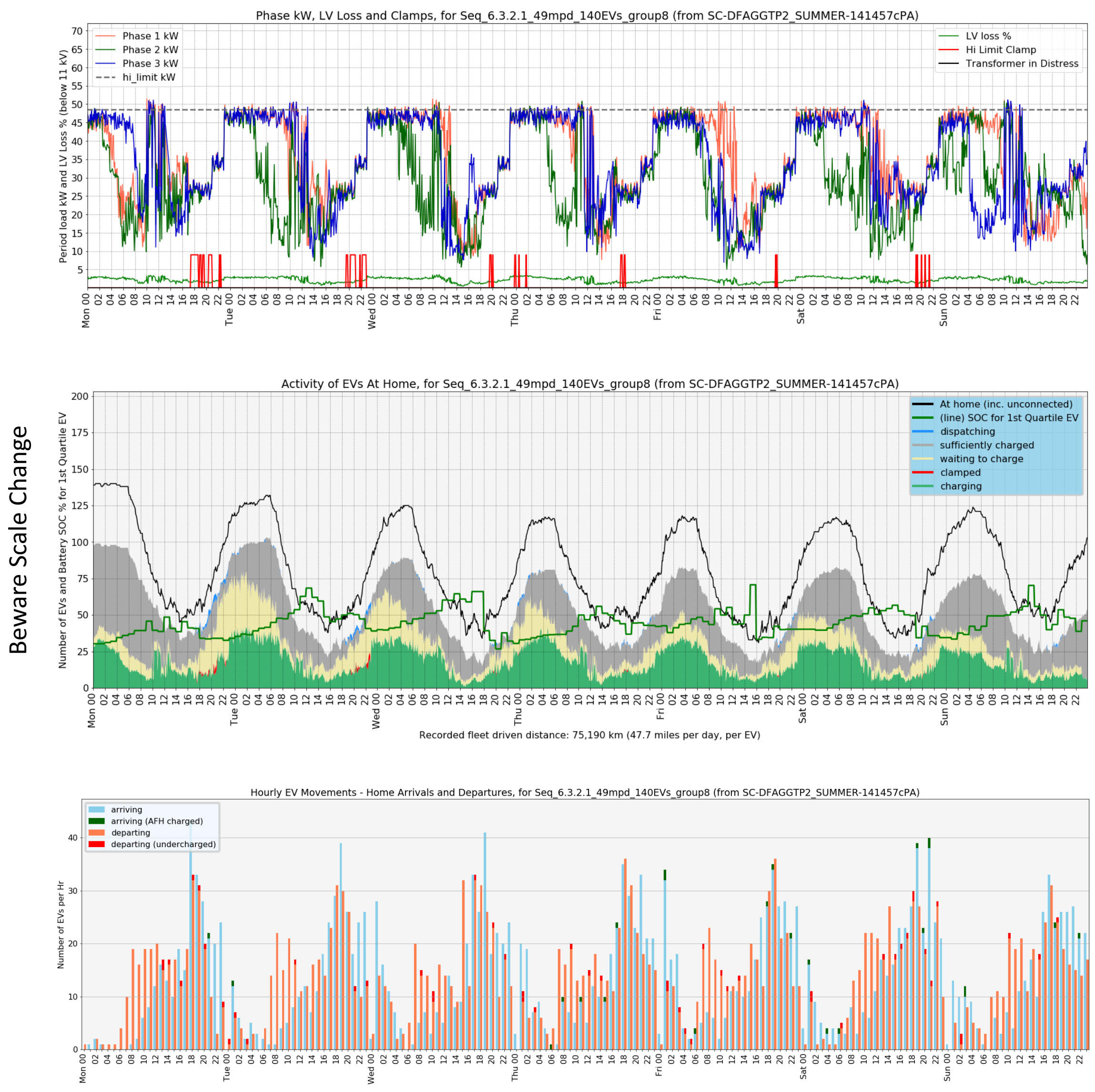
EoW stats: kWh[b] EV total: 3,684 Home: 3,562 AFH: 122 V2G: 10

Figure 2-37: Seq_ 6.3.2.1 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows the regular (mid-day) DR/FFR “B” Sunshine signal (renewables are plentiful; charge now) which provokes charging. Clamping is low
- (CICD) SOC is similar with significant numbers of EVs not bothered to be plugged in (clear) or ready to depart (grey). There is no visible V2G blue
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are very low.

V4-2.49.3 Seq_6.3.2.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 9,842 Home: 8,618 AFH: 1,224 V2G: 298

Figure 2-38: Seq_ 6.3.2.1 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot has clamps assisting the hi_limit modulation, but are otherwise unremarkable
- (CICD) V2G in blue is occasionally present
- undercharging and AFH charging is slightly up but minimal.

V4-2.50 Data Tables Seq_6.3.2.1

Table 2-93: 6.3.2.1 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,239	18,853	18,106	17,348	16,590	15,846	15,070	14,368
	27mpd	19,107	18,564	17,550	16,492	15,445	14,437	13,368	12,388
	38mpd	18,961	18,290	16,928	15,521	14,199	12,774	11,396	9,988
	49mpd	18,793	17,977	16,310	14,654	13,035	11,323	9,590	7,802

6.2.2 span: [10,098] => [4,763]

In summer less power is needed, thus unutilised kWh increases vs. 6.2.2.

Table 2-94: 6.3.2.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.2	0.4	0.3	0.3	0.3	0.3	0.3
	27mpd	0.5	0.7	1.0	1.1	1.2	1.2	1.1	1.2
	38mpd	3.4	3.5	3.7	4.0	4.0	4.2	4.1	4.1
	49mpd	9.2	8.6	8.4	8.5	8.4	8.6	8.7	8.7

6.2.2 span: [8.0] => [34.2]

Given the reduced need for kWh, AFH charging is significantly down by a factor of c. 4.

Table 2-95: 6.3.2.1 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	0.005	0.006	0.010	0.008	0.008	0.009	0.008	0.009
	27mpd	0.019	0.022	0.026	0.029	0.034	0.035	0.033	0.033
	38mpd	0.088	0.095	0.092	0.097	0.099	0.101	0.100	0.099
	49mpd	0.215	0.191	0.186	0.190	0.193	0.197	0.198	0.198

6.2.2 span: [0.3] => [1.05]

As the need for AFH charging falls, so drivers require less AFH connections. This is significant as winter provision is likely to be x10 that of summer.

For example, the winter parity case of 6.2.2 saw the fleet taking AFH supplies 30 times in the week. In summer, the same fleet of 100 vehicles use AFH only 3.5 times.

This will impact the need for public charge points, their turnover and profit.

Table 2-96: ***6.3.2.1 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
	27mpd	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4
	38mpd	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8
	49mpd	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2

6.2.2 span: [1.4] => [5.0]

With demand low hence proportionately plentiful power, EVs can charge to their fill hence the incidence of undercharging drops.

Table 2-97: ***6.3.2.1 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001
	27mpd	0.0002	0.0000	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
	38mpd	0.0002	0.0006	0.0008	0.0008	0.0011	0.0012	0.0012	0.0012
	49mpd	0.0024	0.0019	0.0032	0.0038	0.0045	0.0042	0.0040	0.0046

6.2.2 span: [0.0015] => [0.1631] (limit: < 0.007)

Severe undercharging is now experienced by parity case EVs c. once in 5,000 weeks.

Table 2-98: ***6.3.2.1 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0.3	0.6	1.8	3.3	5.7	8.7	3.6	5.3
	27mpd	0.6	1.1	3.8	8.2	14.7	23.6	12.9	18.5
	38mpd	1.5	2.4	8.2	18.1	34.4	58.9	39.2	61.5
	49mpd	2.2	4.5	14.8	32.2	63.6	107.4	88.5	221.7

6.2.2 span: [366] => [2,985] (limit: < 420)

Clamps have substantively dropped, reflecting a less urgent need to charge. Ratios span x13 to x294 of Winter vs. Summer.

This highlights a concern: Given the drop in clamping rates, should any limit on number of clamps be assessed as:

- per worst-case week(i.e. 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 contentious (as clamps deny charge, which can cause undercharging) then suspected.

The author suggests "worst case week" as this is simple to understand.

Table 2-99: ***6.3.2.1 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
	27mpd	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.6
	38mpd	0.0	0.0	0.1	0.2	0.4	0.8	1.3	1.9
	49mpd	0.1	0.1	0.2	0.4	0.8	1.7	2.9	6.0

6.2.2 span: [7.9] => [27.0]

V2G EVs are now almost unused - for local control. This suggests that V2G will escape to the greater grid so produce the intended effect.

Table 2-100: ***6.3.2.1 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	23.8%	27.4%	30.4%	31.5%	33.3%	36.9%	41.1%	44.0%
	27mpd	25.0%	26.2%	31.0%	34.5%	41.7%	47.0%	51.8%	59.5%
	38mpd	25.0%	28.0%	31.5%	39.9%	46.4%	56.0%	64.3%	72.6%
	49mpd	24.4%	28.6%	36.9%	45.2%	56.0%	64.9%	76.2%	85.7%

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

Hi_limit modulation is less effective in summer as loads are down.

V4-2.51 Seq_6.3.2.1 Results Summary

EV demand is much lower in Summer vs. Winter. This has impact as:

- Summer datasets do not reflect demand seen in Winter. Network measurements taken by DNOs for planning purposes will not apply for the whole year i.e. may need revision or scaling to reflect peak demands;
- use of AFH (public charging) will be much less in Summer vs. Winter; public charger provision needs reflect this
- takings hence profits will be down for long-term charging provision (e.g. commuter car-parks) in summer vs. winter
- the PEH metric is notable degraded.

V4-2.52 Sequence 6.3.2.2

Sequence	**Simulation ID**	**Description**
Seq_6.3.2.2	(S_B0)	Variation vs. Seq_6.3.2.1: SV1G replaces V2G i.e. 19% dumb, 81% SV1G
Baseline Seq	***Description***	
Seq_6.3.2	*Typical network, Summer with ambient temp of 18 °C. Residential loads scaled from 1.3 to 1.1 kW per house, EV mix 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW, normal plugin regime. DR/FFR "B" modulation of hi_limit.*	

In this Summer sequence, V2G EVs are replaced with standard SV1G vehicles. Does anyone notice?

Data originate from MetaMeta spreadsheets for Seq_6.3.2.2.

V4-2.52.1 Seq_6.3.2.2 Outcomes

The only impact is on 3 extreme plies of duty, for which clamps exceed their limit. The parity case is unaffected by removing V2G.

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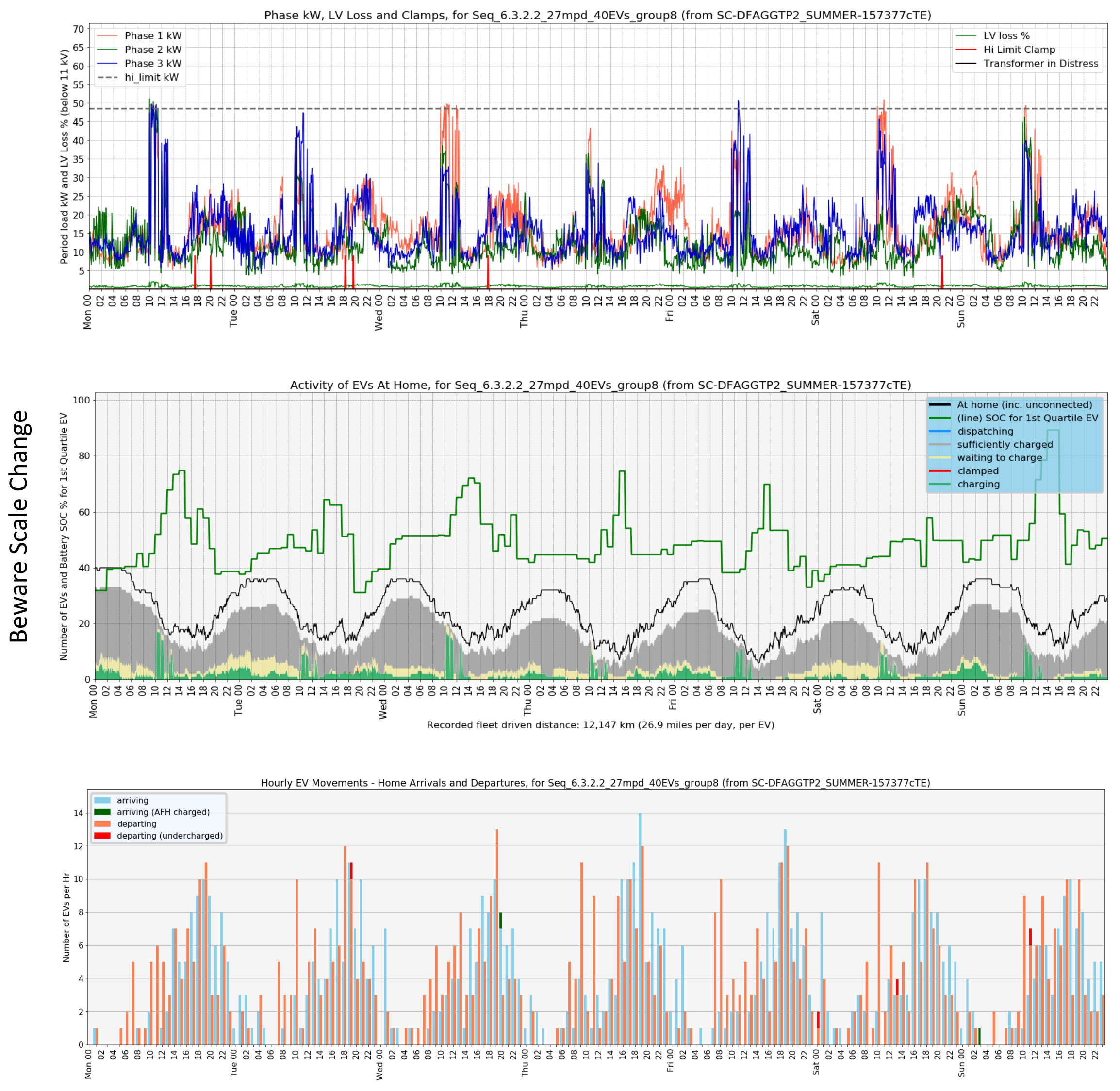
V4-2.53 Seq_6.3.2.2 Feeder and EV Plots

V4-2.53.1 Seq_6.3.2.2: 27mpd 40EVs



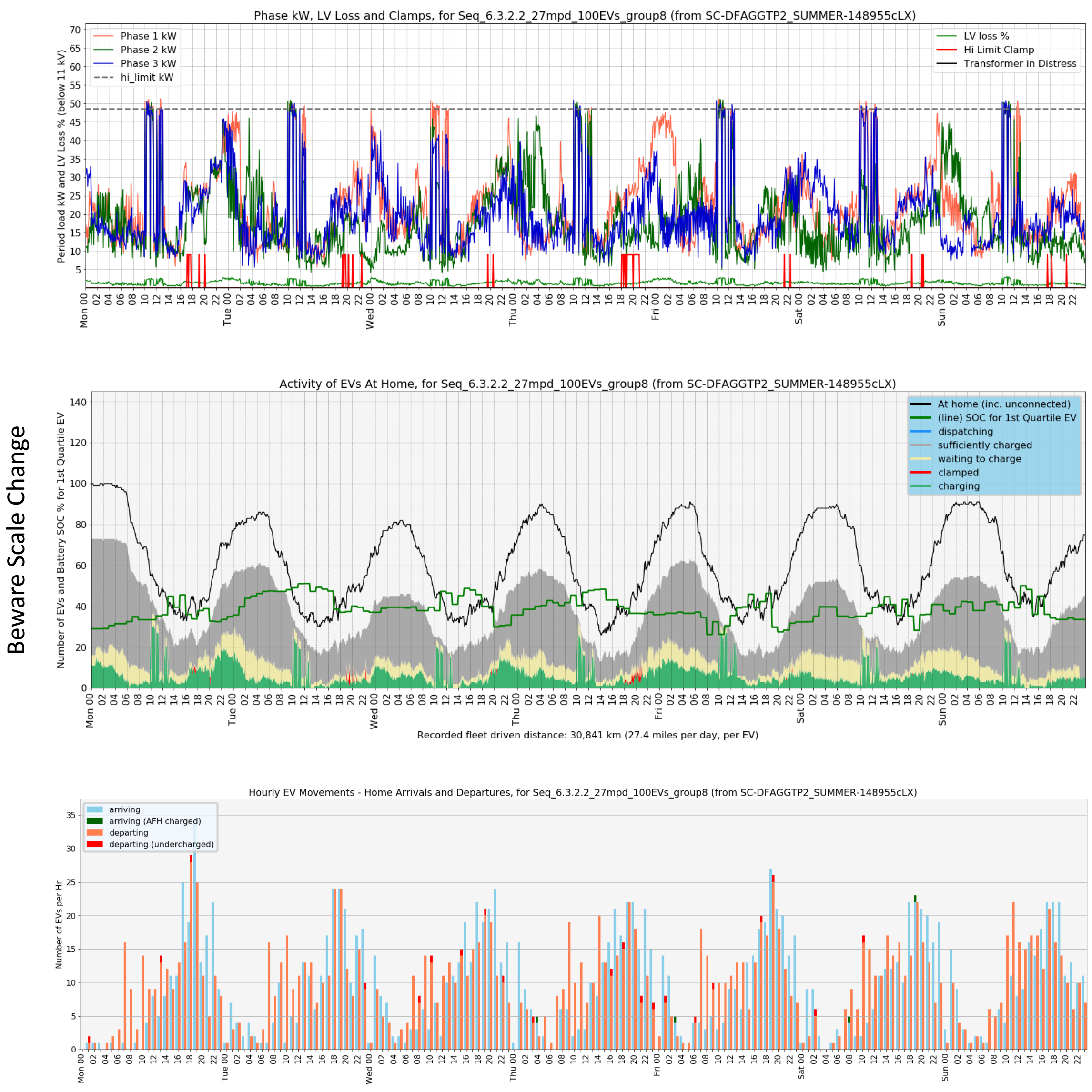
EoW stats: kWh[b] EV total: 1,459 Home: 1,417 AFH: 42 V2G: 0

Figure 2-39: Seq_6.3.2.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.53.2 Seq_6.3.2.2: 27mpd 100EVs



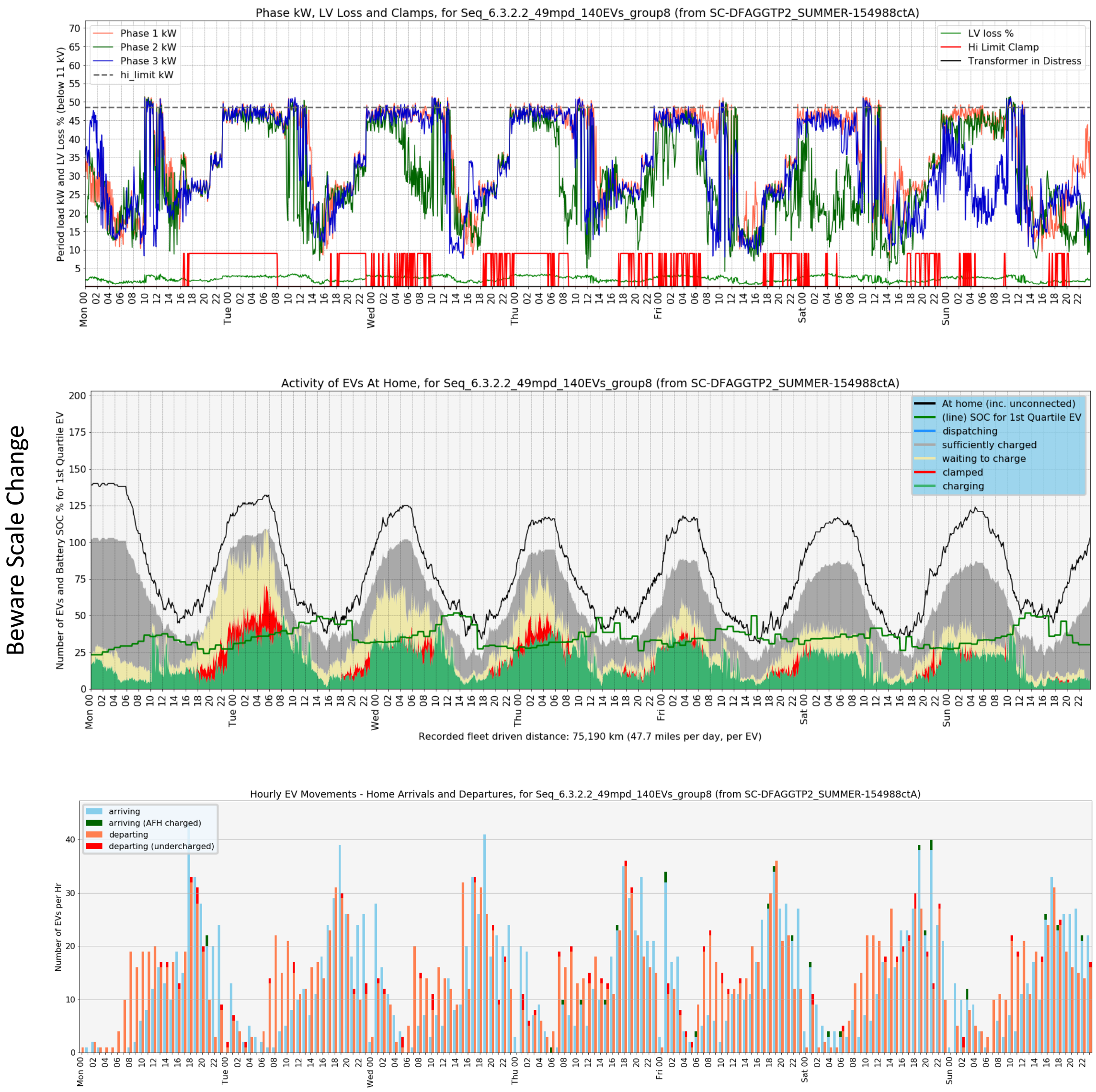
EoW stats: kWh[b] EV total: 3,708 Home: 3,578 AFH: 129 V2G: 0

Figure 2-40: Seq_6.3.2.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps are more common than with 6.3.2.1
- (CICD) SOC is similar with significant numbers of EVs ready to depart
- (Arrive/Depart) has less undercharged departs vs. 6.3.2.1.

V4-2.53.3 Seq_6.3.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 9,532 Home: 8,239 AFH: 1,292 V2G: 0

Figure 2-41: Seq_6.3.2.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot now has frequent clamps
- (CICD) clamping, very rare in 6.3.2.1, is apparent
- undercharging and AFH remain similar to 6.3.2.1.

V4-2.54 Data Tables Seq_6.3.2.2

Table 2-101: 6.3.2.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,231	18,828	18,040	17,246	16,477	15,712	14,917	14,238
	27mpd	19,104	18,550	17,511	16,429	15,376	14,363	13,279	12,295
	38mpd	18,962	18,284	16,909	15,476	14,153	12,714	11,337	9,924
	49mpd	18,797	17,975	16,304	14,636	13,017	11,304	9,611	7,948

6.3.2 span: [14,437] => [7,802]

The lack of V2G EVs has reduced charging further.

Table 2-102: 6.3.2.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.2	0.4	0.3	0.3	0.4	0.3	0.4
	27mpd	0.5	0.7	1.0	1.1	1.3	1.3	1.2	1.2
	38mpd	3.6	3.7	3.9	4.1	4.2	4.4	4.3	4.3
	49mpd	9.6	9.1	8.8	8.9	8.7	8.8	9.1	9.2

6.3.2 span: [1.2] => [8.7]

AFH charging is slightly up.

Table 2-103: 6.3.2.2 Per EV AFH N events (weekly average away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	27mpd	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.04
	38mpd	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11
	49mpd	0.23	0.20	0.20	0.20	0.20	0.20	0.21	0.21

6.3.2 span: [0.03] => [0.20]

The number of AFH connects is slightly up.

Table 2-104: 6.3.2.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3
	27mpd	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6
	38mpd	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0
	49mpd	1.3	1.2	1.3	1.3	1.3	1.4	1.4	1.6

6.3.2 span: [0.4] => [1.2]

With demand reduced, EVs can charge their fill hence incidences of undercharging drops.

Table 2-105: 6.3.2.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001
	27mpd	0.0002	0.0001	0.0003	0.0003	0.0003	0.0004	0.0003	0.0004
	38mpd	0.0006	0.0009	0.0012	0.0010	0.0014	0.0015	0.0016	0.0016
	49mpd	0.0030	0.0023	0.0038	0.0044	0.0052	0.0048	0.0050	0.0067

6.3.2 span: [0.0002] => [0.0046] (limit: < 0.007)

Severe undercharging is now experienced by the parity case EVs c. every 2,500 weeks.

Table 2-106: ***6.3.2.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	1.3	2.0	5.4	10.5	18.4	33.5	46.1	63.5
	27mpd	1.8	3.4	10.1	23.4	42.8	78.5	108.3	149.9
	38mpd	3.4	6.5	23.0	50.2	95.3	180.2	268.4	432.2
	49mpd	4.8	9.9	36.1	84.0	166.9	334.0	591.2	1,122.7

6.3.2 span: [23.6] => [221.7] (< 420) (limit: < 420)

These values have substantively dropped, reflecting the less urgent need to charge.

Table 2-107: ***6.3.2.2 DRFFR Percent Effective Hours (weekly averages)***

7. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	28.0%	30.4%	32.1%	32.1%	35.7%	36.9%	43.5%	47.0%
	27mpd	28.0%	30.4%	32.1%	35.1%	40.5%	47.0%	53.0%	58.9%
	38mpd	28.6%	31.0%	33.9%	41.7%	47.6%	55.4%	63.1%	70.2%
	49mpd	28.0%	31.0%	38.7%	45.8%	56.0%	65.5%	72.6%	80.4%

6.3.2 span: [47.0%] => [85.7%]

Hi_limit modulation is less effective in summer as loads are down.

V4-2.55 Seq_6.3.2.2 Results Summary

From the viewpoint that clamp use has risen substantially at extreme loads, the V2G EVs have been missed. But other than that the charging and LV system appear unaffected.

6.3.2.2 suffers 3 plies with excess clamps vs. no plies with excess clamps in 6.3.2.

The system is, in summer, operable with SV1G and without V2G for cases:

- excluding 140 EVs at 38 or 49mpd, and
- excluding 120 EVs at 49mpd.

This illustrates that V2G does assist; the benefits of V2G suggest adding Static Batteries to the LV network (to stand in for V2G EVs) may be a worthwhile option.

V4-2.56 Sequence 6.3.2.3

Sequence	**Simulation ID**	**Description**
Seq_6.3.2.3	(S_BP)	As 6.3.2.1 without the DR element of DRFFR hi_limit modulation. FFR is still present. A week in Summer with ambient temp of 18 °C. Residential loads scaled from 1.3 to 1.1 kW per house; there are no Aggregator controlled EVs. EV mix of 19% dumb, 48% SV1G and 33% V2G Residential load data is from SSE's NTVV project, for the week starting 15 July 2013.
Baseline Seq	***Description***	
Seq_6.2.2 and 6.3.2.1	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Household loads are lower and EVs benefit from both no auxiliary loads and better battery capacity, due to raised ambient temperatures.

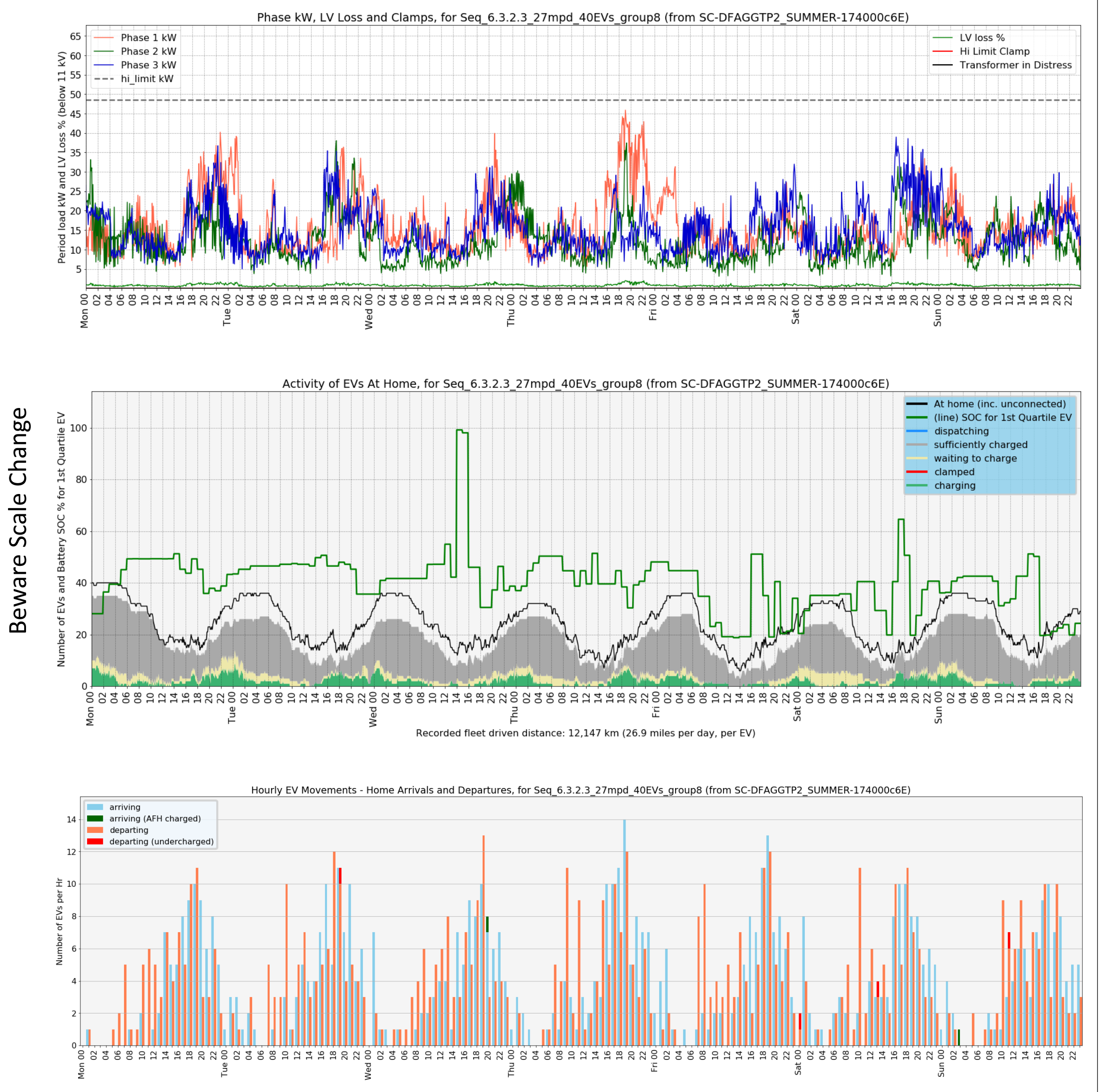
Data originate from MetaMeta spreadsheets for Seq_6.3.2.3.

V4-2.56.1 Seq_6.3.2.3 Outcomes

Removing DR increases the available kWh, aiding extreme load cases (49mpd 140 EVs). The PEH metric shows FFR service response is much degraded. Both clamping and use of VG near vanish.

V4-2.57 Seq_6.3.2.3 Feeder and EV Plots

V4-2.57.1 Seq_6.3.2.3: 27mpd 40EVs



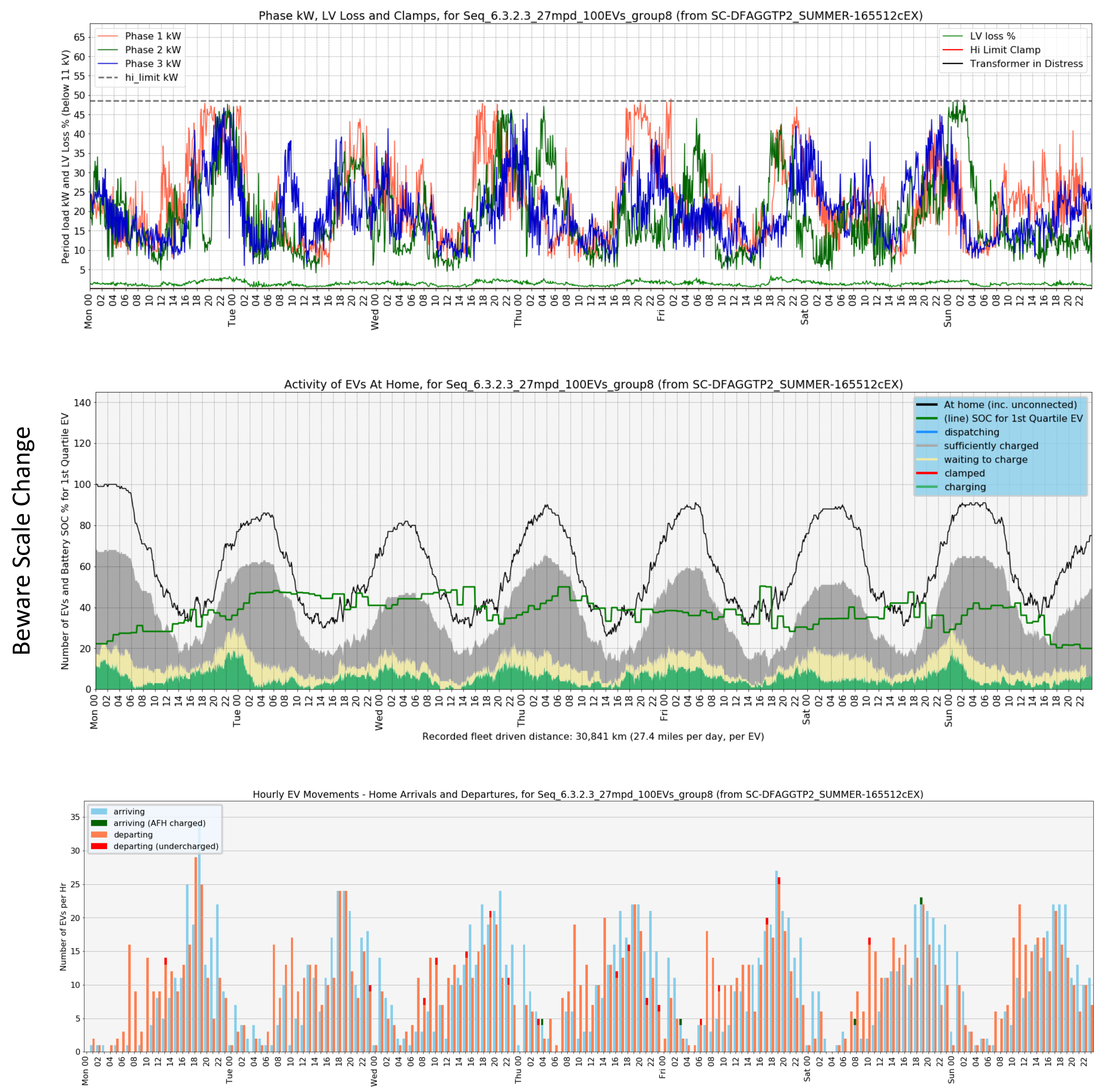
EoW stats: kWh[b] EV total: 1,405 Home: 1,363 AFH: 42 V2G: 0

Figure 2-42: Seq_6.3.2.3 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is low but otherwise unremarkable
- (CICD) EVs have good SOC; many ready to depart
- (Arrive/Depart) there are rare undercharged departs or AFH charging.

V4-2.57.2 Seq_6.3.2.3: 27mpd 100EVs



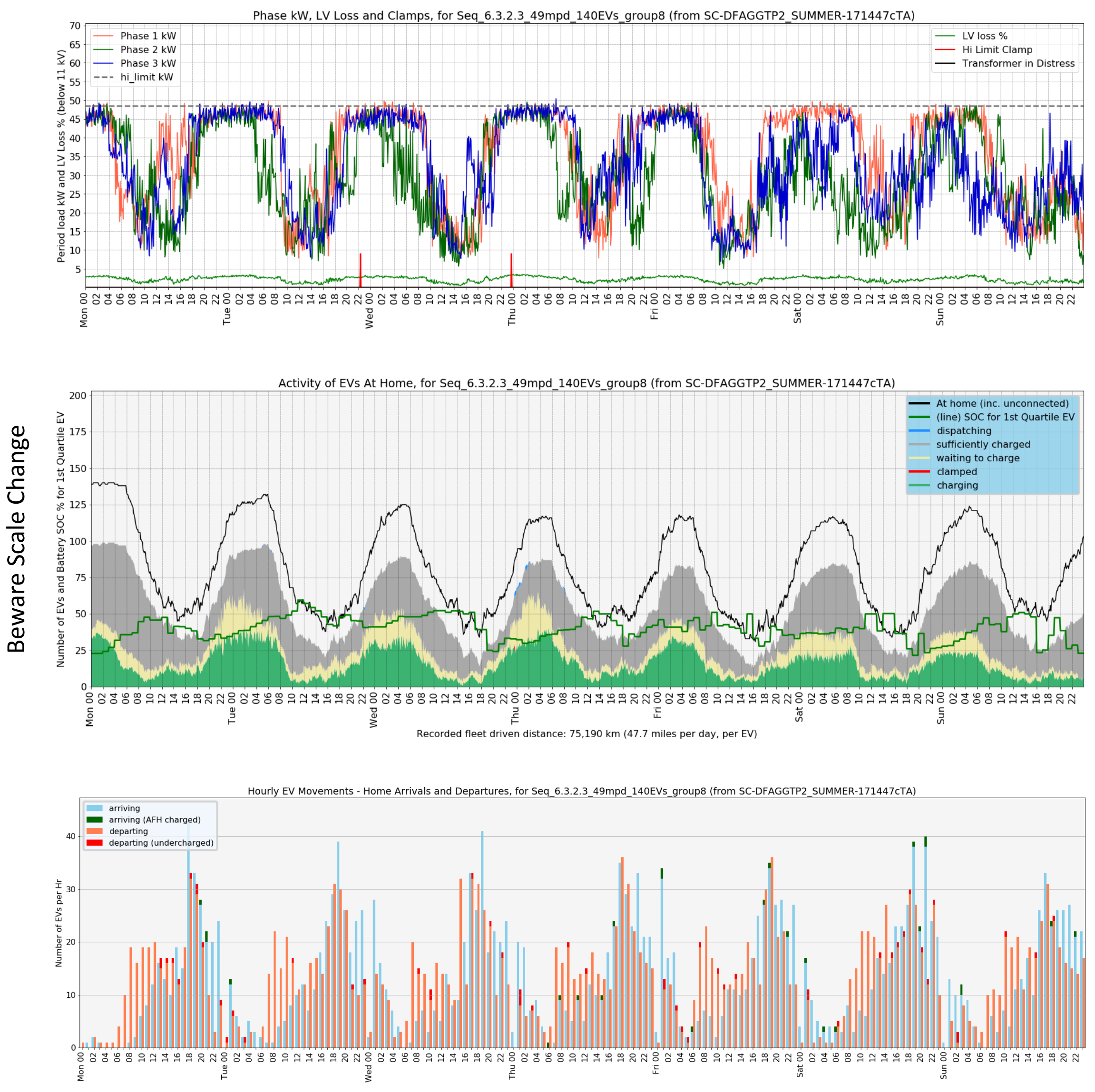
EoW stats: kWh[b] EV total: 3,625 Home: 3,499 AFH: 126 V2G: 0

Figure 2-43: Seq_ 6.3.2.3 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot remains unremarkable. Clamping is low
- (CICD) SOC is perhaps slightly lower. Many EVs are not bothered to be plugged in (clear) with many ready to depart (grey). There is no visible V2G or clamping.
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are very low.

V4-2.57.3 Seq_6.3.2.3: 49mpd 140EVs



EoW stats: kWh[b] EV total: 9,606 Home: 8,372 AFH: 1,234 V2G: 73

Figure 2-44: Seq_ 6.3.2.3 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot has occasional clamps.
- (CICD) V2G in blue is occasionally present but hard to discern by eye
- undercharging and AFH charging is slightly up but is minimal.

V4-2.58 Data Tables Seq_6.3.2.3

Table 2-108: 6.3.2.3 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,240	18,860	18,127	17,374	16,624	15,887	15,145	14,451
	27mpd	19,108	18,567	17,561	16,501	15,464	14,468	13,411	12,431
	38mpd	18,966	18,294	16,940	15,533	14,215	12,809	11,465	10,079
	49mpd	15,392	14,425	12,412	10,358	8,380	6,194	4,036	2,580

6.2.2 span: [10,098] => [4,763]; 6.3.2.1 span: [14,437] => [7,802]

Without DRFFR, the EVs can access more kWh over the week. The most extreme EV cases take advantage of this.

Table 2-109: 6.3.2.3 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.2	0.4	0.4	0.3	0.4	0.3	0.4
	27mpd	0.5	0.7	1.0	1.1	1.2	1.3	1.2	1.2
	38mpd	3.5	3.6	3.8	4.1	4.2	4.3	4.2	4.2
	49mpd	9.3	8.8	8.5	8.7	8.6	8.7	8.8	8.8

6.2.2 span: [8.0] => [34.2]; 6.3.2.1 span: [1.2] => [8.7]

AFH charging kWh taken is very similar 6.3.2.1.

Table 2-110: 6.3.2.3 Per EV AFH N events (weekly average away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.005	0.007	0.011	0.009	0.009	0.010	0.009	0.010
	27mpd	0.020	0.023	0.028	0.031	0.036	0.036	0.034	0.034
	38mpd	0.093	0.098	0.095	0.103	0.105	0.105	0.105	0.103
	49mpd	0.220	0.197	0.192	0.196	0.199	0.202	0.203	0.201

6.2.2 span: [0.3] => [1.05]; 6.3.2.1 span: [0.035] => [0.198]

AFH charging use is similar 6.3.2.1.

Table 2-111: ***6.3.2.3 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3
	27mpd	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5
	38mpd	0.7	0.7	0.8	0.8	0.8	0.9	0.8	0.9
	49mpd	1.1	1.0	1.1	1.2	1.2	1.2	1.2	1.2

6.2.2 span: [1.4] => [5.0]; 6.3.2.1 span: [0.04] => [1.2]

Undercharging is again similar to 6.3.2.1

Table 2-112: ***6.3.2.3 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001
	27mpd	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003
	38mpd	0.0002	0.0006	0.0007	0.0009	0.0011	0.0012	0.0012	0.0012
	49mpd	0.0026	0.0024	0.0033	0.0039	0.0046	0.0042	0.0039	0.0043

6.2.2 span: [0.0015] => [0.1631]; 6.3.2.1 span: [0.0002] => [0.0046] (limit: < 0.007)

Severe undercharging has improved at the top limits of EV load, vs. 6.3.2.1

Table 2-113: ***6.3.2.3 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	0	0	0	0	0
	27mpd	0	0	0	0	0	0	0	0
	38mpd	0	0	0	0	0	1	0	2
	49mpd	0	0	0	0	1	8	5	26

6.2.2 span: [366] => [2,985]; 6.3.2.1 span: [24] => [222] (limit: < 420)

Clamps have substantively dropped vs. 6.3.2.1.

Table 2-114: ***6.3.2.3 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	27mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	38mpd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	49mpd	0.0	0.0	0.0	0.0	0.0	0.2	0.4	1.5

6.2.2 span: [7.9] => [27.0]; 6.3.2.1 span: [0.3] => [6.0]

V2G use is vanishingly small.

Table 2-115: ***6.3.2.3 FFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	21.4%	22.6%	22.6%	21.4%	22.6%	23.2%	22.0%	24.4%
	27mpd	22.0%	22.0%	23.2%	22.0%	23.2%	26.2%	31.5%	38.7%
	38mpd	21.4%	20.8%	22.0%	24.4%	26.8%	36.3%	44.0%	50.6%
	49mpd	21.4%	23.2%	25.6%	25.6%	33.9%	44.0%	56.0%	63.1%

6.2.2 span: [73.8%] => [98.2%]; 6.3.2.1 span: [47%] => [80.4%]

FFR response drops as the network is less loaded.

V4-2.59 Seq_6.3.2.3 Results Summary

Anticipated improvements due to removing the DR element of DRFFR are seen. With no demand reduction imposed, the Typical network is capable of meeting all charging needs of the EV population and providing some FFR services, although there is less PEH utility seen than before.

V4-2.60 Sequence 6.3.2.4

Sequence	**Simulation ID**	**Description**
Seq_6.3.2.4	(S_BQ)	Variation vs. Seq_6.3.2.3: FFR now with Agg ToU control on all vehicles
Baseline Seq	***Description***	
Seq_6.2.2 and 6.3.2.3	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW* *Adds Agg ToU*	

After the success of 6.3.2.3, will adding Agg ToU cause undercharging, which has been a pattern to date?

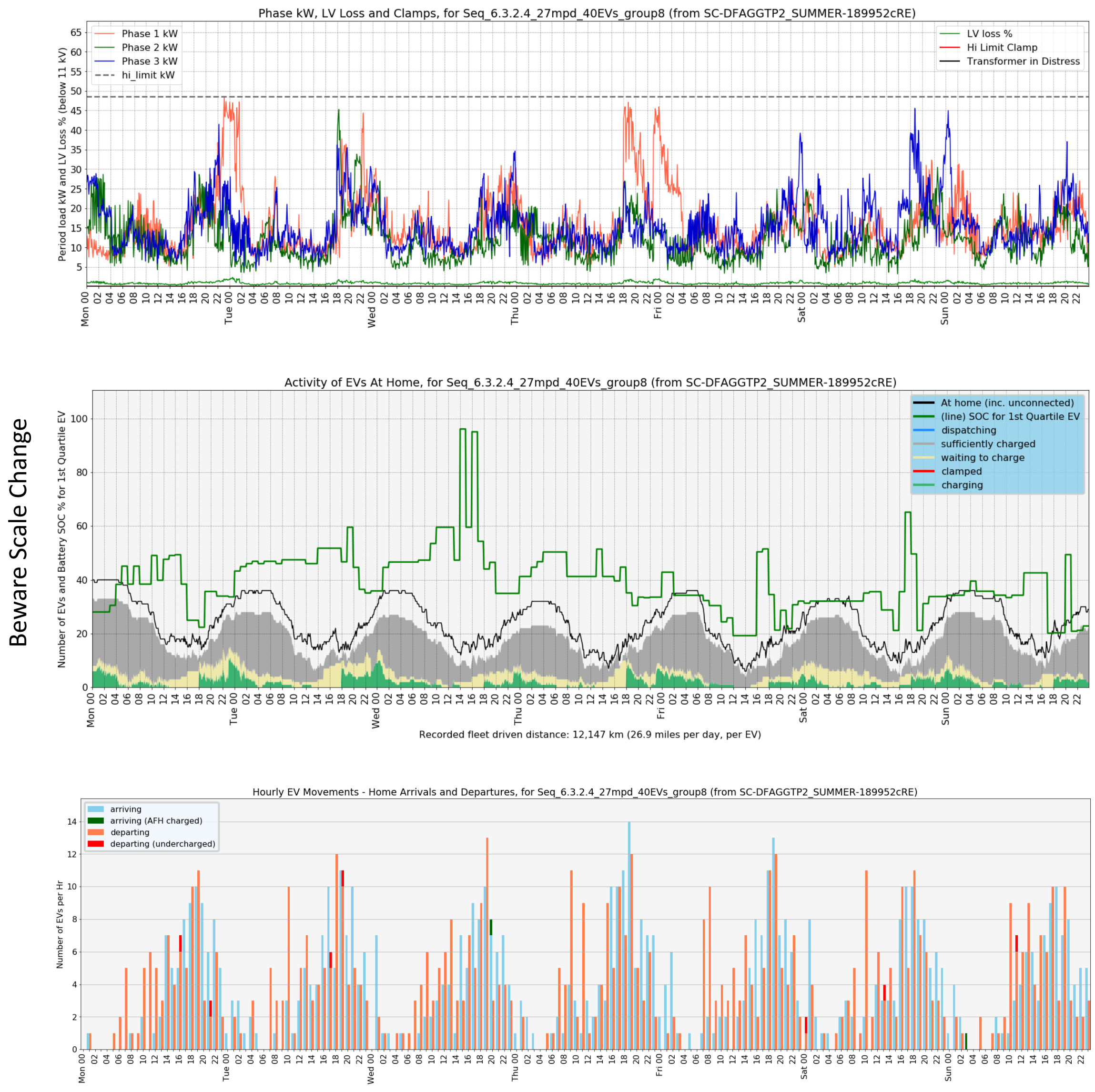
Data originate from MetaMeta spreadsheets for Seq_6.3.2.4.

V4-2.60.1 Seq_6.2.2.5 Outcomes

In Summer, Agg ToU does not suffer as much severe undercharging as in Winter, but the issues does arise for 38 and 49mpd.

V4-2.61 Seq_6.3.2.4 Feeder and EV Plots

V4-2.61.1 Seq_6.3.2.4: 27mpd 40EVs



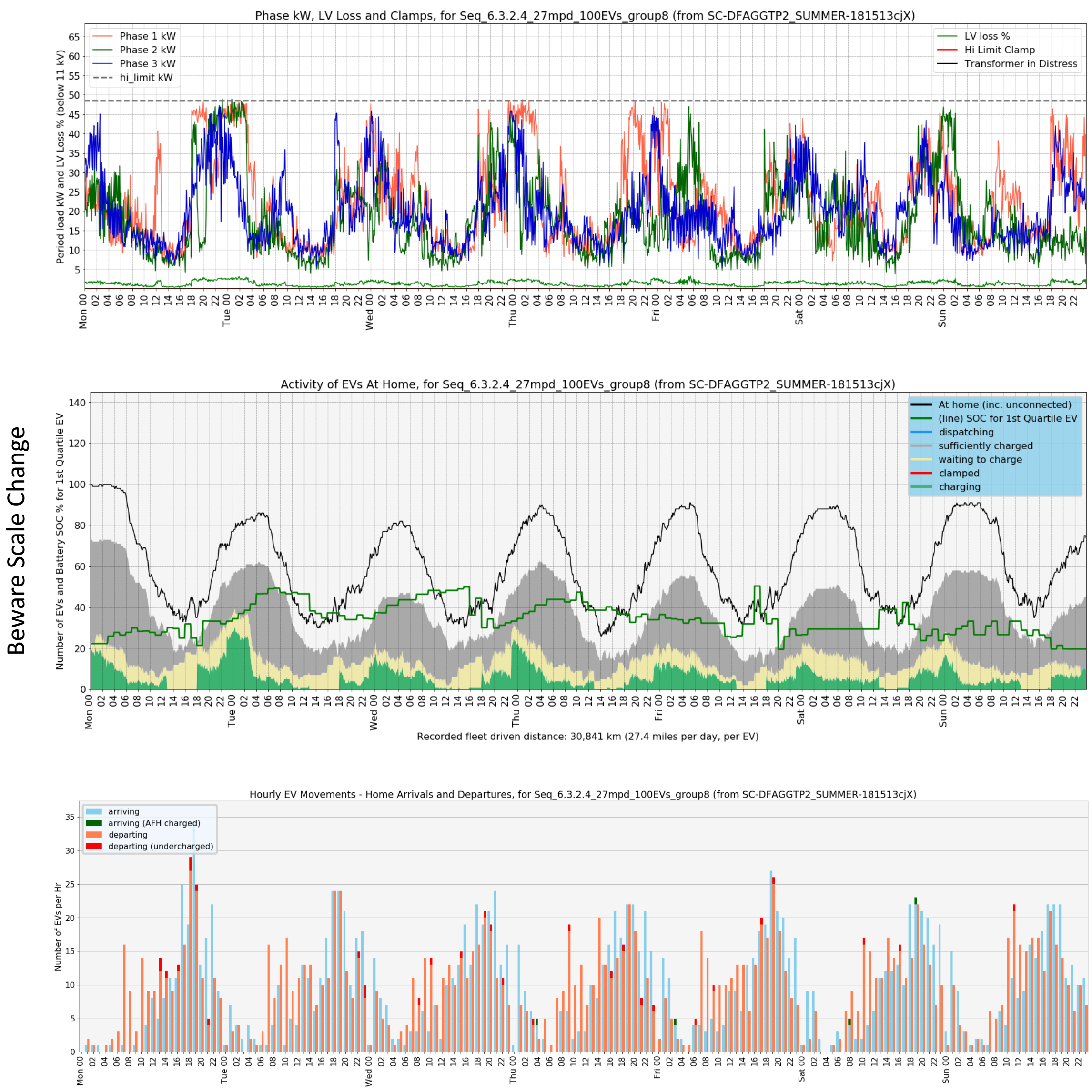
EoW stats: kWh[b] EV total: 1,410 Home: 1,363 AFH: 47 V2G: 0

Figure 2-45: Seq_6.3.2.4 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable other than phase 1 (red) has unusually high loadings
- (CICD) EVs have very variable SOC
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.61.2 Seq_6.3.2.4: 27mpd 100EVs



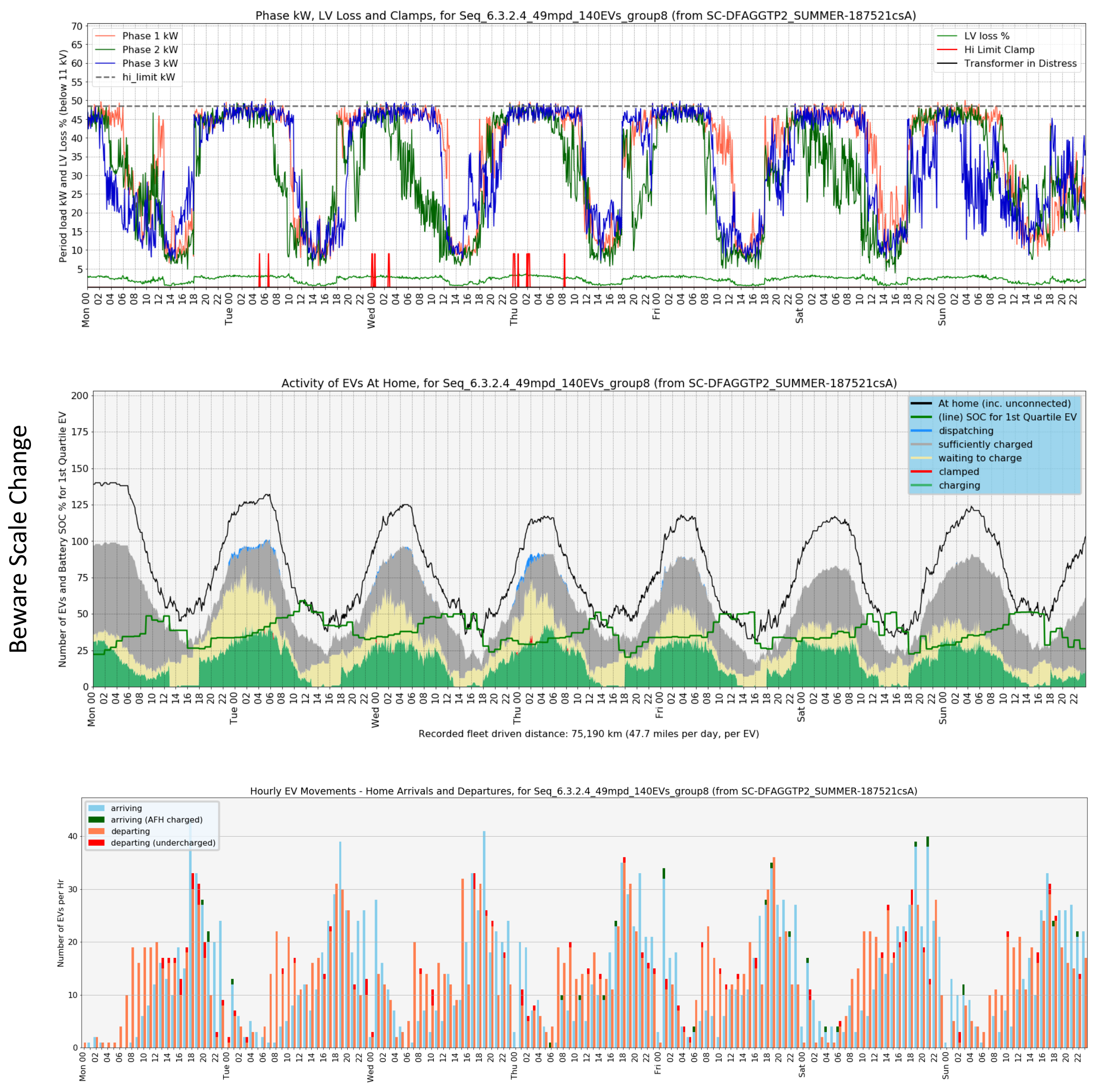
EoW stats: kWh[b] EV total: 3,627 Home: 3,484 AFH: 143 V2G: 0

Figure 2-46: Seq_6.3.2.4 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps are more common than with 6.3.2.1
- (CICD) SOC is similar with significant numbers of EVs ready to depart
- (Arrive/Depart) has less undercharged departs vs. 6.3.2.1.

V4-2.61.3 Seq_6.3.2.4: 49mpd 140EVs



EoW stats: kWh[b] EV total: 9,742 Home: 8,406 AFH: 1,336 V2G: 198

Figure 2-47: Seq_6.3.2.4 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot now has some clamps and shows the ToU signal
- (CICD) V2G is seen but clamping is very rare
- undercharging and AFH remain similar to 6.3.2.1.

V4-2.62 Data Tables Seq_6.3.2.4

Table 2-116: 6.3.2.4 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	19,243	18,863	18,135	17,385	16,634	15,911	15,158	14,474
	27mpd	19,110	18,572	17,568	16,516	15,492	14,496	13,436	12,452
	38mpd	18,971	18,304	16,956	15,566	14,264	12,855	11,513	10,115
	49mpd	18,805	17,994	16,358	14,717	13,116	11,447	9,737	7,980

6.3.2 span: [14,437] => [7,802] 6.3.2.3 span: [14,468] => [2,580]

ToU is excluding use of kWh.

Table 2-117: 6.3.2.4 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.2	0.3	0.5	0.4	0.4	0.4	0.4	0.4
	27mpd	0.6	0.8	1.2	1.2	1.4	1.4	1.3	1.4
	38mpd	3.7	3.9	4.1	4.4	4.5	4.7	4.6	4.6
	49mpd	9.9	9.4	9.2	9.3	9.2	9.3	9.4	9.5

6.3.2 span: [1.2] => [8.7] 6.3.2.3 span: [1.3] => [8.8]

AFH charging is slightly up at extreme loading.

Table 2-118: 6.3.2.4 Per EV AFH N events (weekly average away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.007	0.011	0.015	0.012	0.012	0.013	0.012	0.014
	27mpd	0.023	0.027	0.033	0.035	0.041	0.042	0.039	0.039
	38mpd	0.102	0.108	0.104	0.112	0.115	0.117	0.116	0.114
	49mpd	0.239	0.214	0.211	0.212	0.215	0.219	0.220	0.221

6.3.2 span: [0.03] => [0.20] 6.3.2.3 span: [0.0002] => [0.0043]

The number of AFH connects is slightly up.

Table 2-119: 6.3.2.4 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3
	27mpd	0.4	0.5	0.5	0.6	0.6	0.7	0.6	0.6
	38mpd	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.1
	49mpd	1.4	1.2	1.4	1.4	1.4	1.5	1.5	1.6

6.3.2 span: [0.4] => [1.2] 6.3.2.3 span: [0.5] => [1.2]

With demand reduced, EVs can charge their fill hence incidences of undercharging drops.

Table 2-120: 6.3.2.4 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0006	0.0006	0.0005	0.0007	0.0005	0.0009	0.0008	0.0007
	27mpd	0.0016	0.0008	0.0014	0.0019	0.0021	0.0023	0.0024	0.0024
	38mpd	0.0052	0.0045	0.0068	0.0060	0.0074	0.0076	0.0073	0.0078
	49mpd	0.0084	0.0104	0.0144	0.0128	0.0140	0.0147	0.0144	0.0166

6.3.2 span: [0.0002] => [0.0046] 6.3.2.3 span: [0.0002] => [0.0043] (limit: < 0.007)

Severe undercharging is on the limit for 38mpd and overlimit for 49mpd, over 60 EVs. Interestingly this is the first Agg ToU control which has acceptable degrees of severe undercharging in any area.

Table 2-121: ***6.3.2.4 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	0	0	0	0	0	0	0	0
	27mpd	0	0	0	0	0	0	0	0
	38mpd	0	0	0	0	0	3	1	5
	49mpd	0	0	0	0	3	19	17	101

6.3.2 span: [23.6] => [221.7] 6.3.2.3 span: [0] => [26] (limit: < 420)

Counts have risen on 6.3.2.3, suppressing the periods when EVs want to reclaim kWh after periods when ToU says “no”. However clamp counts levels are acceptable.

Table 2-122: ***6.3.2.4 DRFFR Percent Effective Hours (weekly averages)***

7. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	22.6%	21.4%	22.0%	21.4%	21.4%	25.0%	25.6%	31.5%
	27mpd	22.0%	22.0%	20.2%	20.2%	26.2%	31.0%	33.9%	39.3%
	38mpd	22.6%	22.0%	21.4%	25.6%	30.4%	36.3%	46.4%	54.2%
	49mpd	20.8%	20.8%	22.6%	27.4%	35.1%	44.6%	54.2%	62.5%

6.3.2 span: [47.0%] => [85.7%] 6.3.2.3 span: [26.2%] => [63.1%]

As ToU inhibits opportunity, PEH FFR have dropped.

V4-2.63 Seq_6.3.2.4 Results Summary

In Summer, Agg ToU does not provoke the extreme levels of severe undercharging as seen in Winter, however limits are met from 38mpd and all of 49mpd.

V4-2.64 Sequence 6.4.2

Sequence	**Simulation ID**	**Description**
Seq_6.4.2	(S_91)	Variation vs. Seq_6.3.2: 1 in 4 EVs are now subject to Aggregator control using profile “Agg-B” as against all EVs in 6.3.2 being subject to Aggregator control. DRFFR remains in use.
Baseline Seq	***Description***	
Seq_6.3.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit default 49 kW, DR/FFR hi_limit modulation, Agg-B Aggregator control over all EVs*	

Sequence 6.2.2 had no Aggregators and 6.3.2 wholly Aggregator controlled EVs; 6.4.2 has only 1 in 4 under Aggregator control. This should permit charging to be more staggered, as 1 in every 4 EVs is limited in some manner from 1pm to 11pm, as below:

- from 1pm: Aggregator EVs forced to idle (no charging or dispatch)
- from 6pm: Aggregator EVs: if SOC < 30% can charge, V2G dispatch permitted
- from 11pm: Aggregator control released (normal / MCS operation).

Note that the hi_limit DR/FFR “B” modulation remains present.

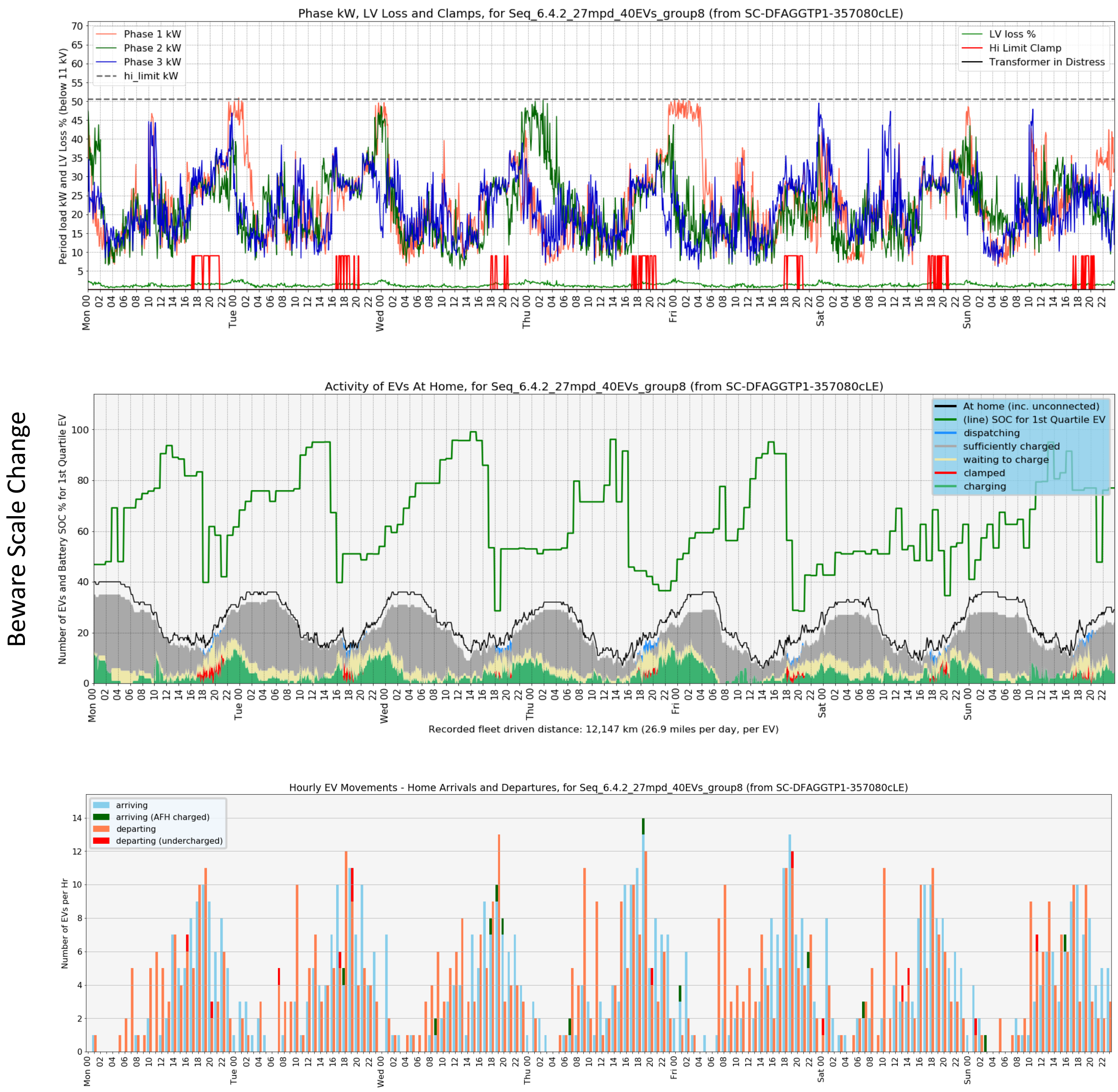
V4-2.64.1 Seq_6.4.2 Outcomes

The reduction of Aggregator input results in reduced severe undercharging, confirming that the Aggregation ToU control was the cause.

The DRFFR PEH metric shows uplift.

V4-2.65 Seq_6.4.2 Feeder and EV Plots

V4-2.65.1 Seq_6.4.2: 27mpd 40EVs



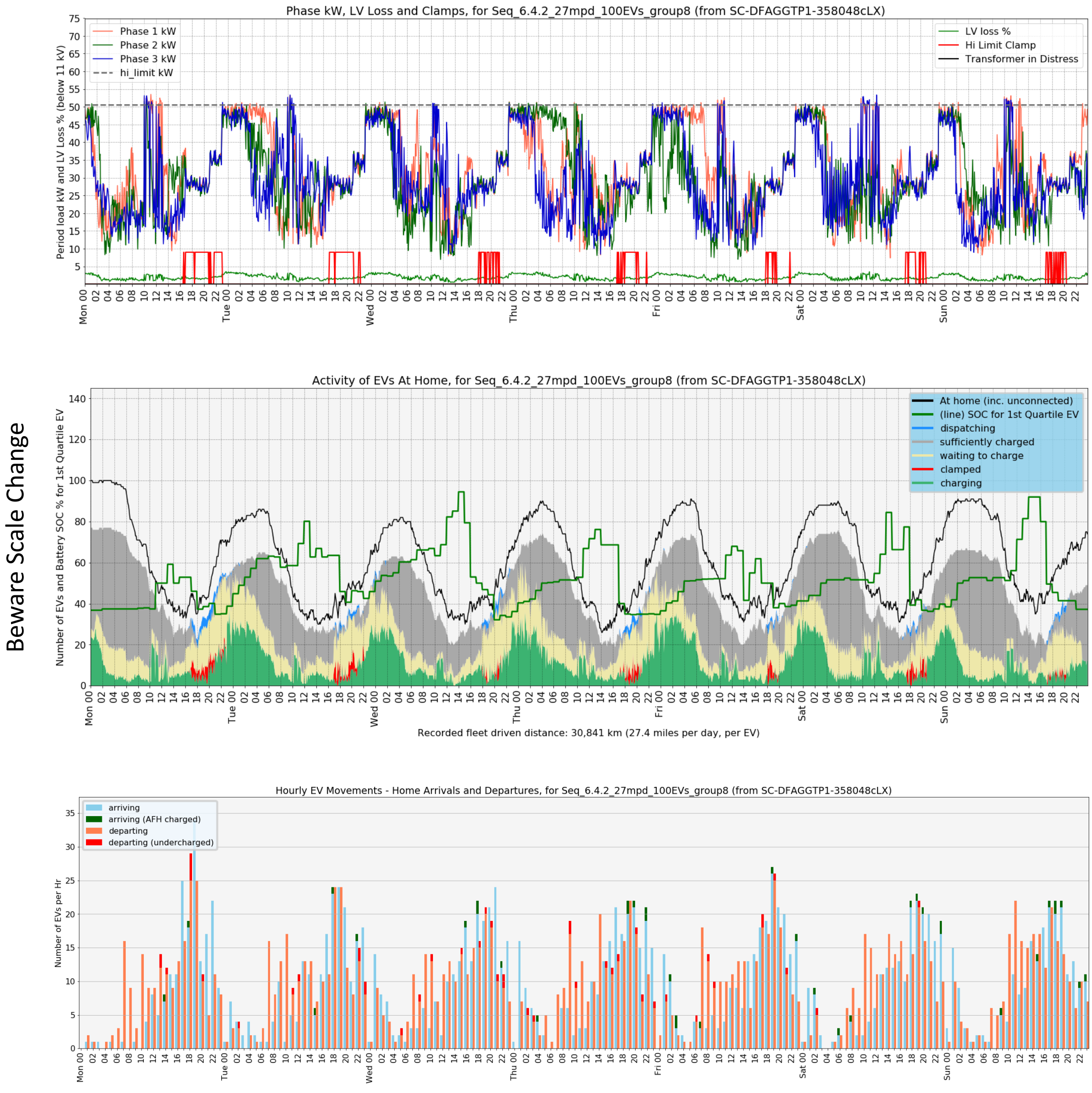
EoW stats: kWh[b] EV total: 2,389 Home: 2,095 AFH: 295 V2G: 76

Figure 2-48: Seq_6.4.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC with occasional V2G and clamps; EVs are ready to depart
- (Arrive/Depart) there are a scattering of departs; AFH charging is rare.

V4-2.65.2 Seq_6.4.2: 27mpd 100EVs



EoW stats: kWh[b] EV total: 6,145 Home: 5,322 AFH: 822 V2G: 235

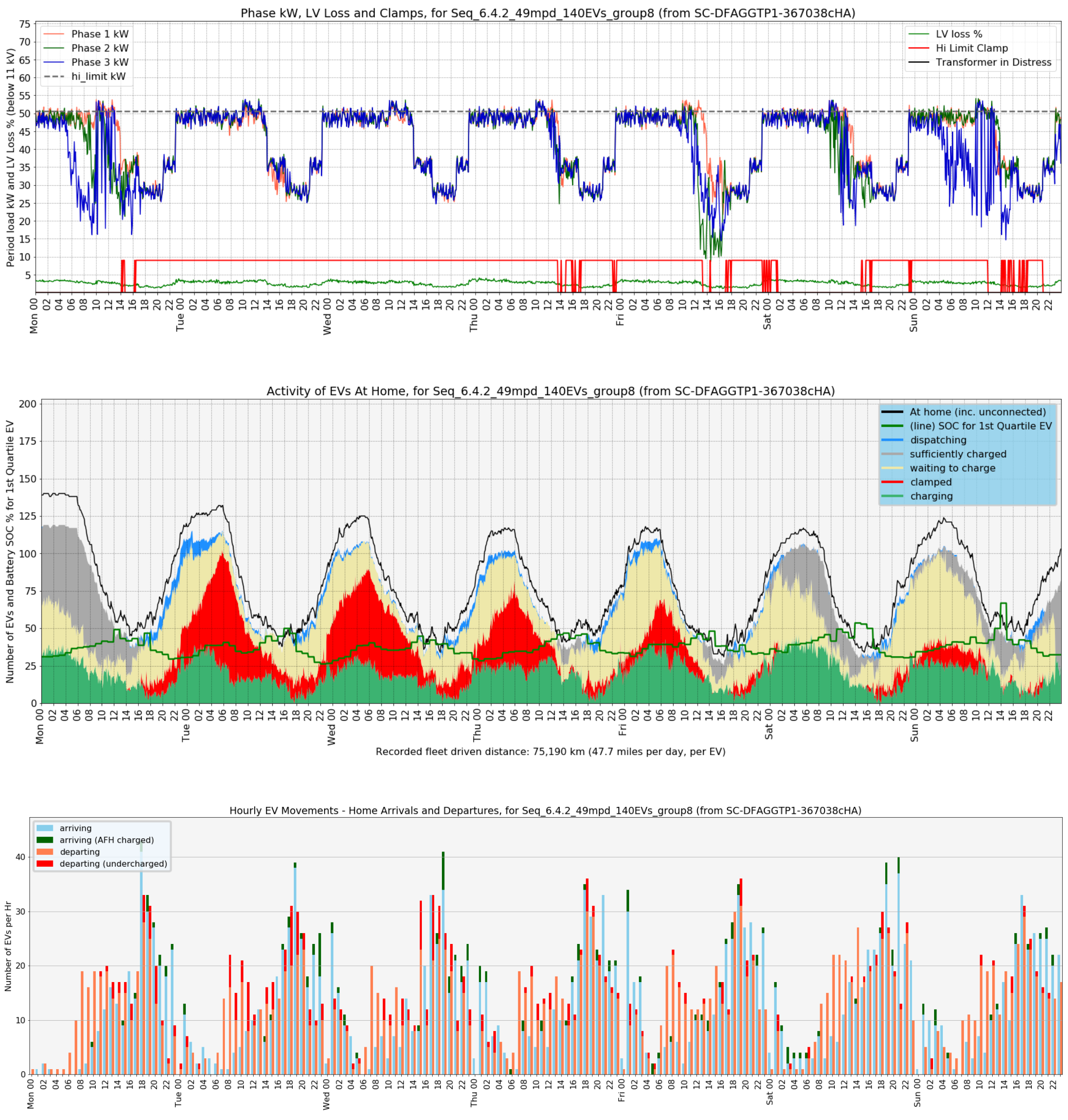
Figure 2-49: Seq_6.4.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps but is unremarkable
- (CICD) SOC is similar with significant numbers of EVs ready to depart; some V2G
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.65.3 Seq_6.4.2: 49mpd 140EVs

Beware Scale Change



EoW stats: kWh[b] EV total: 14,878 Home: 9,998 AFH: 4,880 V2G: 1,302

Figure 2-50: Seq_6.4.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal well
- (CICD) V2G pre-burn are overwhelmed by clamps. Few EVs are ready to depart
- undercharging and AFH charging has clearly risen but is not extreme.

V4-2.66 Data Tables Seq_6.4.2

Table 2-123: 6.4.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	17,108	16,481	15,241	13,987	12,712	11,415	10,106	8,797	8,776
	16,993	16,226	14,727	13,191	11,677	10,128	8,521	6,860	6,713
	16,897	16,034	14,275	12,482	10,732	8,880	7,051	5,386	5,240
	16,814	15,868	13,919	11,955	10,059	8,067	6,197	4,868	4,758

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

A minor reduction ion consumption vs. 6.2.2. unutilised kWh increases vs. 6.2.2.

Table 2-124: 6.4.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.1	3.2	3.1	3.2	3.5	3.4	3.4
	27mpd	6.4	7.5	7.4	7.7	8.2	8.2	8.1	8.0
	38mpd	16.6	16.8	17.3	17.8	17.8	18.3	18.2	19.2
	49mpd	34.4	32.2	30.9	30.7	30.6	30.9	31.9	34.8

6.2.2 span: [8.0] => [34.2] and 6.3.2: [8.7] => [39.2]

Given the reduced need for kWh, AFH charging is down.

Table 2-125: 6.4.2 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	0.12	0.14	0.13	0.13	0.14	0.15	0.14	0.14
	27mpd	0.28	0.29	0.28	0.29	0.31	0.31	0.31	0.30
	38mpd	0.58	0.58	0.58	0.59	0.60	0.61	0.61	0.65
	49mpd	1.08	0.98	0.93	0.91	0.93	0.94	0.97	1.08

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

As the need for AFH charging falls, so drivers require less AFH connections.

Table 2-126: ***6.4.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.9	0.9	0.9	1.0	1.1	1.0	1.1
	27mpd	1.3	1.4	1.4	1.4	1.5	1.5	1.5	1.7
	38mpd	1.9	2.1	2.2	2.2	2.2	2.3	2.4	3.1
	49mpd	2.6	2.7	2.8	2.8	2.8	3.0	3.4	5.1

6.2.2 span: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

A modest increase is seen over 6.2.2, but a notable improvement over 6.3.2.

Table 2-127: ***6.4.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0034	0.0040	0.0044	0.0032	0.0031	0.0036	0.0031	0.0036
	27mpd	0.0004	0.0043	0.0056	0.0053	0.0059	0.0066	0.0066	0.0073
	38mpd	0.0062	0.0144	0.0144	0.0132	0.0131	0.0149	0.0162	0.0482
	49mpd	0.0080	0.0232	0.0251	0.0200	0.0241	0.0284	0.0542	0.1786

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175]

Severe undercharging is up to 16 plies vs. 6.2.2's 6, but much improved over 6.3.2 which had no acceptable operation in any ply.

Table 2-128: ***6.4.2 V2G kWh dispatch per EV (weekly averages)***

6. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	8.1	5.3	4.4	4.0	4.6	5.3	6.1	6.6
	27mpd	7.5	5.1	4.5	4.6	5.7	7.1	8.9	13.2
	38mpd	7.3	5.1	4.9	5.3	7.2	11.1	16.8	23.7
	49mpd	7.2	5.1	5.2	6.1	9.2	15.6	22.2	26.0

6.2.2 span: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

V2G use has fallen from levels in 6.2.2, but not by as much as seen in 6.3.2.

Table 2-129: ***6.4.2 MCS Clamps (weekly averages)***

7. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	91.3	116.9	161.1	196.1	227.0	249.9	189.3	223.0
	27mpd	98.0	133.4	191.2	233.0	279.2	328.4	297.3	551.1
	38mpd	113.0	153.6	227.2	287.6	364.9	541.8	851.4	1,926.3
	49mpd	120.8	168.4	258.6	337.6	485.5	941.7	1,616.5	2,763.3

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (< 420)

These values have dropped slightly vs. 6.2.2, but remain higher than 6.4.2.

Table 2-130: ***6.4.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.7%	35.7%	42.3%	48.8%	57.1%	65.5%	70.8%	76.8%
	27mpd	32.1%	36.3%	43.5%	54.2%	66.7%	72.6%	81.0%	86.9%
	38mpd	31.5%	36.9%	46.4%	57.7%	71.4%	78.0%	86.3%	94.6%
	49mpd	31.5%	36.9%	48.8%	61.3%	73.8%	82.1%	90.5%	95.8%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

The PEH metric for 6.4.2 are near the levels seen for 6.2.2, which had no Aggregator ToU control.

V4-2.67 Seq_6.4.2 Results Summary

The problem with 6.3.2 was that severe undercharging was unacceptably high. This has moderated by reducing Aggregation duties from 100% to 25% EV coverage, confirming that the root cause was the Aggregators stifle charging.

Or, would Aggregators claim that the hi_limit was set too low, and that the network should be reinforced?

It would be difficult to see a plausible rationale which would give a remote 3rd party sway over decisions to suit local conditions; however this is not unknown and devolves to an intermingling of economics and politics.

V4-2.68 Sequence 6.5.2 (withdrawn)

Sequence	**Simulation ID**	**Description**
Seq_6.5.2	(S_BE)	Variation vs. Seq_6.2.2: "Hybrid" Aggregation mode applied to all EVs (including dumb)
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

This Sequence has been Withdrawn as the author was not satisfied the FPB was working in the Hybrid mode as intended. As this is a potentially interesting approach, the descriptive text is retained.

Sequence 6.5.2 explores a hybrid modulation method. The hi_limit modulation of DR/FFR may meet resistance, as control of this (hence any income) is in one set of hands, the DNO. This does not match the "multiple players in markets" paradigm and may be forbidden.

The next most likely method to obtain DR/FFR modulation of load levels is:

- *allow MCS to discover the instantaneous headroom which limits EVs, and to calculate an EV load distribution, then*
- *apply the modulation to the determined EV output load levels.*

This allows the MCS to use the DNO's peak level, yet apply a modulation from a 3rd party to targeted EVs; a hybrid control method. However this impacts the control authority. For example, if the DR/FFR signal is -4% i.e. ratio 0.96, the base hi_limit is 49 kW and instantaneous phase load is 17 kW:

- *hi_limit modulation: the ratio applies to 49 kW and the EVs arranged to total*

  *0.96 * 49 - 17 = 30 kW, so giving 47 kW total load, vs.*

- *hybrid method: MCS discovers headroom of 30 kW which is partitioned to EVs in the usual manner. Before commands are sent to individual EVs, each EV is assessed as being under Aggregator control; if so the DR/FFR ratio is applied to the EV's load message, so effecting that EV only.*

*The control authority has dropped from 4% * 49 kW to 4% * 30 kW, less if some EVs do not take Aggregator control or even less if the residential load is high (limiting EV kW).*

The DR/FFR "B" signal now modulates EV charging outcomes. The author expects the method to work, but have impaired control.

V4-2.69 Sequence 6.6.2 (withdrawn)

Sequence	**Simulation ID**	**Description**
Seq_6.6.2	(S_AH)	Variation vs. Seq_6.2.2: "Hybrid" Aggregation mode applied to 1 in 4 of all EVs (including dumb)
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

This Sequence has been Withdrawn as the author was not satisfied the FPB was working in the Hybrid mode as intended.

V4-2.70 Sequence 6.7.2

Sequence	**Simulation ID**	**Description**
Seq_6.7.2	(S_A1)	Variation vs. Seq_6.2.2: the FFR fast modulation component is dropped, leaving the DR signal only
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Sequence 6.7.2 takes the FFR component from the DR-B/FFR modulation signal, applied as ratios of demand. FFR is ±5% modulation about a base of 95%; this implies a 5% drop of average energy available to EVs. Removing FFR removes the offset, leaving the DR signal, Figure 2-51 below:

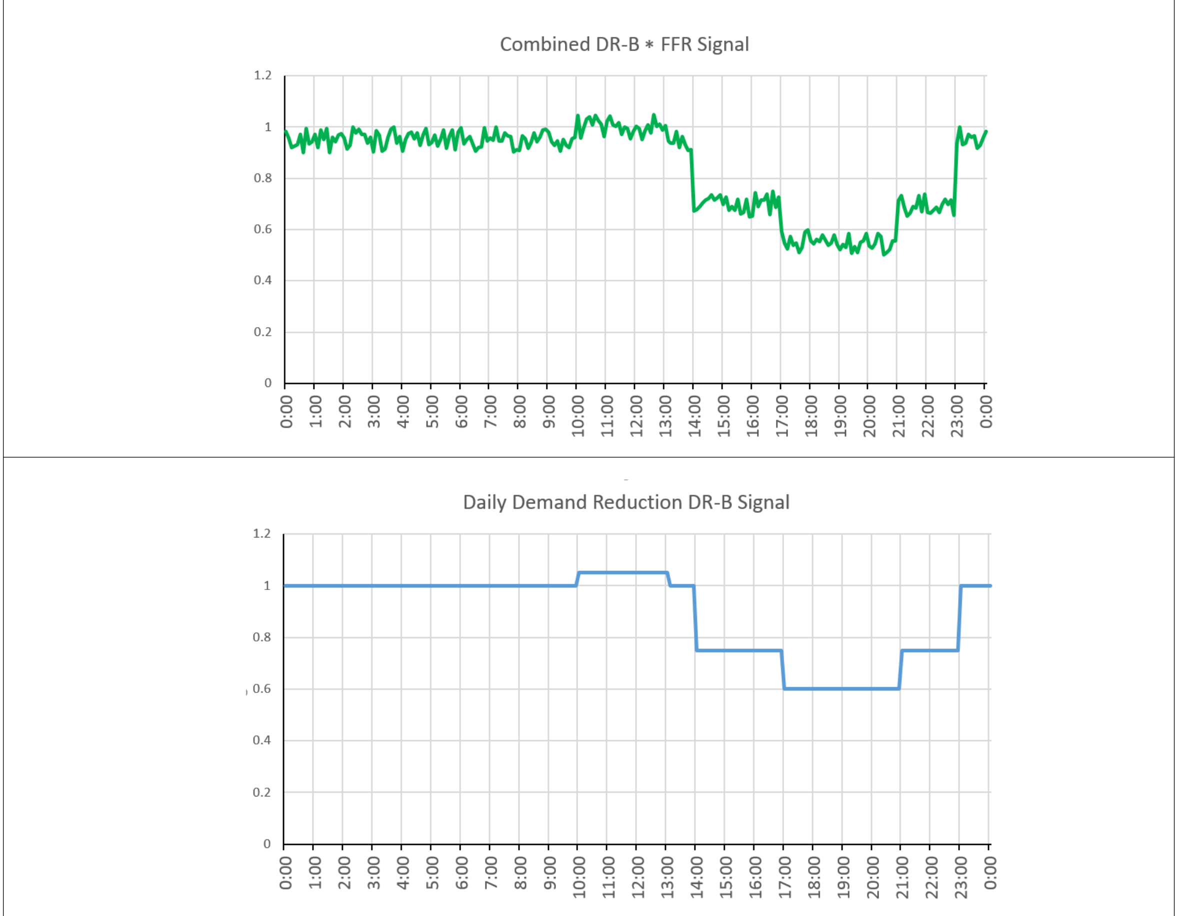


Figure 2-51: Combined DR-B / FFR Signal (top) and DR-B alone

This implies that 5% more energy might be available to the EVs. Is this so?

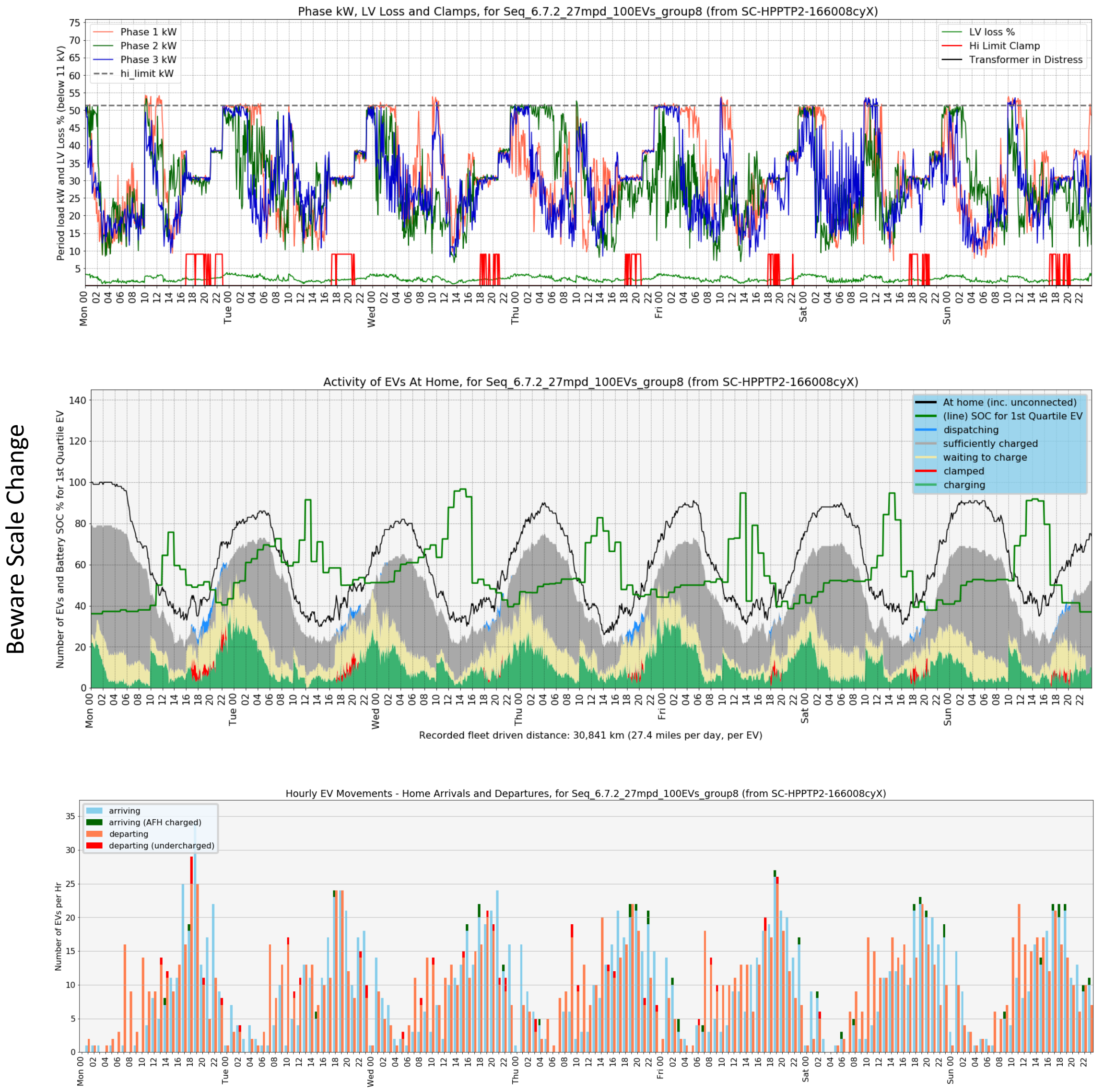
The 27mpd 100EVs and 49mpd 140EV cases only will be shown.

V4-2.70.1 Seq_6.7.2 Outcomes

Recovery of FFR's 5% diminution does allow improved kWh throughput to EVs; it is noticeable that severe undercharging is improved, so recovering unacceptable high-duty N EV plies.

V4-2.71 Seq_6.7.2 Feeder and EV Plots

V4-2.71.1 Seq_6.7.2: 27mpd 100EVs



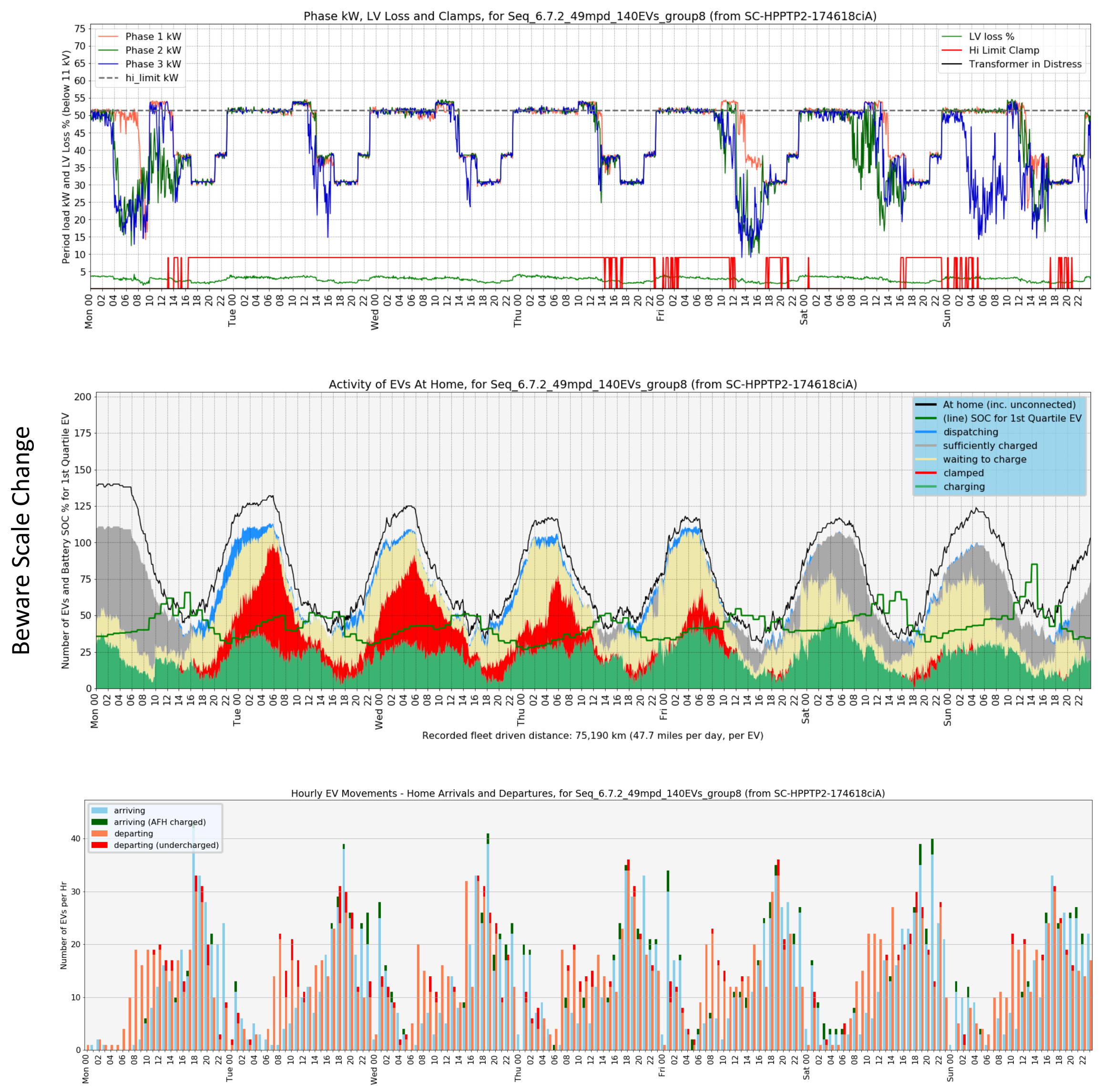
EoW stats: kWh[b] EV total: 6,052 Home: 5,257 AFH: 795 V2G: 155

Figure 2-52: Seq_6.7.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows the DR signal emerging
- (CICD) compared to 6.2.2, SOC adequate, with little use of clamps and V2G. Readiness for depart is good.
- (Arrive/Depart) light, occasional undercharged departs and AFH.

V4-2.71.2 Seq_6.7.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,767 Home: 10,356 AFH: 4,411 V2G: 1,162

Figure 2-53: Seq_6.7.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot clearly shows the DR signal
- (CICD) clamping and V2G are both decreased vs. 6.2.2
- undercharging on Monday, Tuesday and Wednesday are noticeably less prevalent.

V4-2.72 Data Tables

Table 2-131: 6.7.2 Average Weekly Unutilised Network kWh vs. Seq_6.2.2

		N EV	10	20	40	60	80	100	120	140
Seq_6.2.2	1. Unused kWh A	19mpd	17,107	16,476	15,231	13,973	12,694	11,390	10,075	8,760
		27mpd	16,992	16,221	14,711	13,175	11,654	10,098	8,470	6,805
		38mpd	16,895	16,026	14,258	12,452	10,690	8,822	6,969	5,279
		49mpd	16,813	15,858	13,895	11,925	10,012	7,990	6,087	4,763
Seq_6.7.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	17,112	16,487	15,252	14,002	12,739	11,468	10,185	8,918
		27mpd	16,996	16,230	14,727	13,202	11,699	10,172	8,590	6,998
		38mpd	16,897	16,031	14,267	12,477	10,732	8,887	7,064	5,174
		49mpd	16,813	15,859	13,904	11,940	10,039	8,009	6,022	3,673
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	5	10	21	28	44	78	110	158
		27mpd	4	9	16	27	45	74	120	193
		38mpd	2	5	10	25	43	64	95	-105
		49mpd	0	2	9	14	27	19	-65	-1,090

Average LV Losses kWh: Seq_6.7.2 (B) vs. Baseline 6.2.2 (A)

At the extremes of demand, unused kWh falls - thus, FFR does limit EV kWh take-up.

Table 2-132: 6.7.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.0	3.1	3.0	3.1	3.4	3.3	3.3
	27mpd	6.3	7.3	7.1	7.4	7.9	7.9	7.8	7.7
	38mpd	16.3	16.3	16.8	17.4	17.3	17.8	17.5	17.7
	49mpd	34.1	31.5	30.3	30.1	29.9	30.0	30.5	31.5

6.2.2 span: [8.0] => [34.2] and 6.3.2: [8.7] => [39.2]

The count of AFH charging is down.

Table 2-133: 6.7.2 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	0.11	0.13	0.13	0.12	0.13	0.14	0.14	0.14
	27mpd	0.27	0.28	0.27	0.28	0.30	0.30	0.29	0.29
	38mpd	0.56	0.56	0.56	0.57	0.57	0.59	0.58	0.58
	49mpd	1.07	0.95	0.90	0.89	0.89	0.90	0.91	0.94

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

As is the need for AFH connections.

Table 2-134: 6.7.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.6	0.7	0.7	0.8	0.8	0.9	0.8	0.8
	27mpd	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3
	38mpd	1.7	1.8	1.9	1.9	1.9	2.0	2.0	2.2
	49mpd	2.4	2.4	2.4	2.5	2.5	2.6	2.7	3.5

6.2.2 span: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

Undercharging has dropped.

Table 2-135: ***6.7.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0003	0.0008	0.0005	0.0004	0.0004	0.0003	0.0003
	27mpd	0.0002	0.0006	0.0007	0.0012	0.0014	0.0012	0.0008	0.0009
	38mpd	0.0026	0.0031	0.0038	0.0042	0.0036	0.0044	0.0041	0.0066
	49mpd	0.0050	0.0026	0.0060	0.0051	0.0069	0.0082	0.0111	0.0583

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175]

Severe undercharging has fallen. 3 plies are now no longer out of limit.

Table 2-136: ***6.7.2 V2G kWh dispatch per EV (weekly averages)***

6. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	4.1	2.7	2.3	2.2	2.7	3.3	3.9	4.3
	27mpd	3.8	2.6	2.4	2.7	3.6	4.7	5.9	7.4
	38mpd	3.7	2.6	2.8	3.4	4.9	7.4	10.9	17.4
	49mpd	3.7	2.7	3.2	4.1	6.4	11.2	17.4	23.2

6.2.2 span: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

The V2G EVs duty has fallen vs. both 6.2.2. and 6.3.2

Table 2-137: ***6.7.2 MCS Clamps (weekly averages)***

7. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	52	67	96	119	146	167	120	144
	27mpd	56	80	120	154	194	233	199	263
	38mpd	69	97	152	204	273	366	454	1,064
	49mpd	75	112	182	252	355	607	1,025	2,081

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (< 420)

These values have substantively dropped, liberating 3 plies.

V4-2.73 Seq_6.7.2 Results Summary

It is clear that by removal, the modest 5% diminution of headroom allowed for FFR services has noticeable and detrimental impact. The issue then arising: is profit from such services sufficient to recompense the onset of need to reinforce systems? Most likely not.

From the above, it is suggested that FFR services are not provided from the more loaded of the pool of DNO networks.

V4-2.74 Sequence 6.8.2

Sequence	Simulation ID	Description
Seq_6.8.2	(S_A2)	Variation vs. Seq_6.1.2: phase hi_limit is made 40 kW
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Sequence 6.8.2 is part of a set exploring hi_limit reduction and impact on losses. This has been suggested before, but not in the EV context. Acosta et al (see **(Acosta, Higgins, Hughes, & Manolopoulos, 2017)**) correlated losses with peak load, Figure 2-54:

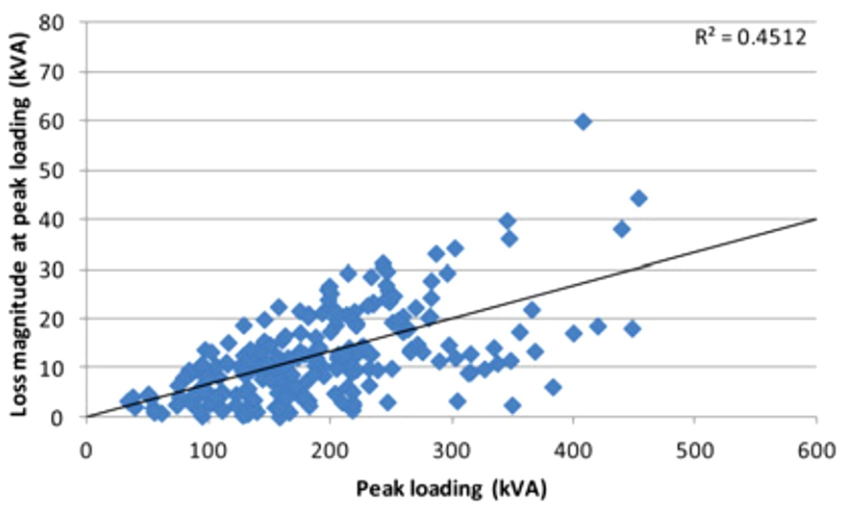


Figure 2-54: Acosta's Fig. 5: Correlation of losses [..] with peak loading

DNOs are concerned about these losses, as:

- the cost of the lost kWh falls on them / they pay for these, and

- Ofgem is interested in minimising these and periodically requires DNOs to produce "loss mitigation plans" (see **(Ofgem, 2010)**, **(WPD., 2017)** and **(SSEPD., 2015)**).

Losses occur in all electrical systems but especially at LV, which has maximum currents.

Having an adjustable hi_limit setpoint allows MCS a notional control over losses. However this implies that EVs may come off the worst, for they are now deliberately throttled.

Table 2-138: Annual losses with loss intervention test scenarios (Acosta, 2017)

Table 1 Annual losses with loss intervention test scenarios

Scenario no.	Scenario	Annual losses, MWh	Annual losses reduction, %
1	base case (power factor = 0.97)	19.45	0.00
2	balancing loads	17.65	9.3
3	upgrading transformer	18.99	2.4
4	upgrading LV conductors	15.69	21.5
5	upgrading transformer and LV conductors (combination of 3 and 4)	15.29	23.5
6	power factor = 0.99	18.52	4.8
7	balancing phases, upgrading transformers and conductors, and correcting power factor (combination of 2, 3, 4 and 6)	12.53	35.6

The magnitude of loss at hand is c.:

- total UK power delivery losses (c. 2018): 8% of throughput i.e. c. 0.08 * 336 TWh
- 27 GWh with commercial value of c. 7p per kWh i.e. £1.9 bn. pa,
- Parliamentary evidence (see https://publications.parliament.uk/pa/cm201415/cmselect/cmenergy/386/38607.html) states that:

> *"47. Jonathan Smith, Head of Trading and Pricing, First Utility, told us [...] From a domestic perspective the average [annual] bill is around the £1,000 mark. About half is the wholesale element, about £500. We have heard that losses are about 7% or 8% on distribution, 1% or 2% on transmission. That is 10%, so that is £50 [...] a big piece we can try to reduce on consumer bills, if we can find ways to reduce losses "*

- thus distribution losses accounts for c. 8 parts in 10 i.e. £1.5 bn. pa

- with **(Sohn, 2009)** page 10 stating the LV element of distribution causes c. 4 parts in 7 of distribution losses i.e. c. £860 m on the LV network alone
- but not all the LV system is domestic (so in purview) the proportion is not known.

However these figures predate the arrival of EVs; the carried load must rise so losses rise also. This can be estimated by looking at total losses for a Typical feeder and an amorphous core transformer, for Seq_0 (no EVs) vs. the parity case:

- Seq_0: in the Winter week: 93 kWh vs.
- Seq_1.1.2 (no controller) has losses of 352 kWh (but with broaches)
- Seq_6.1.2 with losses of 345 kWh (@ 27mpd 100EVs),

which, taking the Seq_6.1.2 outcomes vs. Seq_0 is an unfortunate x 3.7 escalation. The value of UK LV losses are then estimated at c. £3.2 bn. pa.

FPB's loss kWh figures are found by OpenDSS, including all losses from the 11 kV transformer primary to the consumer meter. This is not a harmonics study; however if uncontrolled, EV inverter harmonics will escalate this figure. See **(WPD., 2018)**.

There are several sequences related to this important issue. All assess the loss reduction afforded by adjusting the default hi_limit downwards under various conditions, and to assess what impact these have on the EVs.

The greatest impact expected is in rising severely undercharged departures, a likely politically sensitive aspect.

Note that DR/FFR is not used for this exercise.

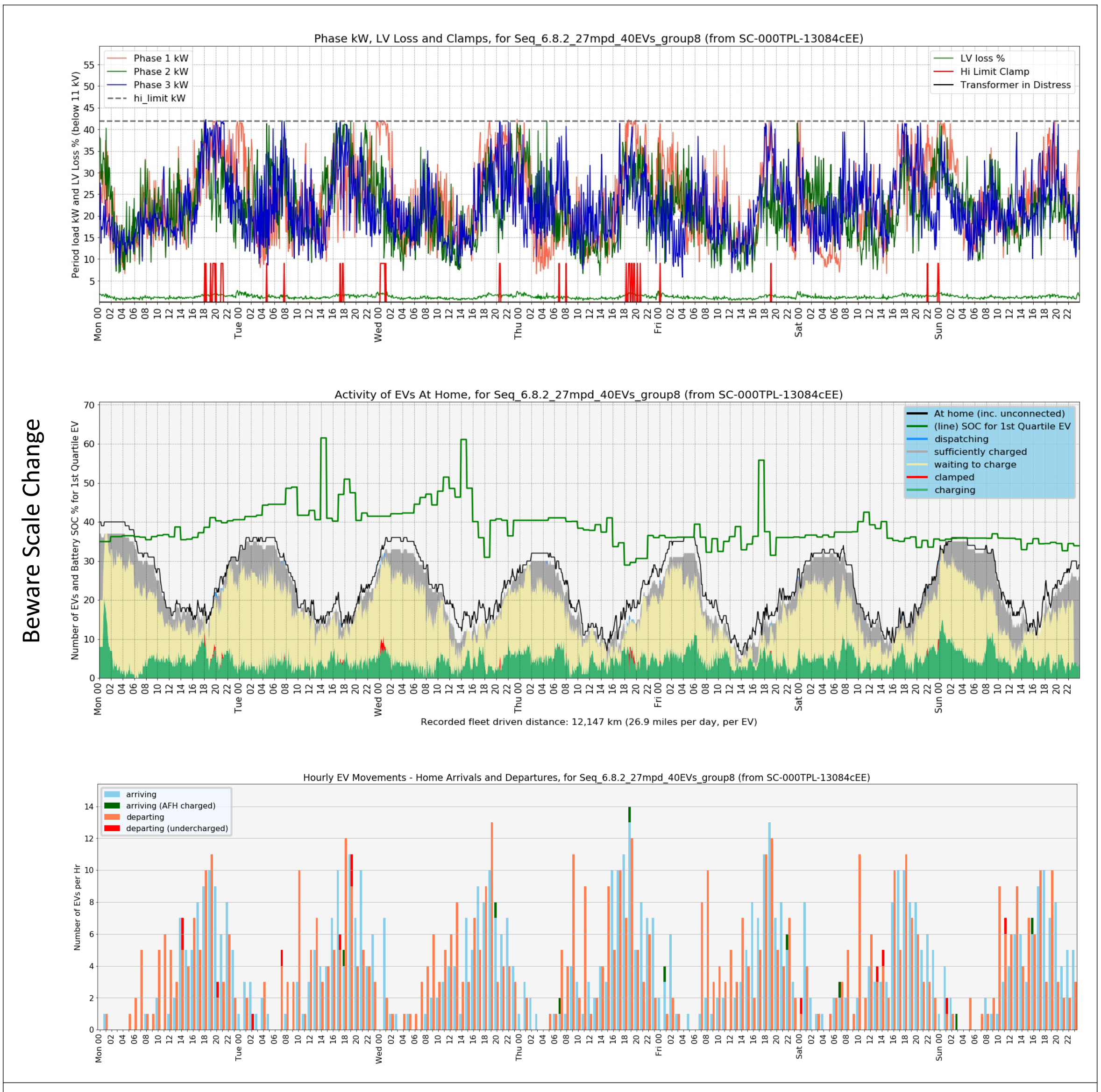
Sequence_6.8.2 begins by reducing the hi_limit to 40 kW from 49 kW (per phase, default ambient rating). Simulations are set in Winter and data originate from MetaMeta spreadsheets for Seq_6.8.2.

V4-2.74.1 Seq_6.8.2 Outcomes

Direct DNO Losses are reduced by c. 5% for the parity case, but provoke further severe undercharging and an unacceptable numbers of clamps. Also EV V2G losses rise, limiting benefit gained.

V4-2.75 Seq_6.8.2 Feeder and EV Plots

V4-2.75.1 Seq_6.8.2: 27mpd 40EVs



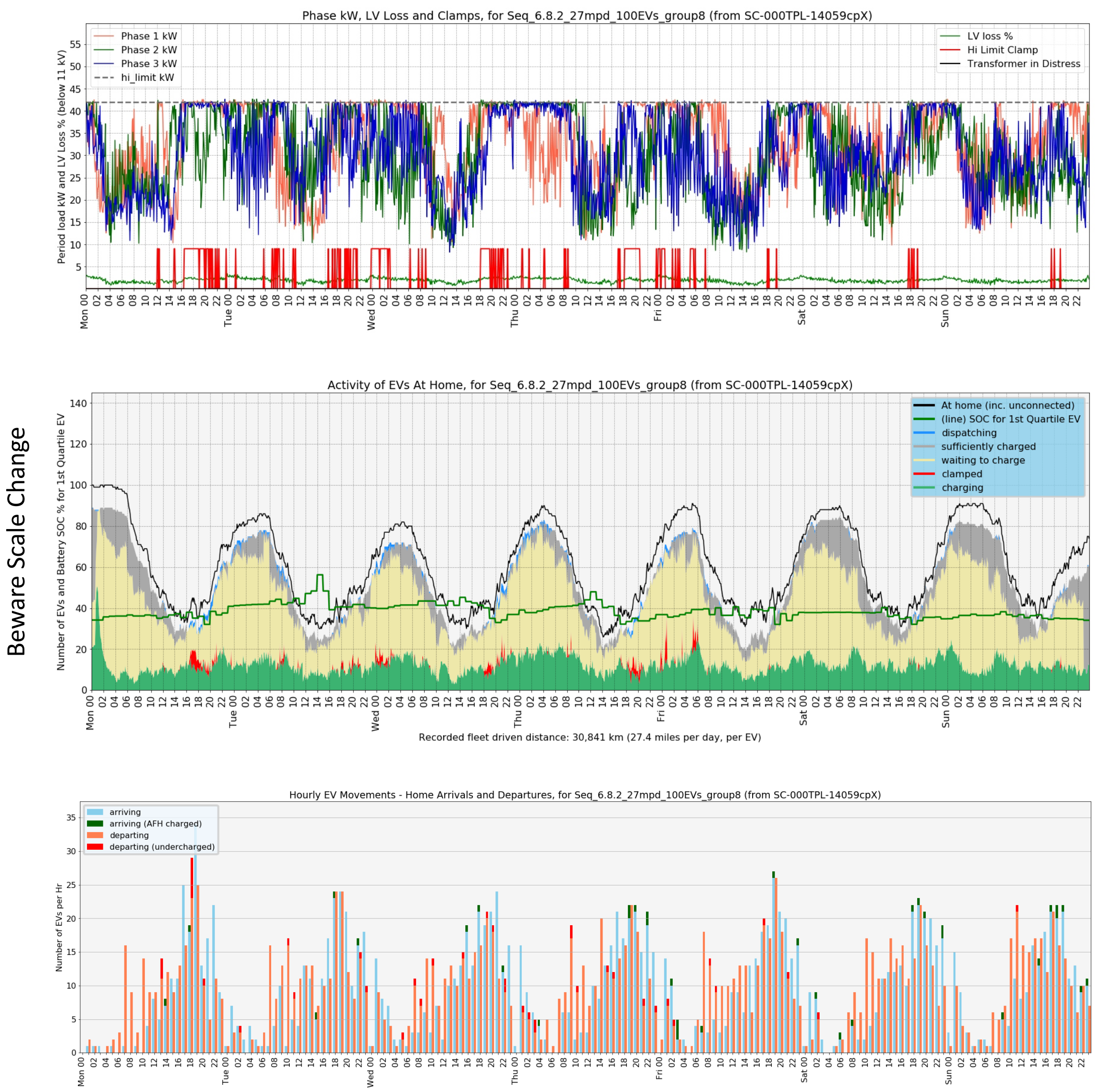
EoW stats: kWh[b] EV total: 2,321 Home: 2,024 AFH: 297 V2G: 7

Figure 2-55: Seq_6.8.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable, other than to show the hi_limit has lowered
- (CICD) EVs have good SOC
- (Arrive/Depart) there are very few undercharged departs; AFH charging is rare.

V4-2.75.2 Seq_6.8.2: 27mpd 100EVs



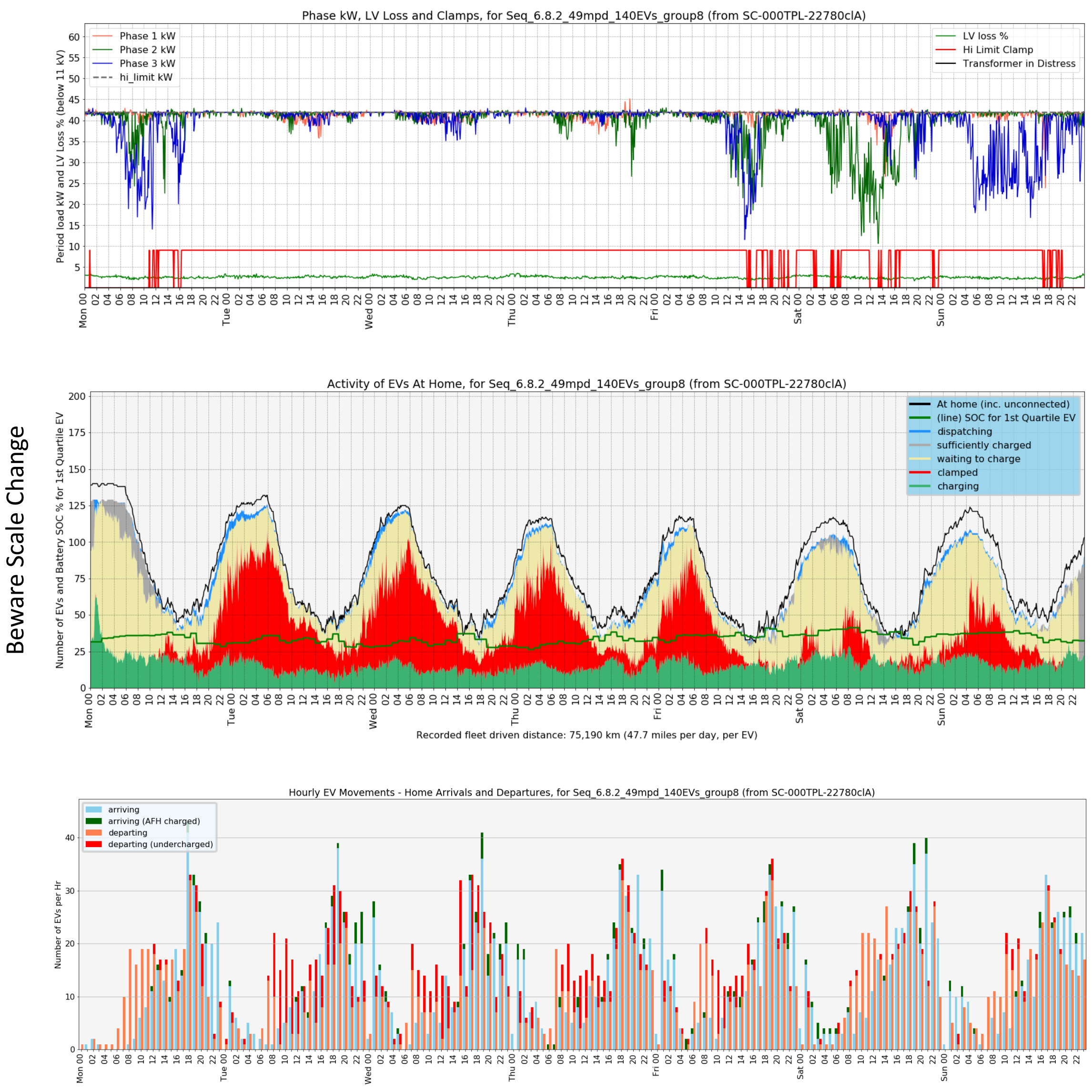
EoW stats: kWh[b] EV total: 6,145 Home: 5,322 AFH: 822 V2G: 235

Figure 2-56: Seq_6.8.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows more clamps but is unremarkable
- (CICD) SOC is similar with EVs ready to depart; some V2G
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.75.3 Seq_6.8.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,878 Home: 9,998 AFH: 4,888 V2G: 1,302

Figure 2-57: Seq_6.8.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the system is clearly in saturation
- (CICD) V2G pre-burn and clamps dominate. Few EVs are ready to depart
- undercharging and AFH charging has clearly risen.

V4-2.76 Data Tables Seq_6.8.2

Table 2-139: 6.8.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12,350	11,683	10,368	9,036	7,721	6,386	5,059	3,693
	27mpd	12,239	11,441	9,884	8,303	6,762	5,193	3,604	2,020
	38mpd	12,144	11,254	9,459	7,637	5,873	4,047	2,378	982
	49mpd	12,062	11,101	9,119	7,142	5,244	3,331	1,767	677

6.1.2 span: [10,219] => [0]

Note the reduced hi_limit has lowered the weekly available energy by 4,700 kWh.

Table 2-140: 6.8.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.0	3.2	3.1	3.2	3.5	3.4	3.4
	27mpd	6.5	7.6	7.4	7.7	8.1	8.2	8.1	8.0
	38mpd	16.8	16.9	17.3	17.8	17.7	18.3	18.3	19.9
	49mpd	34.5	32.5	30.9	30.6	30.4	30.8	32.7	36.5

6.1.2 span: [8.0] => [31.7]

Given the reduced availability of home power, AFH charging has risen.

Table 2-141: 6.8.2 Per EV AFH N events (weekly average away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.12	0.13	0.13	0.13	0.13	0.15	0.14	0.14
	27mpd	0.28	0.30	0.28	0.29	0.31	0.31	0.30	0.30
	38mpd	0.59	0.58	0.58	0.59	0.59	0.61	0.61	0.67
	49mpd	1.09	0.99	0.92	0.91	0.92	0.93	1.00	1.13

6.1.2 span: [0.30] => [0.96]

Table 2-142: ***6.8.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.9	1.1	1.0	1.0	1.1	1.1	1.1	1.1
	27mpd	1.4	1.5	1.5	1.5	1.5	1.6	1.6	1.7
	38mpd	2.0	2.1	2.1	2.1	2.1	2.3	2.6	4.0
	49mpd	2.6	2.6	2.6	2.6	2.6	3.1	4.2	6.4

6.2.2: [1.4] => [3.5]

Table 2-143: ***6.8.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0003	0.0003	0.0002	0.0002	0.0002	0.0003	0.0002
	27mpd	0.0002	0.0002	0.0005	0.0009	0.0011	0.0009	0.0009	0.0030
	38mpd	0.0008	0.0012	0.0018	0.0028	0.0021	0.0052	0.0177	0.0959
	49mpd	0.0028	0.0025	0.0042	0.0037	0.0049	0.0264	0.1084	0.2848

6.1.2 span: [0.0008] => [0.0736] (limit: < 0.007)

Sequence 6.8.2 has lost 3 severe undercharging plies vs. Seq_6.1.2.

Table 2-144: ***6.8.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	4	8	23	44	85	152	202	336
	27mpd	5	12	36	79	158	308	542	1,166
	38mpd	6	16	58	136	292	766	1,488	2,686
	49mpd	7	20	77	200	518	1,289	2,250	3,342

6.1.2 span: [9.5] => [1,540] (limit: < 420)

These values have substantively risen, reflecting the EVs need to charge, loosing 6 further plies.

***Table 2-145:** 6.8.2 V2G kWh dispatch per EV (weekly averages)*

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	0.1	0.1	0.4	1.3	2.8	5.5	9.1	13.8
	27mpd	0.1	0.2	0.7	2.3	5.4	10.5	17.6	25.9
	38mpd	0.1	0.2	1.3	4.1	9.3	17.8	26.0	30.2
	49mpd	0.1	0.2	1.5	5.3	12.5	20.5	26.0	28.0

6.1.2 span: [0.2] => [13.6]

The V2G EVs have increased duty.

***Table 2-146:** 6.8.2 Average LV Losses Comparison*

		N EV	10	20	40	60	80	100	120	140
Seq_6.1.2	8. A	19mpd	96.4	112.7	138.3	181.3	235.9	298.5	363.1	426.1
		27mpd	97.7	115.8	154.8	204.2	267.9	344.6	427.2	508.9
		38mpd	99.9	118.2	162.4	226.2	303.0	398.2	496.1	590.6
		49mpd	101.6	120.2	169.3	239.4	324.4	430.4	537.8	631.5
Seq_6.8.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	96.6	113.0	139.9	179.0	227.4	284.9	345.9	405.9
		27mpd	97.8	116.3	146.2	196.5	258.0	327.7	401.0	471.6
		38mpd	98.8	118.5	158.7	215.9	288.1	373.1	450.8	519.0
		49mpd	99.8	120.3	167.2	228.9	303.7	393.0	473.2	531.0
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.2	0.3	1.6	-2.3	-8.5	-13.6	-17.2	-20.2
		27mpd	0.1	0.5	-8.6	-7.7	-9.9	-17.0	-26.2	-37.3
		38mpd	-1.0	0.3	-3.7	-10.3	-15.0	-25.1	-45.3	-71.6
		49mpd	-1.8	0.2	-2.1	-10.6	-20.6	-37.4	-64.5	-100.6

Average LV Losses kWh: Seq_6.8.2 (B) vs. Baseline 6.1.2 (A)

This is a loss reduction (for the parity case) of 100 % * (17 / 344) = 4.94 %.

V4-2.77 Seq_6.8.2 Results Summary

Clear cells are Usable. Yellow: Severe undercharging too high, blue: Clamp limits exceeded, pink both too high.

Copy of Table 2.29: ***6.1.2 Overall Usable EV Plies***

Seq_6.1.2	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd								
	38mpd								C
	49mpd							S	SC

Table 2-147: ***6.8.2 Overall Usable EV Plies***

Seq_6.8.2	N EV	10	20	40	60	80	100	120	140
	19mpd								
	27mpd							C	C
	38mpd						C	SC	SC
	49mpd						SC	SC	SC

The strategy has lost 5 useful plies. Performance on the parity EV case is acceptable; moreover the hi_limit can be adjusted as EV numbers rise. It is likely that this can be automated i.e. a count of known EVs may be detected (this is part of WPD's EN project); the known count can be used to correct the hi_limit dynamically up or down, likely over a wide time window, e.g. 2 weeks.

The economic value of this likely useful, being approximately:

£860 m for LV losses across UK of 25 million homes => c. £21.50 per home, pa

for 1 million DNO supplied houses, with the DNO initially paying for the loss, this is:

£21.5 million pa

rising by x 3.7 so likely: £79.6 m pa, per million houses with EVs supplied. Lowering the hi_limit as in 6.8.2 has given 4.95% reduction, which is £3.94 m per million houses, pa. For a typical DNO such as SSEPD (c. 3.8 million supplied homes) a 2 in 3 EV uptake with MCS managing the hi_limit down by 9 kW per phase yields:

£3.9 m * 3.8 * 2 / 3 = £9.9 m pa

i.e. c. £190 k per week or £1.9 m over a 10 week hi-load winter, notionally available by no more than managing the hi_limit setpoint, a purely soft-set data value. This corresponds to c. £385 k per 1% reduction over Winter. As this is a cost reduction, it raises profit (for SSE Distribution profit £371 m in 2015/16). Can this be used in all cases, or pushed further? **Note** that the costs of V2G has not been included.

V4-2.78 Sequence 6.9.2 (Later Withdrawn)

Sequence	**Simulation ID**	**Description**
Seq_6.9.2	(S_Ai)	Variation vs. Seq_6.2.2 and Seq_6.8.2: DR/FFR “C” is in use with hi_limit reduced to 40 kW from 49 kW per phase. Clamp are active in mode 2. EVs are **75% dumb and 25% V2G. Pre-burn V2G is OFF**
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

This sequence explores operation with different EV population conditions and DR/FFR “C” hi_limit modulation. “C” has less aggressive DR than “B”, and retains the FFR pattern.

From Time of Day	DR “B”	DR “C”	Purpose
Midnight	1.0	1.0	normal operation
10am	1.05	1.05	Sunshine (charge now) signal
1:06pm	1.0	1.0	normal operation
2pm	0.75	0.9	early afternoon DR
5pm	0.6	0.72	late afternoon DR
9pm	0.75	0.9	late evening DR
11pm	1.0	1.0	normal operation

The DR reduction in “C” is an attempt to improve severe undercharging rates.

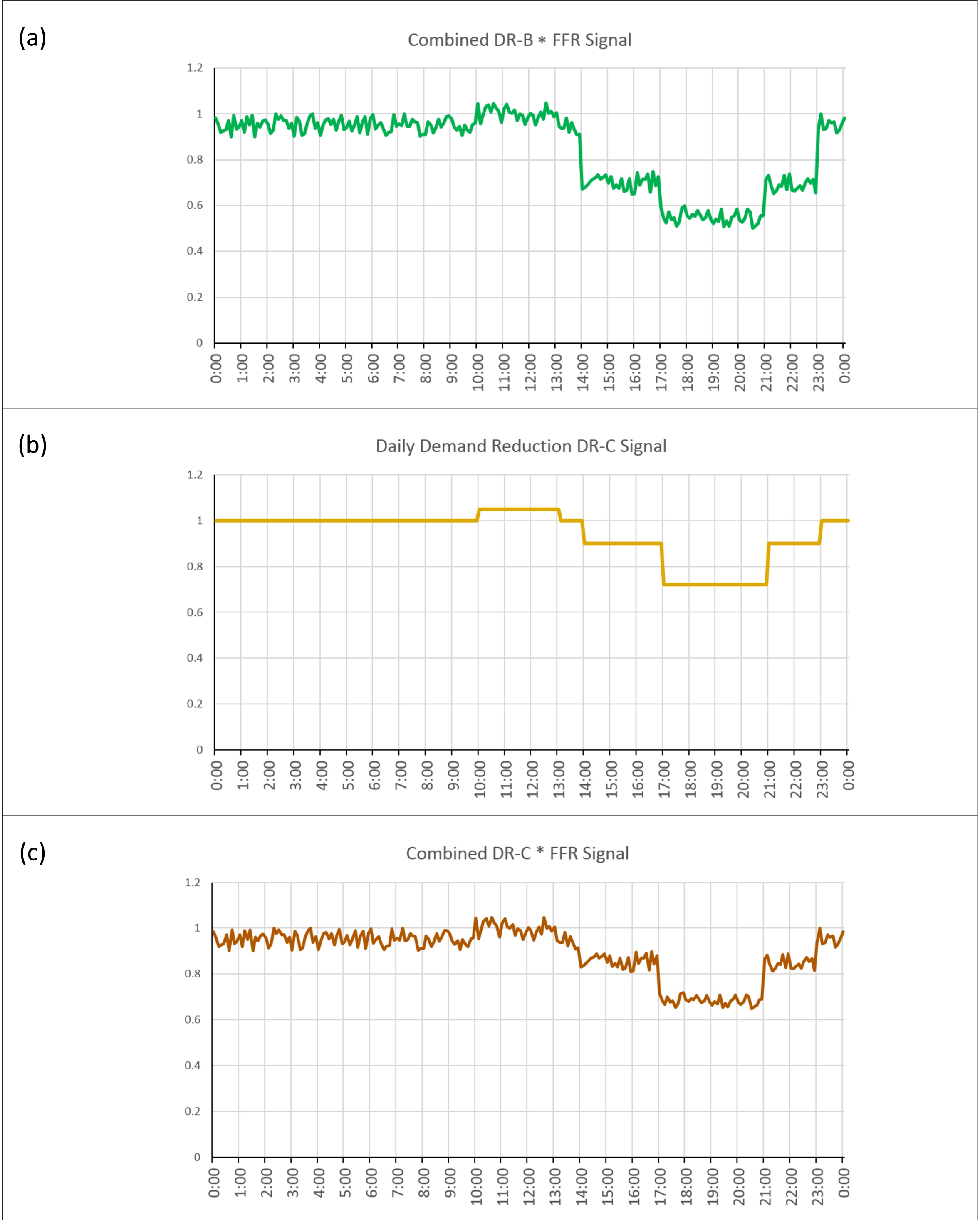


Figure 2-58: Prior DR-B / FFR Signal (top), DR-C, Combined DR-C and FFR

Data originate from MetaMeta spreadsheets for Seq_6.9.2. Note that:

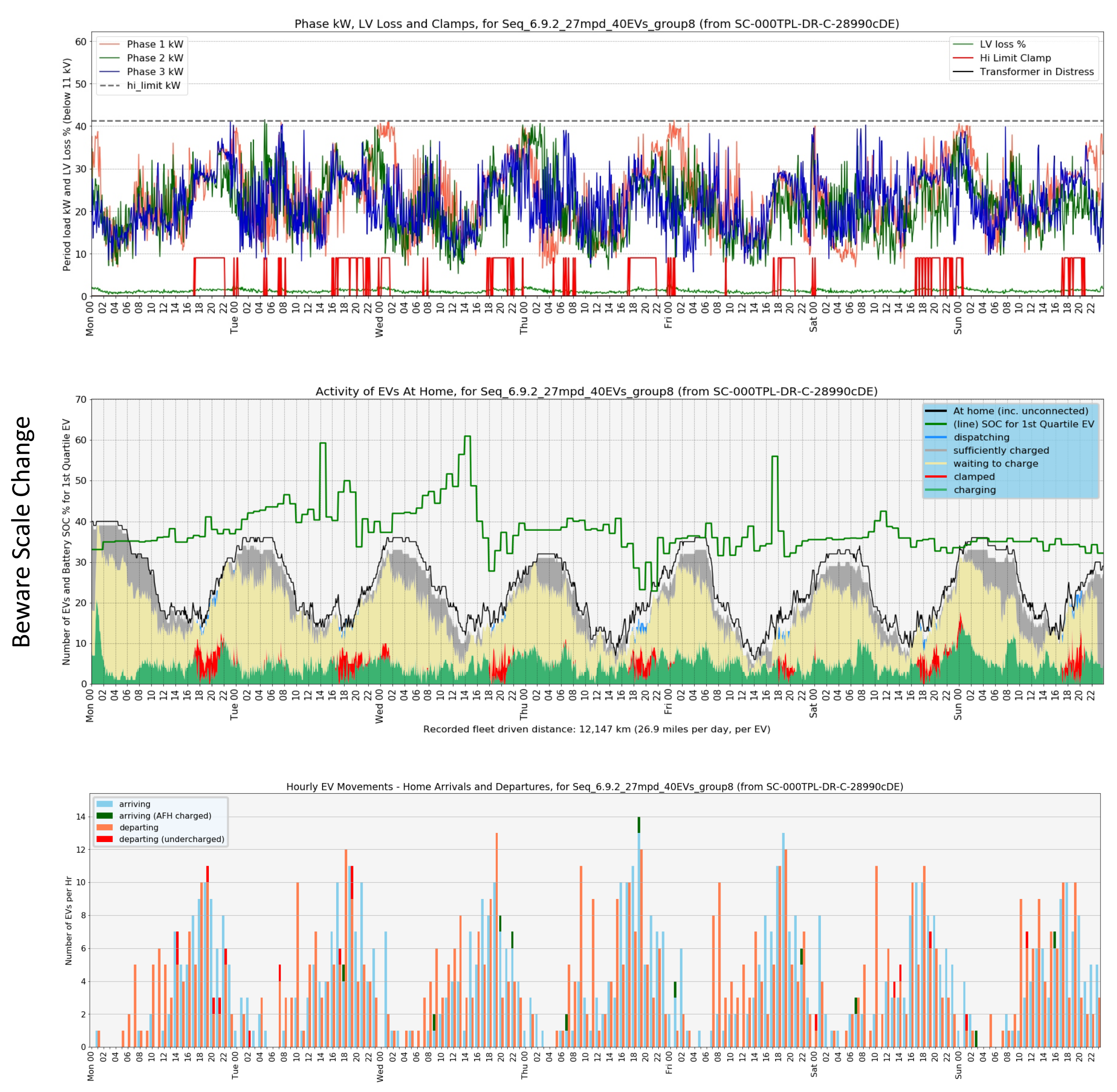
- 6.2.2 has no Aggregation control,
- 6.3.2 has 100% of EVs under Aggregation control,
- 6.9.2 has no EVs under Aggregation control.

V4-2.78.1 Seq_6.9.2: Outcomes

The method shows residential spikes. Losses are improved but undercharging is raised.

V4-2.79 Seq_6.9.2 Feeder and EV Plots

V4-2.79.1 Seq_6.9.2: 27mpd 40EVs



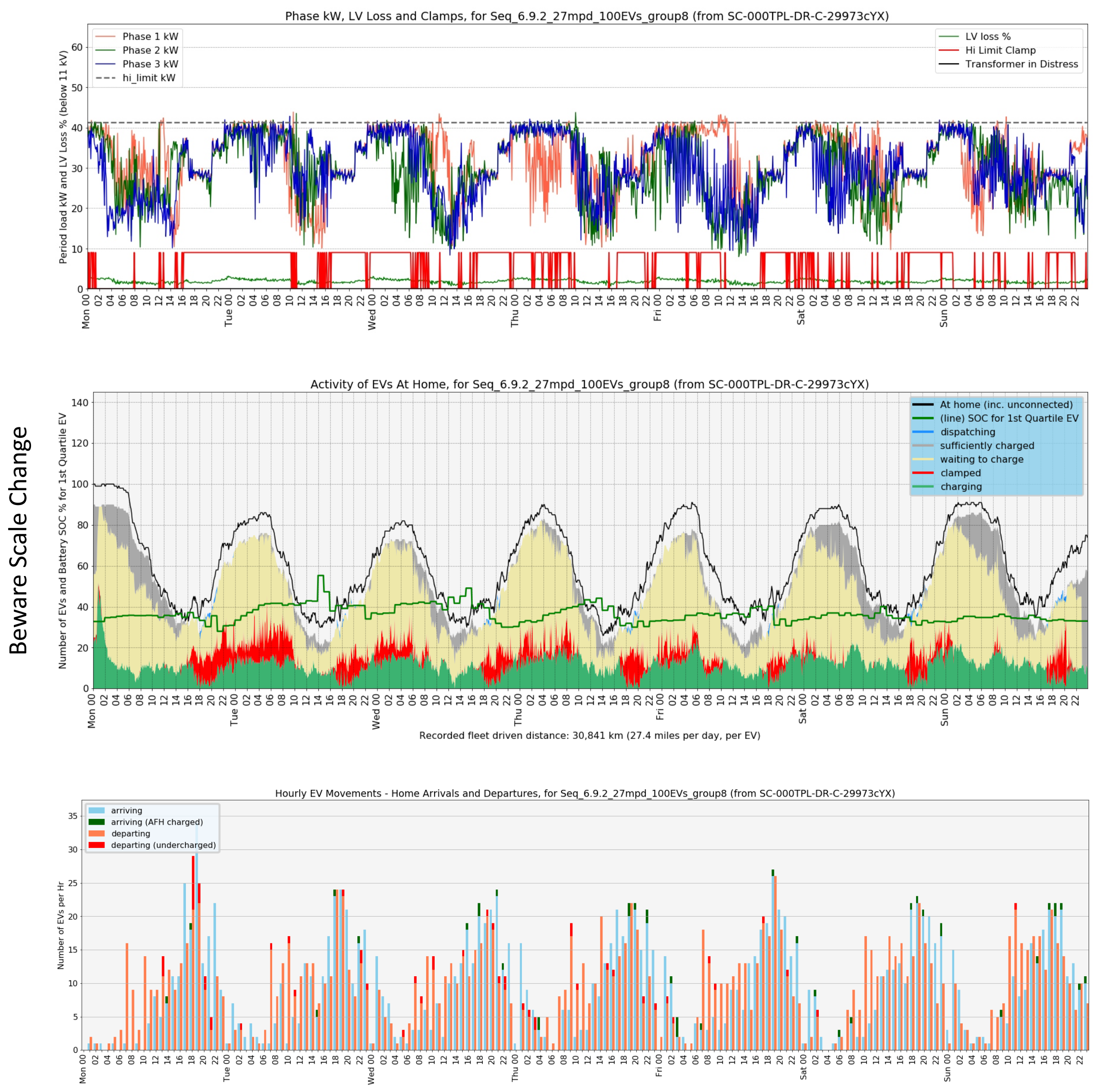
EoW stats: kWh[b] EV total: 2,363 Home: 2,052 AFH: 311 V2G: 41

Figure 2-59: Seq_6.9.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot shows clamps and the lowered hi_limit
- (CICD) EVs have good SOC but relatively few are ready to depart. Some V2G
- (Arrive/Depart) there are few undercharged; AFH charging is rare.

V4-2.79.2 Seq_6.9.2: 27mpd 100EVs



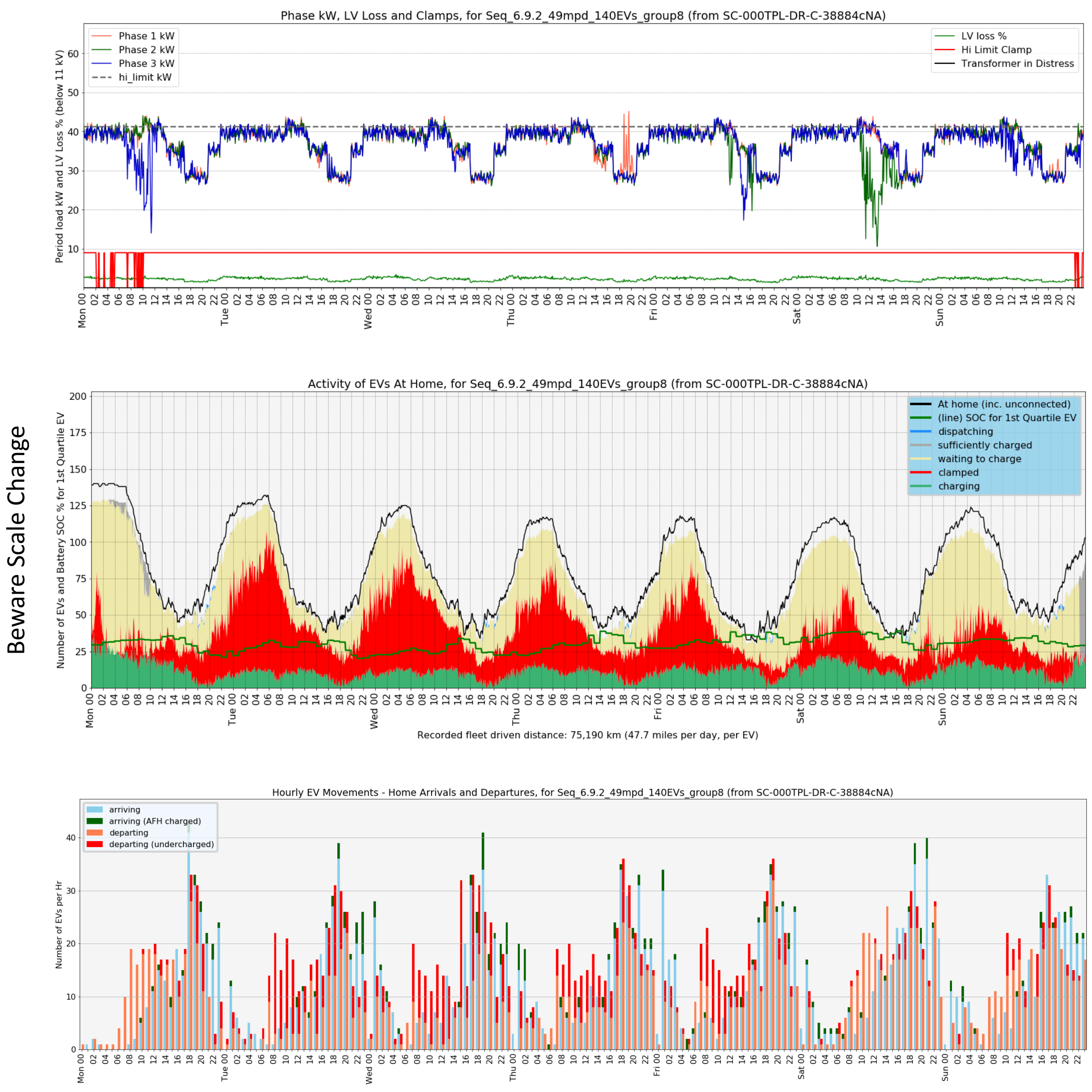
EoW stats: kWh[b] EV total: 5,966 Home: 5,101 AFH: 865 V2G: 63

Figure 2-60: Seq_6.9.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows many clamps but is unremarkable
- (CICD) SOC is similar with significant numbers of EVs ready to depart; some V2G
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.79.3 Seq_6.9.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,515 Home: 7,328 AFH: 6,187 V2G: 69

Figure 2-61: Seq_6.9.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal well, also the residential load "bursting through" c. Thursday 9pm
- (CICD) clamps dominate. Very few EVs seem ready to depart
- undercharging and AFH charging has risen to likely unacceptable levels.

V4-2.80 Data Tables Seq_6.9.2

Table 2-148: 6.9.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12,348	11,687	10,378	9,068	7,798	6,545	5,345	4,167
	27mpd	12,240	11,451	9,908	8,367	6,902	5,474	4,112	2,957
	38mpd	12,150	11,275	9,510	7,746	6,105	4,541	3,305	2,607
	49mpd	12,073	11,129	9,190	7,294	5,579	4,054	3,016	2,568

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

Note that the reduced hi_limit has lowered all values by c. 4,700 kWh. It can then be seen the span here would be: [10,174] => [7,268] which implies that the DR/FFR signal is less restricting the upper load ranges.

Table 2-149: 6.9.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.6	3.2	3.3	3.3	3.4	3.7	3.6	3.6
	27mpd	6.8	7.9	7.8	8.1	8.5	8.6	8.7	9.4
	38mpd	17.4	17.6	18.1	18.6	18.6	19.6	21.1	25.6
	49mpd	35.6	33.4	31.9	31.8	31.8	33.8	38.0	44.2

6.2.2 span: [8.0] => [34.2] and 6.3.2: [8.7] => [39.2]

AFH kWh taken is slightly up.

Table 2-150: 6.9.2 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	0.12	0.14	0.14	0.14	0.14	0.16	0.15	0.15
	27mpd	0.30	0.31	0.30	0.31	0.33	0.33	0.34	0.37
	38mpd	0.62	0.62	0.62	0.62	0.63	0.67	0.73	0.92
	49mpd	1.14	1.04	0.97	0.96	0.98	1.05	1.21	1.45

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

Clearly there are more AFH connections, however for the parity case these are modest.

Table 2-151: ***6.9.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.0	1.2	1.2	1.2	1.3	1.3	1.3	1.4
	27mpd	1.6	1.7	1.8	1.8	1.8	1.9	2.1	3.3
	38mpd	2.3	2.4	2.5	2.5	2.6	3.2	4.5	7.2
	49mpd	3.0	3.0	3.1	3.2	3.4	4.7	6.6	9.0

6.2.2: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

Undercharging has risen overall.

Table 2-152: ***6.9.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0030	0.0021	0.0015	0.0014	0.0014	0.0017	0.0015	0.0016
	27mpd	0.0010	0.0008	0.0024	0.0035	0.0036	0.0042	0.0097	0.0433
	38mpd	0.0042	0.0045	0.0090	0.0091	0.0106	0.0325	0.1102	0.2973
	49mpd	0.0070	0.0063	0.0103	0.0099	0.0271	0.1204	0.2799	0.5229

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175] (limit: < 0.007)

Severe undercharging is up; the blue being for 6.2.2.

Table 2-153: ***6.9.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	183	282	442	627	885	1,238	1,648	2,191
	27mpd	189	305	500	766	1,166	1,738	2,468	3,449
	38mpd	199	329	584	979	1,588	2,476	3,378	4,202
	49mpd	210	345	649	1,162	1,950	2,941	3,757	4,440

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 420)

Perhaps an unfair comparison, as we are managing 75% dumb EVs and 25% V2G EVs.

Table 2-154: 6.9.2 V2G kWh dispatch per EV (weekly averages)

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7.1	5.2	4.3	3.6	2.9	2.5	2.2	2.0
	27mpd	6.8	5.2	4.1	3.6	2.9	2.5	2.3	2.1
	38mpd	6.7	5.2	4.3	3.6	2.9	2.5	2.3	2.1
	49mpd	6.1	4.5	4.0	3.4	2.8	2.5	2.2	2.0

6.2.2: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

V2G EVs have surprisingly low duty; this is likely as Pre-Burn is OFF.

Table 2-155: 6.9.2 Average LV Losses Comparison

	8. A	N EV	10	20	40	60	80	100	120	140
Seq_6.2.2		19mpd	96.6	112.9	138.5	178.7	230.6	292.8	357.9	420.6
		27mpd	97.8	116.0	150.2	200.8	261.8	335.9	420.7	502.2
		38mpd	98.9	118.3	162.3	221.9	294.2	389.0	486.5	570.4
		49mpd	99.8	120.3	167.8	236.2	317.4	418.7	518.7	591.4
Seq_6.9.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	96.6	109.2	138.1	171.8	217.6	274.2	325.8	373.9
		27mpd	97.8	115.8	145.9	191.5	241.9	307.5	371.0	418.7
		38mpd	98.8	118.3	151.1	209.3	270.5	341.7	401.4	437.9
		49mpd	99.6	120.0	157.6	219.7	283.0	358.6	413.7	438.8

Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.1	-3.7	-0.4	-6.9	-13.0	-18.6	-32.1	-46.7
		27mpd	0.0	-0.2	-4.3	-9.3	-19.9	-28.4	-49.7	-83.5
		38mpd	-0.1	0.0	-11.2	-12.6	-23.7	-47.3	-85.1	-132.5
		49mpd	-0.2	-0.3	-10.2	-16.5	-34.4	-60.1	-104.9	-152.6

Average LV Losses kWh: Seq_6.9.2 (B) vs. Baseline 6.2.2 (A)

This is a good loss reduction of 100 % * (28 / 336) = 8.33 %, at £385 k per 1% reduction yielding c. £3.2 m over Winter.

Table 2-156:* *6.9.2 DRFFR Percent Effective Hours (weekly averages)

9. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.7%	35.7%	42.3%	48.8%	57.1%	65.5%	70.8%	76.8%
	27mpd	32.1%	36.3%	43.5%	54.2%	66.7%	72.6%	81.0%	86.9%
	38mpd	31.5%	36.9%	46.4%	57.7%	71.4%	78.0%	86.3%	94.6%
	49mpd	31.5%	36.9%	48.8%	61.3%	73.8%	82.1%	90.5%	95.8%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

Hi_limit modulation is acceptable.

V4-2.81 Seq_6.9.2 Results Summary

Note that the author decided that the EV mix used was not correct (75% dumb, no SV1G, 25% V2G) so withdrew the sequence. The run was valid, even though miss-configured and was re-run as Seq_6.9.2.2.

The author was concerned about the spikes seen on the 49mpd 140EV feeder plot which occur Thursday c. 18:00 - 20:00. These appeared anomalous and potentially a defect.

Investigations show the observed peaks are in the core residential load dataset, but usually hidden by:

- hi_limit exceeding the peak value, and
- V2G support.

Note “idle” EVs draw 140 W each; a full set taking 4.6 kW occasionally lifting the peaks.

Setting those aside, the system appears to otherwise be behaving as intended, with parity-case losses improving by 8.3%. However undercharging has suffered and V2G has effectively disappeared as vehicles have no SOC to spare.

In this case, the author thinks that this mix of hi_limit reduction is on the edge of being acceptable. AFH charging is up, but not terribly so.

V4-2.82 Sequence 6.9.2.1

Sequence	**Simulation ID**	**Description**
Seq_6.9.2.1	(S_AK)	Variation vs. Seq_6.2.2 and Seq_6.9.2: DR/FFR “C” is in use with hi_limit 40 kW from 49 kW per phase. EVs are 19% dumb, 48% SV1G and 33% V2G. Pre-burn V2G is OFF
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

In comparison to Seq_6.9.2, the EV mix is here changed; returning the SV1G EVs will hopefully assist reduce clamps. However no other great changes are expected.

Data is from MetaMeta spreadsheets for Seq_6.9.2. Note that:

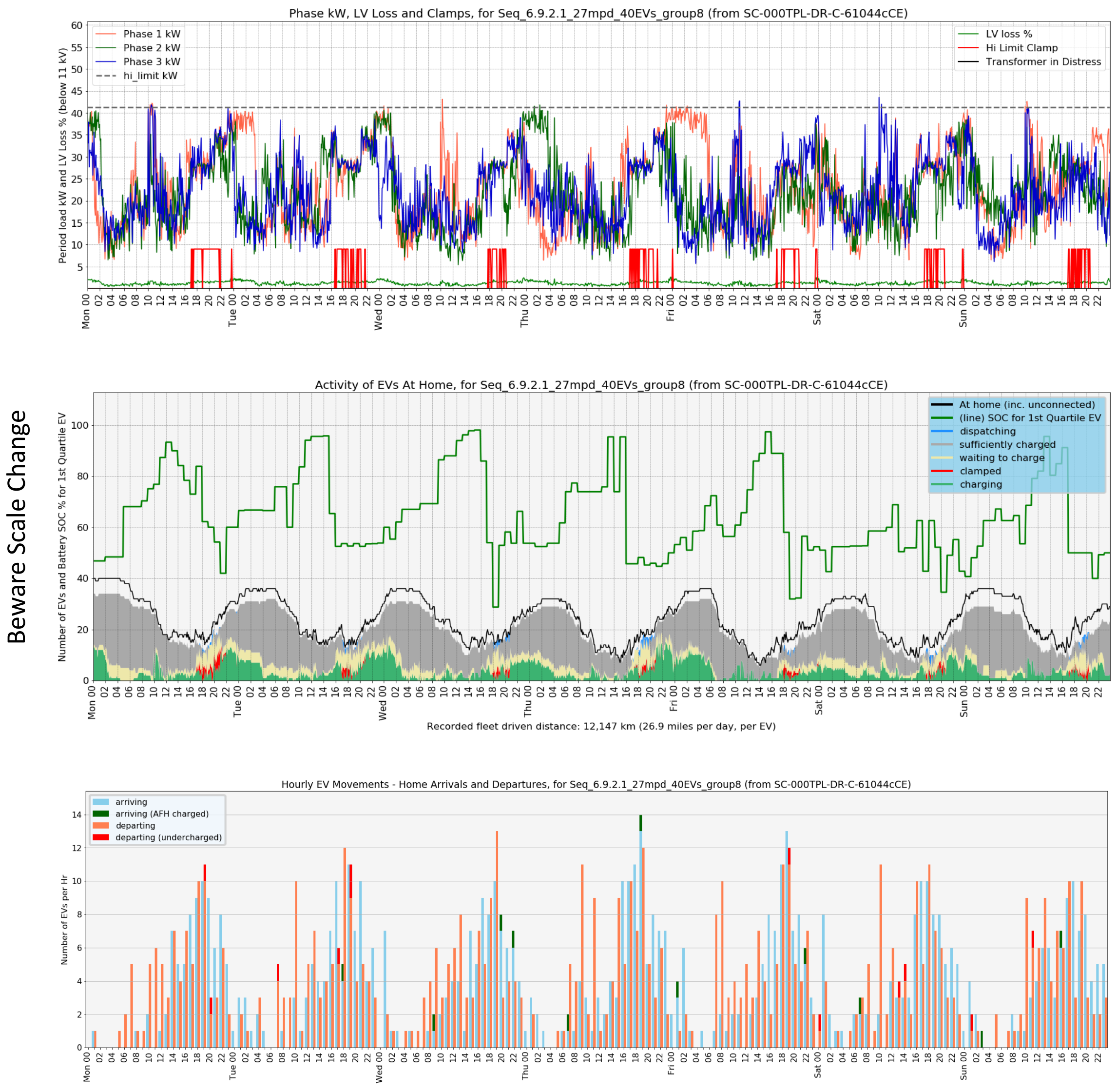
- 6.2.2 has no Aggregation control,
- 6.3.2 has 100% of EVs under Aggregation control,
- 6.9.2 has no EVs under Aggregation control.

V4-2.82.1 Seq_6.9.2.1 Outcomes

Clamp usage drops, but V2G is nearly absent.

V4-2.83 Seq_6.9.2.1 Feeder and EV Plots

V4-2.83.1 Seq_6.9.2.1: 27mpd 40EVs



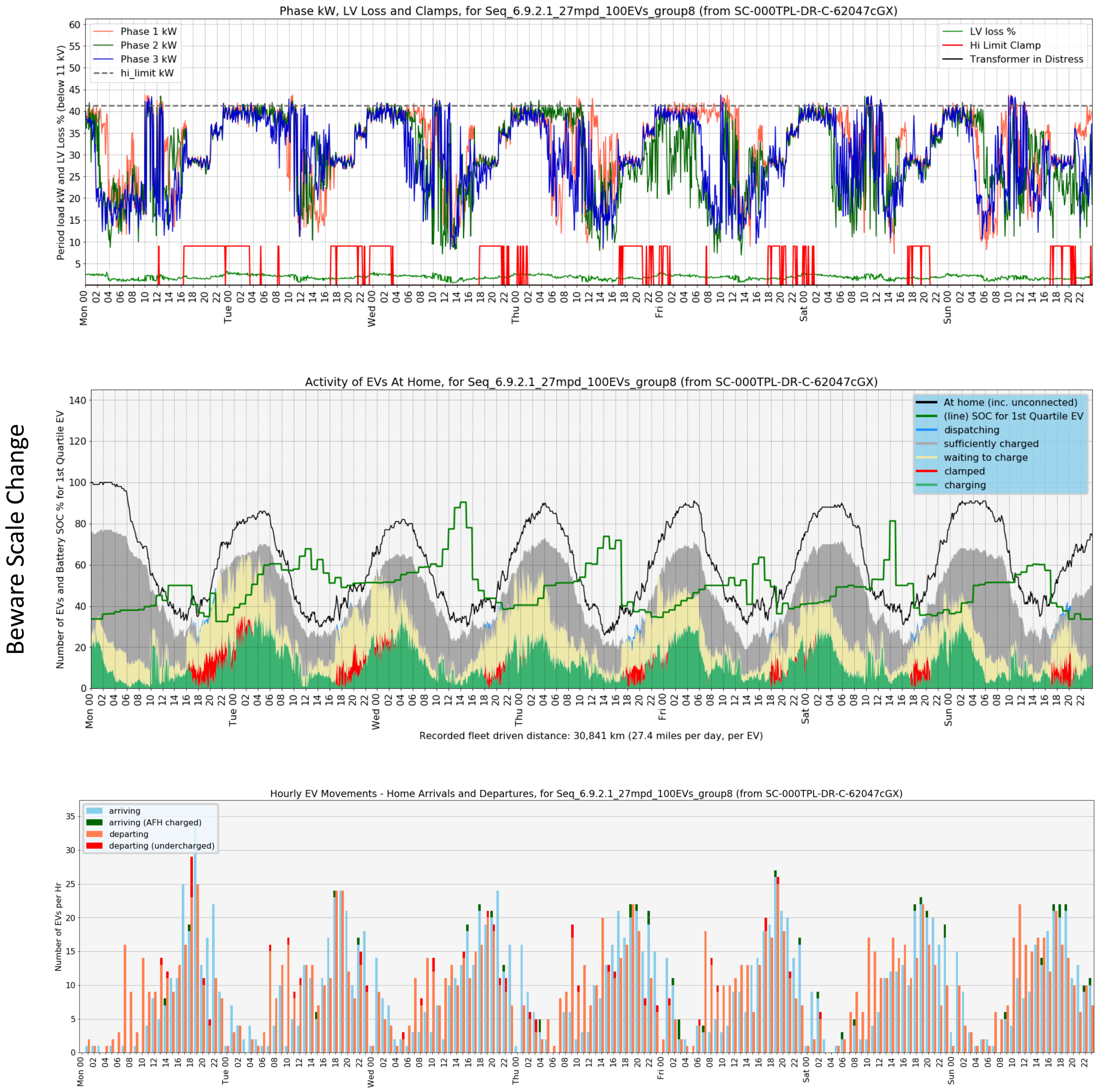
EoW stats: kWh[b] EV total: 2,368 Home: 2,076 AFH: 292 V2G: 55

Figure 2-62: Seq_6.9.2.1 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC and many more are waiting to depart cf. 6.9.2
- (Arrive/Depart) there are few undercharged departs; AFH charging is rare.

V4-2.83.2 Seq_6.9.2.1: 27mpd 100EVs



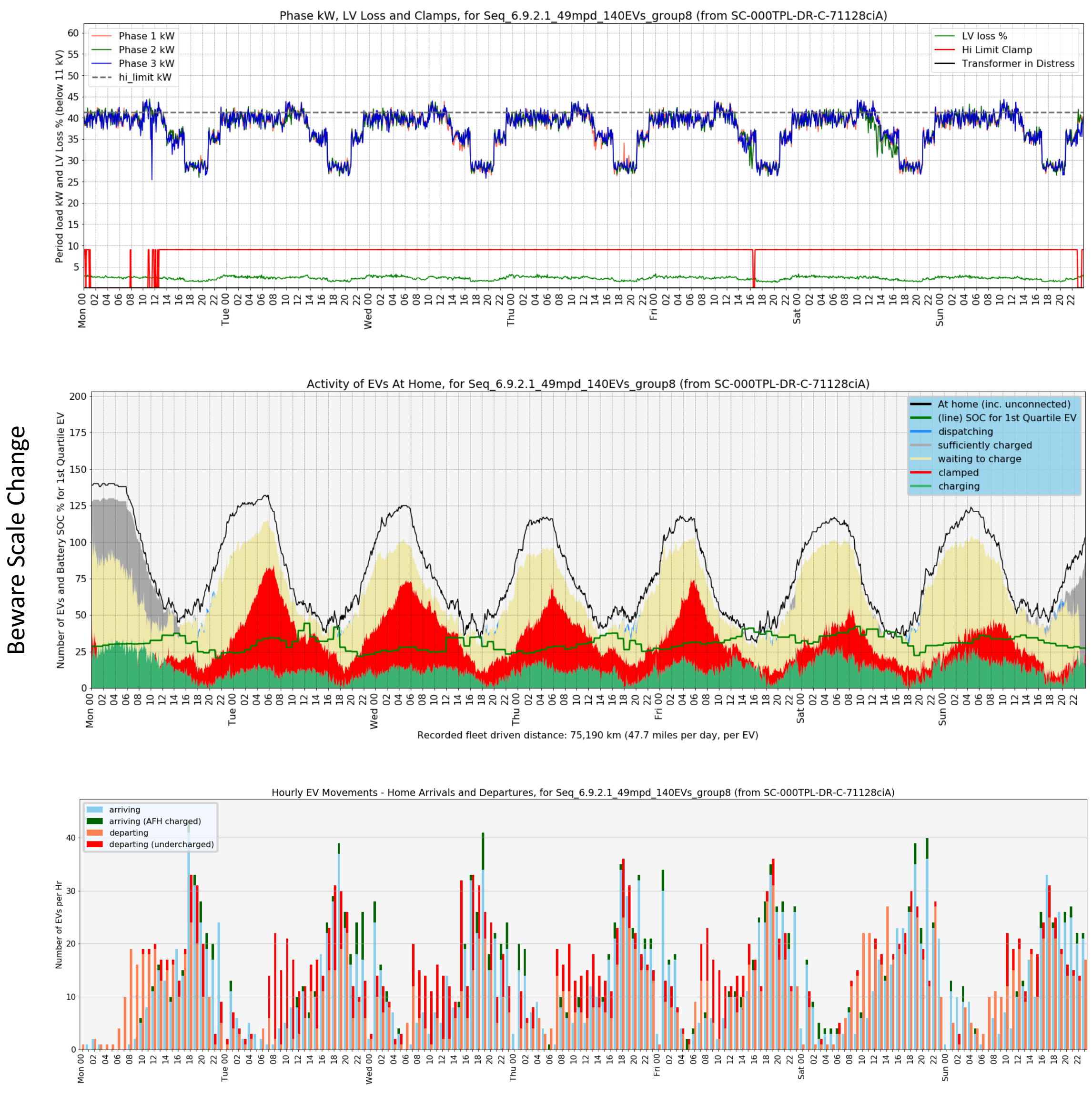
EoW stats: kWh[b] EV total: 5,985 Home: 5,155 AFH: 830 V2G: 71

Figure 2-63: Seq_6.9.2.1 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps but is unremarkable
- (CICD) SOC is similar with significant numbers of EVs ready to depart; some V2G
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.83.3 Seq_6.9.2.1: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,533 Home: 7,384 AFH: 6,148 V2G: 82

Figure 2-64: Seq_6.9.2.1 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal well
- (CICD) clamping is high but range anxiety is down vs. 6.9.2 (as more people don't bother plugging-in on arriving home). Few EVs are ready to depart
- undercharging and AFH charging have to perhaps worrying levels.

V4-2.84 Data Tables Seq_6.9.2.1

Table 2-157: 6.9.2.1 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12,354	11,727	10,487	9,230	7,945	6,652	5,371	4,067
	27mpd	12,239	11,470	9,972	8,435	6,924	5,409	3,896	2,680
	38mpd	12,142	11,276	9,520	7,728	6,009	4,323	2,945	2,425
	49mpd	12,060	11,110	9,165	7,223	5,420	3,753	2,660	2,416

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

Note the reduced hi_limit has lowered values by c. 4,700 kWh. The span here would be: [10,109] => [7,116] which implies that the DR/FFR signal is "limiting by less" of upper load ranges.

Table 2-158: 6.9.2.1 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.1	3.2	3.1	3.2	3.5	3.4	3.5
	27mpd	6.3	7.4	7.3	7.6	8.2	8.3	8.3	9.1
	38mpd	16.5	16.6	17.2	17.8	17.9	18.8	19.9	25.3
	49mpd	34.4	31.9	30.8	30.8	30.9	32.3	36.6	43.9

6.2.2 span: [8.0] => [34.2] and 6.3.2: [8.7] => [39.2]

AFH charging is slightly up.

Table 2-159: 6.9.2.1 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	0.11	0.13	0.13	0.13	0.14	0.15	0.15	0.15
	27mpd	0.28	0.29	0.28	0.29	0.31	0.31	0.32	0.36
	38mpd	0.58	0.57	0.58	0.59	0.60	0.63	0.68	0.90
	49mpd	1.08	0.96	0.92	0.92	0.94	0.99	1.15	1.43

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

Drivers are connecting more often.

Table 2-160: ***6.9.2.1 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.2
	27mpd	1.2	1.3	1.4	1.4	1.5	1.6	1.7	3.0
	38mpd	1.8	1.9	2.1	2.1	2.3	2.6	3.7	7.1
	49mpd	2.6	2.6	2.7	2.8	3.0	4.0	6.1	9.0

6.2.2: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

With demand low hence proportionately plentiful power, EVs can charge to their fill hence the incidence of undercharging drops.

Table 2-161: ***6.9.2.1 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0028	0.0020	0.0015	0.0011	0.0012	0.0016	0.0012	0.0012
	27mpd	0.0002	0.0007	0.0017	0.0026	0.0024	0.0030	0.0038	0.0337
	38mpd	0.0032	0.0038	0.0065	0.0067	0.0068	0.0156	0.0721	0.2849
	49mpd	0.0072	0.0051	0.0086	0.0085	0.0161	0.0759	0.2354	0.5102

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175] (limit: < 0.007)

As might be expected there is a reduction vs. 6.9.2, the plys in grey now being acceptable but not on 6.9.2.

Table 2-162: ***6.9.2.1 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	97	144	250	335	435	567	701	1,020
	27mpd	104	165	290	407	574	872	1,360	2,702
	38mpd	120	191	349	526	872	1,673	2,752	3,971
	49mpd	128	212	399	653	1,241	2,296	3,375	4,296

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 420)

Table 2-163: ***6.9.2.1 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7.3	4.6	3.3	2.5	2.4	2.1	1.8	1.7
	27mpd	6.7	4.4	3.2	2.5	2.4	2.2	1.9	1.7
	38mpd	6.6	4.2	3.2	2.6	2.4	2.2	1.9	1.7
	49mpd	6.4	4.2	3.3	2.6	2.5	2.3	1.9	1.6

6.2.2: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

The V2G EVs still do little.

Table 2-164: ***6.9.2.1 DRFFR Percent Effective Hours (weekly averages)***

9. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.7%	33.9%	41.7%	50.6%	63.7%	72.0%	81.5%	88.1%
	27mpd	32.1%	36.3%	42.9%	58.3%	69.6%	79.8%	88.1%	97.6%
	38mpd	32.1%	36.3%	47.6%	64.9%	76.8%	88.1%	95.8%	100.0%
	49mpd	31.0%	36.9%	48.8%	67.3%	79.2%	91.7%	97.6%	100.0%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

Hi_limit modulation is improved.

Table 2-165: ***6.9.2.1 Average LV Losses Comparison***

Seq_6.2.2	8. A	N EV	10	20	40	60	80	100	120	140
		19mpd	96.6	112.9	138.5	178.7	230.6	292.8	357.9	420.6
		27mpd	97.8	116.0	150.2	200.8	261.8	335.9	420.7	502.2
		38mpd	98.9	118.3	162.3	221.9	294.2	389.0	486.5	570.4
		49mpd	99.8	120.3	167.8	236.2	317.4	418.7	518.7	591.4
Seq_6.9.2.1	B	N EV	10	20	40	60	80	100	120	140
		19mpd	96.5	112.5	138.4	175.6	222.6	275.1	330.9	381.5
		27mpd	97.8	115.9	145.1	191.9	247.2	313.8	379.1	427.3
		38mpd	98.9	118.3	156.5	213.4	273.4	352.3	416.8	444.4
		49mpd	99.8	120.2	166.1	222.5	290.9	364.9	424.8	445.4
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	0.0	-0.4	-0.1	-3.0	-8.0	-17.7	-27.0	-39.0
		27mpd	0.0	0.0	-5.1	-8.9	-14.7	-22.1	-41.6	-74.9
		38mpd	0.0	0.0	-5.8	-8.5	-20.8	-36.7	-69.7	-125.9
		49mpd	0.0	-0.1	-1.8	-13.7	-26.5	-53.8	-93.9	-146.0

Average LV Losses kWh: Seq_6.9.2.1 (B) vs. Baseline 6.2.2 (A)

This is a loss reduction of 100 % * (22 / 336) = 6.5 %, at £385 k per 1% reduction yielding c. £2.5 m over a Winter period.

V4-2.85 Seq_6.9.2.1 Results Summary

20 plies are not usable due to clamps. Lowering dumb EV counts reduced clamps. The minimal V2G use misuses their capability as Pre-burn was OFF; ON is needed to improve undercharging and clamps (but will degrade losses as more V2G use implies more round-trip losses, V2G being c. 60-70% efficient).

V4-2.86 Sequence 6.9.2.2

Sequence	**Simulation ID**	**Description**
Seq_6.9.2.2	(S_AT)	Variation vs. Seq_6.2.2 and Seq_6.9.2.1: As 6.9.2.1 but with Pre-burn V2G ON
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

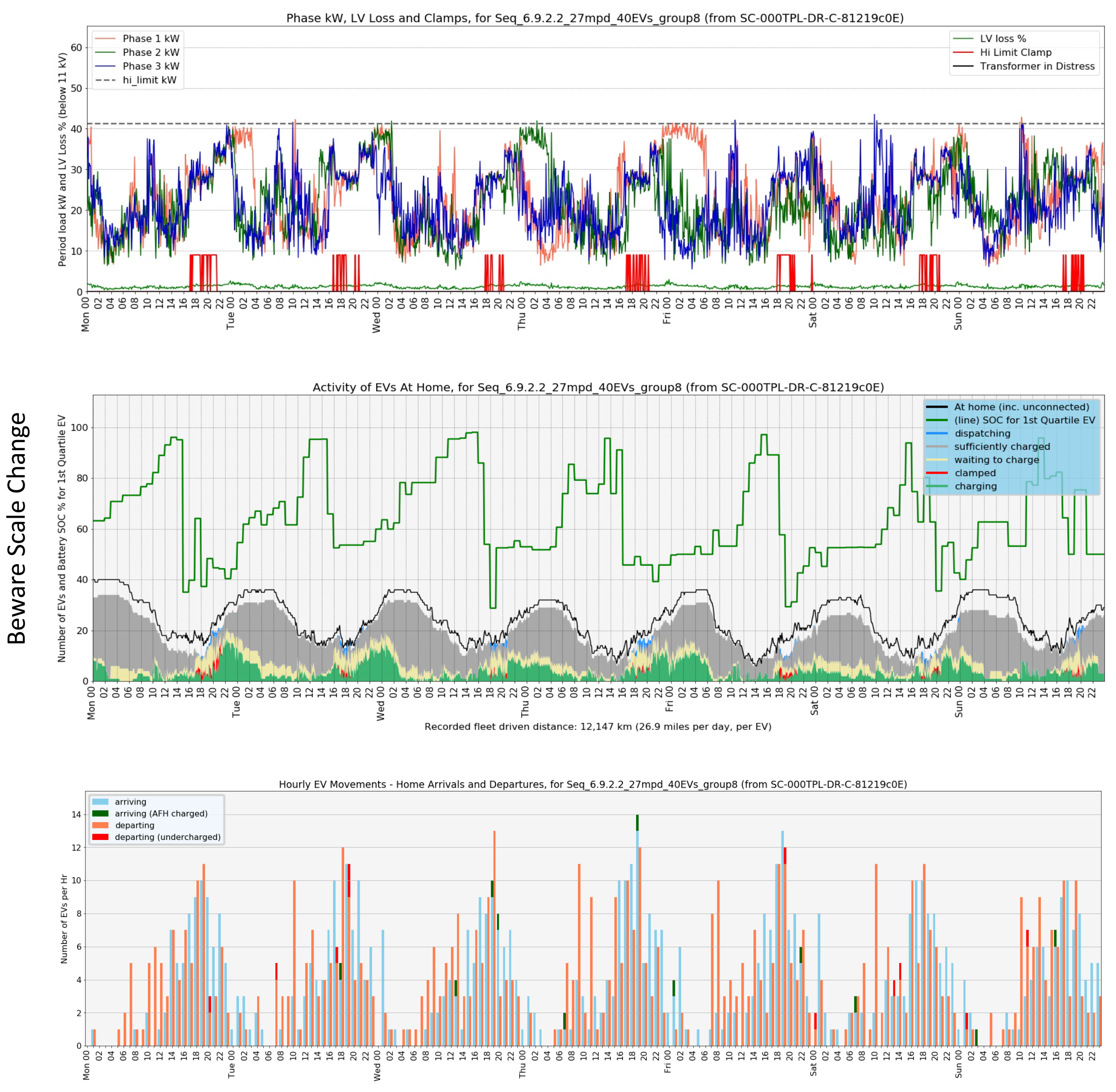
This is Seq_6.9.2 with the correct EV mix. Here, Pre-burn V2G is turned ON meaning V2G is factored in before clamps. Pre-burn is likely to assist the lower load ranges i.e. reduce severe undercharging and clamp counts, but is unlikely to assist with higher load ranges as V2G related losses contribute to V2G EVs experiencing lower spare SOC. Data is from MetaMeta spreadsheets for Seq_6.9.2.2.

V4-2.86.1 Seq_6.9.2.2 Outcomes

Pre-burn V2G does improve undercharging and clamping, gaining 7 plies vs. 6.9.2.1.

V4-2.87 Seq_6.9.2.2 Feeder and EV Plots

V4-2.87.1 Seq_6.9.2.2: 27mpd 40EVs



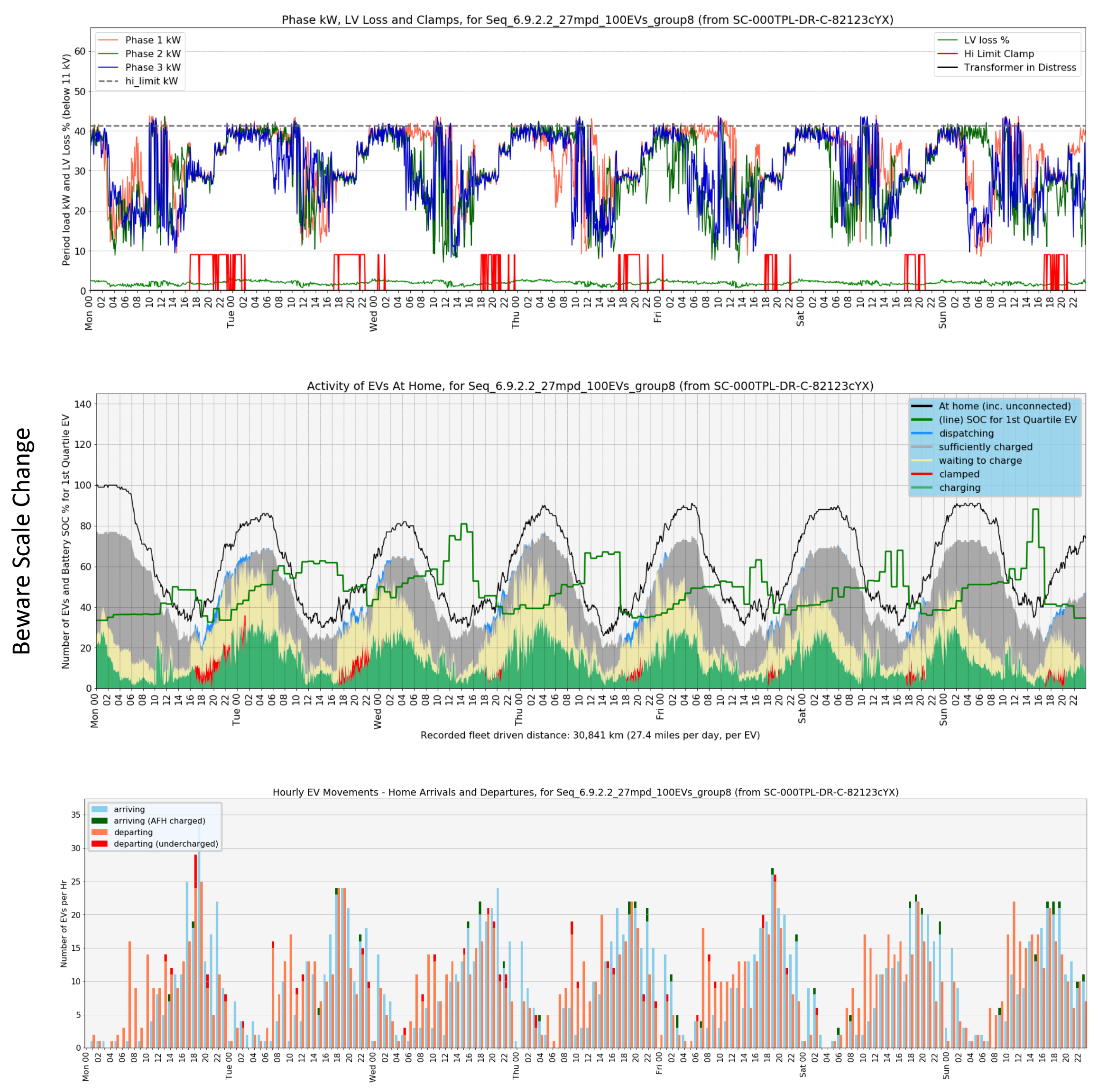
EoW stats: kWh[b] EV total: 2,387 Home: 2,099 AFH: 288 V2G: 74

Figure 2-65: Seq_6.9.2.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC; some V2G pre-burn supporting occasional clamps
- (Arrive/Depart) few undercharged departs with occasional AFH charging.

V4-2.87.2 Seq_6.9.2.2: 27mpd 100EVs



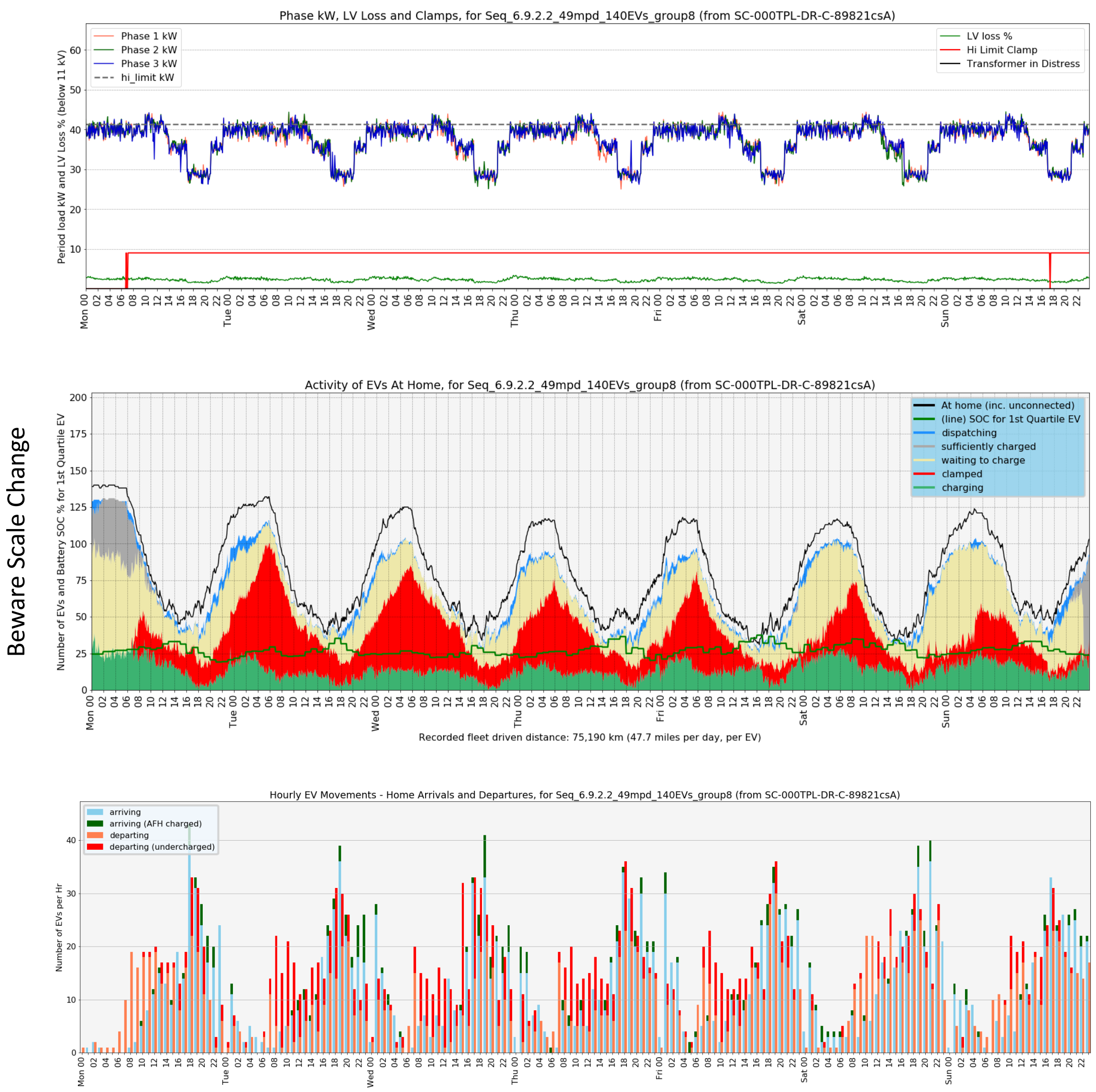
EoW stats: kWh[b] EV total: 6,273 Home: 5,460 AFH: 814 V2G: 362

Figure 2-66: Seq_6.9.2.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps but is unremarkable
- (CICD) SOC is similar with many EVs ready to depart; some V2G and clamping
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.87.3 Seq_6.9.2.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,683 Home: 8,275 AFH: 6,409 V2G: 1,293

Figure 2-67: Seq_6.9.2.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal well; the network is saturated
- (CICD) V2G pre-burn and clamps operate; very few EVs are ready to depart
- undercharging and AFH charging are high.

V4-2.88 Data Tables Seq_6.9.2.2

Table 2-166: 6.9.2.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12,353	11,724	10,477	9,205	7,891	6,553	5,182	3,743
	27mpd	12,239	11,468	9,954	8,391	6,833	5,219	3,528	2,455
	38mpd	12,141	11,271	9,495	7,662	5,860	4,019	2,674	2,381
	49mpd	12,058	11,102	9,129	7,128	5,220	3,474	2,515	2,394

6.2.2 span: [10,098] => [4,763] and 6.9.2.1: [10,109] => [7,116]

Note the reduced hi_limit has lowered values by c. 4,700 kWh. The adjusted span here would be: [9,919] => [7,094] which implies better utilisation at low loads and worse utilisation for high load ranges vs. 6.2.2.

Table 2-167: 6.9.2.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.5	3.0	3.1	3.0	3.2	3.5	3.3	3.4
	27mpd	6.3	7.3	7.2	7.5	8.0	8.1	8.1	10.0
	38mpd	16.5	16.6	17.0	17.6	17.7	18.5	20.6	27.1
	49mpd	34.3	31.8	30.6	30.4	30.5	32.3	37.8	45.8

6.2.2 span: [8.0] => [34.2] and 6.9.2.1: [8.3] => [43.9]

AFH is down vs. 6.9.2.1 for the parity case, but higher with higher load ranges.

Table 2-168: 6.9.2.2 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	0.11	0.13	0.13	0.13	0.13	0.14	0.14	0.14
	27mpd	0.28	0.29	0.27	0.28	0.31	0.31	0.31	0.40
	38mpd	0.58	0.57	0.57	0.58	0.59	0.62	0.70	0.98
	49mpd	1.08	0.96	0.91	0.90	0.92	0.98	1.20	1.51

6.2.2 span: [0.3] => [1.05] and 6.9.2.1: [0.31] => [1.43]

The need to connect for AFH charging has risen for high load situations.

Table 2-169: 6.9.2.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.8	0.9	1.0	1.0	1.1
	27mpd	1.2	1.3	1.3	1.4	1.4	1.5	1.7	4.1
	38mpd	1.8	1.9	2.0	2.0	2.1	2.5	4.4	8.1
	49mpd	2.6	2.5	2.6	2.6	2.8	4.1	6.7	9.6

6.2.2: [1.4] => [5.0] and 6.9.2.1: [1.6] => [9.0]

Undercharging for the parity case is down but up for the higher load plys.

Table 2-170: 6.9.2.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0020	0.0013	0.0010	0.0008	0.0005	0.0007	0.0006	0.0006
	27mpd	0.0002	0.0006	0.0013	0.0015	0.0016	0.0018	0.0039	0.0804
	38mpd	0.0032	0.0035	0.0048	0.0052	0.0047	0.0165	0.1147	0.3609
	49mpd	0.0066	0.0041	0.0067	0.0065	0.0128	0.0893	0.3038	0.5865

6.2.2 span: [0.0015] => [0.1631] and 6.9.2.1: [0.0030] => [0.5102] (limit: < 0.007)

This sequence wins 3 green plies over 6.9.2.1

Table 2-171: 6.9.2.2 MCS Clamps (weekly averages)

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	83	108	154	190	233	269	223	544
	27mpd	89	126	189	241	318	480	1,037	3,077
	38mpd	106	150	234	324	552	1,423	2,856	4,136
	49mpd	114	170	276	428	952	2,199	3,500	4,415

6.2.2 span: [366] => [2,985] and 6.9.2: [1,780] => [4,440] (limit: < 420)

With only 13 plies lost, 6.9.2.2 wins 5 green cells over 6.9.2.1.

Table 2-172: 6.9.2.2 V2G kWh dispatch per EV (weekly averages)

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7.4	4.9	4.1	3.9	4.9	6.3	8.0	13.6
	27mpd	6.9	4.8	4.3	4.8	6.8	11.0	18.8	26.8
	38mpd	6.7	4.8	4.9	6.2	10.7	20.2	27.0	26.7
	49mpd	6.7	4.8	5.5	7.7	14.6	22.9	26.8	25.9

6.2.2: [7.9] => [27.0] and 6.9.2.1: [2.2] => [1.6]

V2G use equates to 1 days driving use for the parity case, and c. 2.5 days use for the extreme case. If this occurs for 10 weeks of the year, over 10 years, V2G EVs potentially lose c. 250 days life from the battery. This will need some form of compensation.

Table 2-173: ***6.9.2.2 Average LV Losses Comparison***

Seq_6.2.2	8. A	N EV	10	20	40	60	80	100	120	140
		19mpd	96.6	112.9	138.5	178.7	230.6	292.8	357.9	420.6
		27mpd	97.8	116.0	150.2	200.8	261.8	335.9	420.7	502.2
		38mpd	98.9	118.3	162.3	221.9	294.2	389.0	486.5	570.4
		49mpd	99.8	120.3	167.8	236.2	317.4	418.7	518.7	591.4
Seq_6.9.2.2	**B**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	96.5	112.5	138.5	176.5	223.5	277.0	336.2	395.0
		27mpd	97.8	115.9	145.3	193.1	251.6	318.2	391.5	441.5
		38mpd	98.9	118.3	157.8	214.9	279.7	360.0	424.5	450.0
		49mpd	99.8	120.3	167.1	224.0	299.7	372.9	428.9	448.9
Difference B - A	**C**	**N EV**	**10**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
		19mpd	0.0	-0.4	0.0	-2.2	-7.1	-15.8	-21.7	-25.5
		27mpd	0.0	0.0	-4.9	-7.7	-10.2	-17.7	-29.2	-60.7
		38mpd	0.0	0.0	-4.5	-7.0	-14.4	-29.0	-62.0	-120.4
		49mpd	0.0	0.0	-0.8	-12.1	-17.7	-45.8	-89.8	-142.5

Average LV Losses kWh: Seq_6.9.2.2 (B) vs. Baseline 6.2.2 (A)

This is a loss reduction of 100 % * (17.7 / 336) = 5.3 %, at £385 k per 1% notionally yielding c. £2 m over a Winter period, for the parity case which however needs lowered clamp rates.

Table 2-174: ***6.9.2.2 DRFFR Percent Effective Hours (weekly averages)***

9. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	34.5%	35.7%	36.9%	41.1%	46.4%	55.4%	65.5%	74.4%
	27mpd	33.3%	35.7%	39.9%	45.2%	52.4%	64.3%	73.8%	83.3%
	38mpd	32.7%	36.9%	41.1%	47.6%	59.5%	72.6%	82.7%	91.7%
	49mpd	34.5%	35.7%	43.5%	48.2%	60.1%	78.0%	88.1%	96.4%

6.2.2 span: [73.8%] => [98.2%] and 6.9.2.1 span: [79.8%] => [100%]

The response is adequate.

V4-2.89 Seq_6.9.2.2 Results Summary

Pre-burn certainly assists. From all these, it is clear that hi_limit reduction can provide savings, however the exact reduction needs be tempered with other controls so to not raise issues elsewhere i.e. an increase in severe undercharging or excess clamps.

V4-2.90 Sequence 6.10.2

Sequence	Simulation ID	Description
Seq_6.10.2	(S_AJ)	Variation vs. Seq_6.2.2 and Seq_6.9.2.1: As 6.9.2.1 but SV1G EVs replace all V2G. hi_limit is 40 kW.
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

V2G EVs are replaced by SV1G. The author expects this to be very similar to 6.9.2.1, which possessed V2G EVs but with Pre-burn OFF. However, for V2G EVs to be able to offer any power, they need build an excess of SOC. The SV1G EVs do not do that; total demand should notionally be reduced.

DR/FFR “C” hi_limit modulation is used.

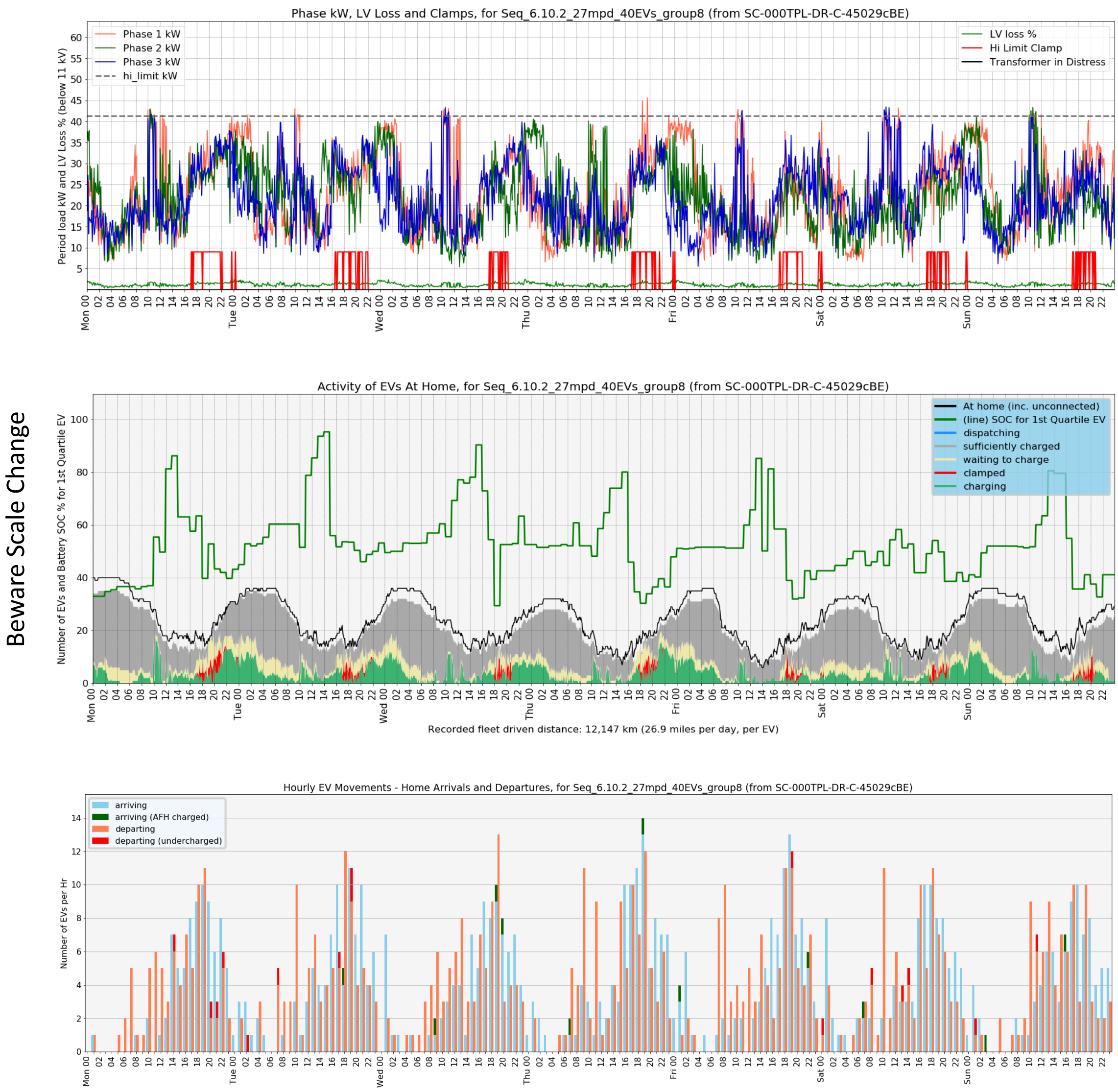
A note on numbering: 6.10.2 might be thought a natural 6.9.2.3, however 6.9.2.1 and 6.9.2.2 were not initially planned. 6.9.2 was to be V2G and to lead on to 6.10.2

V4-2.90.1 Seq_6.10.2 Outcomes

SV1G was not as successful as anticipated, with rises of severe undercharging.

V4-2.91 Seq_6.10.2 Feeder and EV Plots

V4-2.91.1 Seq_6.10.2: 27mpd 40EVs



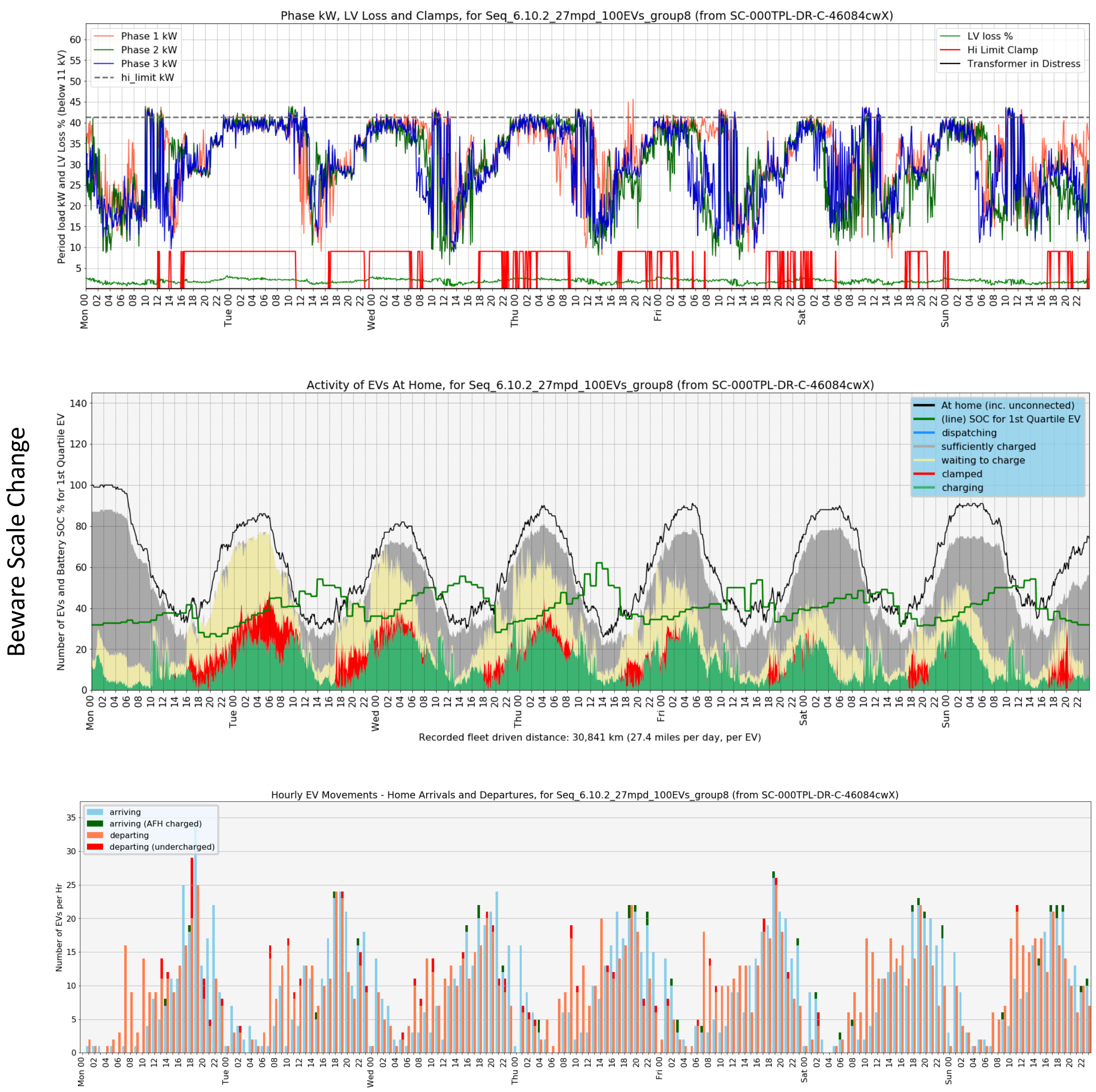
EoW stats: kWh[b] EV total: 2,332 Home: 2,032 AFH: 300 V2G: 0

Figure 2-68: Seq_6.10.2 27mpd 40EVs group 8 plots. Weekly km: 12,212

Notes re above plots:

- the Feeder plot is unremarkable
- (CICD) EVs have good SOC; many ready for departure
- (Arrive/Depart) there are few undercharged departs; AFH charging is occasional.

V4-2.91.2 Seq_6.10.2: 27mpd 100EVs



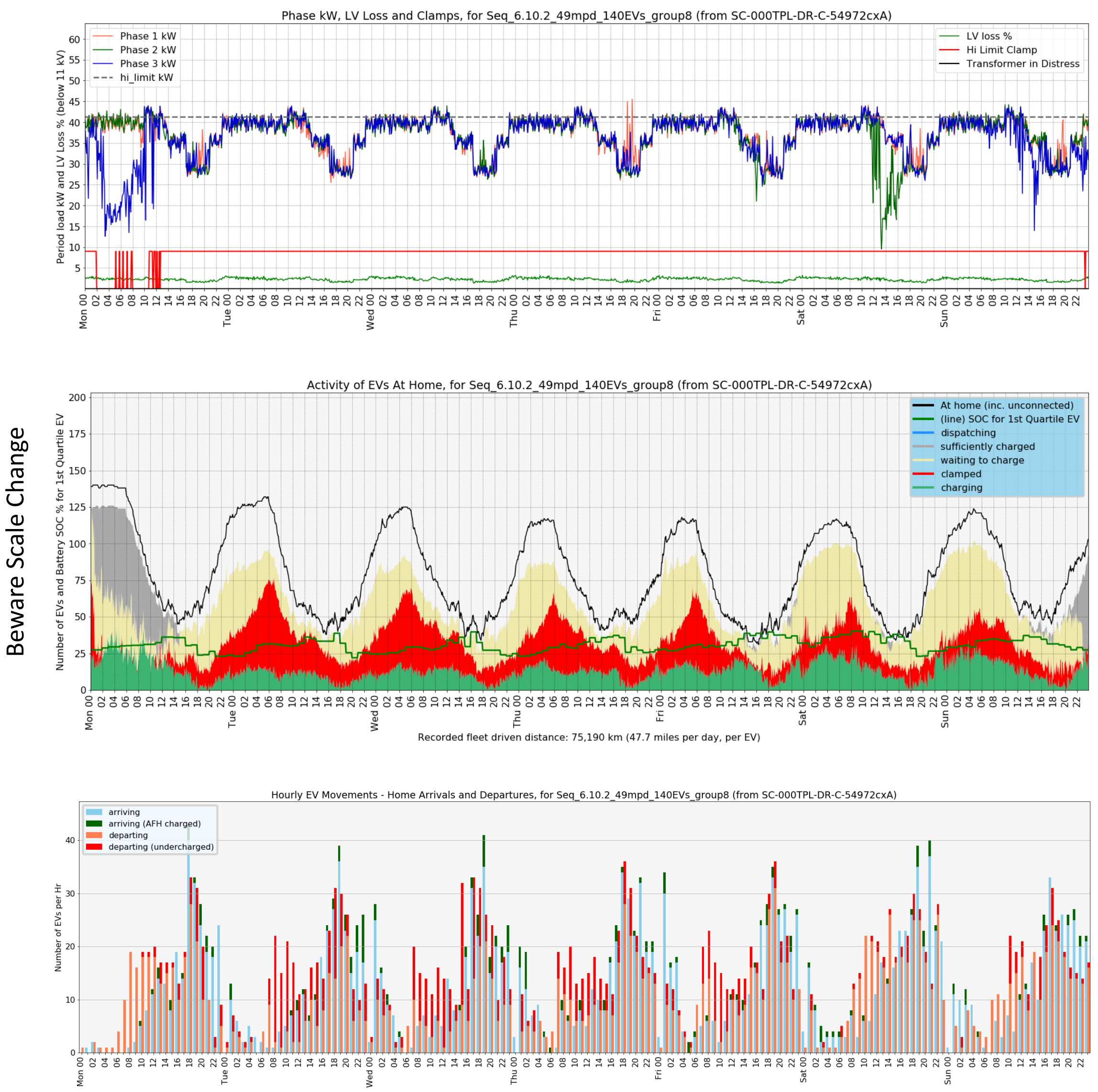
EoW stats: kWh[b] EV total: 5,918 Home: 5,058 AFH: 860 V2G: 0

Figure 2-69: Seq_6.10.2 27mpd 100EVs group 8 plots. Weekly km: 30,876

Notes re above plots:

- the Feeder plot shows clamps but is unremarkable
- (CICD) SOC is similar with significant numbers of EVs ready to depart
- (Arrive/Depart) has more undercharged departs; AFH charging has increased. However both are low.

V4-2.91.3 Seq_6.10.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 13,44,8 Home: 7,260 AFH: 6,188 V2G: 0

Figure 2-70: Seq_6.10.2 49mpd 140EVs group 8 plots. Fleet drives 77,327 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal well but clamping is continuous
- (CICD) Few EVs are ready to depart, although the not plugged-in gap means that range anxiety is low
- undercharging and AFH charging is frequent.

V4-2.92 Data Tables Seq_6.10.2

Table 2-175: 6.10.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	12,378	11,755	10,512	9,224	7,902	6,566	5,266	4,022
	27mpd	12,262	11,499	9,992	8,433	6,897	5,401	4,025	2,955
	38mpd	12,168	11,308	9,557	7,748	6,054	4,493	3,339	2,632
	49mpd	12,083	11,145	9,205	7,270	5,540	4,053	3,092	2,551

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

The hi_limit lowering is 4,700 kWh. The corrected span is: 6.10.2: [10,101] => [7,251]

Table 2-176: 6.10.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.6	3.2	3.3	3.2	3.4	3.7	3.6	3.7
	27mpd	6.5	7.6	7.5	7.9	8.4	8.6	8.8	9.9
	38mpd	17.1	17.1	17.6	18.3	18.4	19.6	21.6	25.9
	49mpd	34.9	32.6	31.4	31.5	31.8	34.1	38.7	44.2

6.2.2 span: [8.0] => [34.2] and 6.3.2 span: [8.7] => [39.2]

A modest increase in AFH is seen.

Table 2-177: 6.10.2 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	0.12	0.14	0.13	0.13	0.14	0.15	0.15	0.16
	27mpd	0.29	0.30	0.28	0.30	0.32	0.33	0.34	0.39
	38mpd	0.61	0.60	0.60	0.61	0.62	0.67	0.76	0.94
	49mpd	1.11	0.99	0.95	0.95	0.98	1.07	1.24	1.45

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

The need for AFH connections has risen.

Table 2-178: ***6.10.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.6
	27mpd	1.6	1.6	1.7	1.7	1.8	2.0	2.4	4.0
	38mpd	2.2	2.2	2.4	2.5	2.6	3.3	4.9	7.4
	49mpd	2.9	2.9	3.0	3.1	3.4	4.9	6.8	9.0

6.2.2: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

Undercharging is up for the parity case.

Table 2-179: ***6.10.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0004	0.0008	0.0008	0.0008	0.0010	0.0010	0.0014
	27mpd	0.0004	0.0009	0.0021	0.0029	0.0032	0.0042	0.0116	0.0600
	38mpd	0.0036	0.0038	0.0071	0.0070	0.0087	0.0330	0.1253	0.2987
	49mpd	0.0076	0.0055	0.0089	0.0100	0.0256	0.1273	0.2920	0.5104

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175] (limit: < 0.007)

Severe undercharging has risen, with another 11 plys unacceptable vs. 6.2.2, and 3 more unacceptable vs. 6.9.2.1.

Table 2-180: ***6.10.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	164	208	291	383	515	745	1,098	1,769
	27mpd	166	227	341	493	781	1,357	2,244	3,396
	38mpd	179	253	415	690	1,292	2,263	3,263	4,131
	49mpd	190	276	475	910	1,712	2,746	3,643	4,384

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 420)

These values have risen, with 5 extra plies not being unacceptable.

Table 2-181: ***6.10.2 Average LV Losses Comparison***

Seq_6.2.2	7. A	N EV	10	20	40	60	80	100	120	140
		19mpd	96.6	112.9	138.5	178.7	230.6	292.8	357.9	420.6
		27mpd	97.8	116.0	150.2	200.8	261.8	335.9	420.7	502.2
		38mpd	98.9	118.3	162.3	221.9	294.2	389.0	486.5	570.4
		49mpd	99.8	120.3	167.8	236.2	317.4	418.7	518.7	591.4
Seq_6.10.2	B	N EV	10	20	40	60	80	100	120	140
		19mpd	96.3	112.5	138.0	175.7	223.3	276.7	333.1	378.4
		27mpd	97.5	115.6	144.8	191.0	247.1	312.7	375.6	418.8
		38mpd	98.6	117.9	156.0	212.5	272.0	346.1	400.6	437.3
		49mpd	99.5	119.8	166.0	221.8	287.5	358.6	411.3	439.2
Difference B - A	C	N EV	10	20	40	60	80	100	120	140
		19mpd	-0.3	-0.4	-0.4	-2.9	-7.3	-16.1	-24.8	-42.1
		27mpd	-0.3	-0.4	-5.4	-9.8	-14.7	-23.2	-45.1	-83.4
		38mpd	-0.3	-0.4	-6.3	-9.4	-22.2	-42.9	-85.8	-133.1
		49mpd	-0.3	-0.5	-1.9	-14.4	-30.0	-60.1	-107.4	-152.2

Average LV Losses kWh: Seq_6.10.2 (B) vs. Baseline 6.2.2 (A)

This is a loss reduction of 100 % * (23.2 / 336) = 6.9 %, worth at £385 k per 1% reduction c. £2.6 m over a Winter period; however the clamps are unacceptable.

Table 2-182: ***6.10.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	32.1%	36.3%	41.1%	48.2%	58.9%	69.0%	73.8%	81.5%
	27mpd	33.9%	38.7%	44.0%	55.4%	67.3%	74.4%	83.9%	92.3%
	38mpd	33.3%	38.7%	48.2%	64.3%	71.4%	81.5%	89.3%	95.2%
	49mpd	32.7%	39.3%	50.0%	67.9%	75.6%	85.1%	91.7%	96.4%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

Hi_limit modulation shows effective DR/FFR response.

V4-2.93 Seq_6.10.2 Results Summary

For both severe undercharging and clamp counts, pure SV1G has a more limited range of ability to cope than V2G. V2G then does have a use for:

- opportunistically gathering “excess charge” when loads are otherwise low
  - also bringing-in charge from AFH sources
- locally dispatching in support of:
  - limiting clamp counts and
  - providing extra charge to vehicles otherwise severely undercharged.

The major questions though are:

- what of the V2G losses (an extra 30-50%): who pays for these, and
- who pays for battery degradation.

Ofgem may well take the stance:

- V2G is a source of extra dissipated kWh therefore should be counted as a loss
- V2G is technological alternative to reinforcement, therefore
  - DNOs must justify their financial choices in paying for V2G vs. the alternatives.

V2G alas fails in both these areas at this time:

- Seq 6.9.2.2 parity case had weekly network losses of 318 kWh vs. 6.2.2’s 336 kWh
- but V2G in 6.9.2.2 lost energy estimated as 109 kWh, so totalling 427 kWh loss
- V2G also costs money to operate (battery wear, costs to recharge)

- which in 2 years matches the costs of reinforcement, which has a 25 - 40 year life.

From the above V2G is a bad deal - at this time. The author knows of no scheme which would make V2G profitable; the UK markets have low values and the arrival of major controllable loads, such as EVs, means prices must significantly depress.

The UK DR/FFR market, now c. 400 MW allocated per month (see NGESO Balancing Market webpages) is matched by controlling 58,000 EVs, let alone the 10’s millions expected from c. 2040.

Given no profit at this time and strong expectations of a collapsing market, the author sees no route allowing the recovery of the costs of V2G losses, let alone anything else.

V4-2.94 Sequence 6.11.2

Sequence	Simulation ID	Description
Seq_6.11.2	(S_AY)	MCS with standard EV mix (19% dumb, 48% SV1G and 33% V2G), 9 Static Batteries and lowered hi_limit: 24 kW per phase. Pre-Burn V2G ON, DR-C with FFR
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, hi_limit 51.3 kW*	

Can large static batteries aid a further lowered hi_limit?

So to find the lower practical limit, a value at half the standard hi_limit is used.

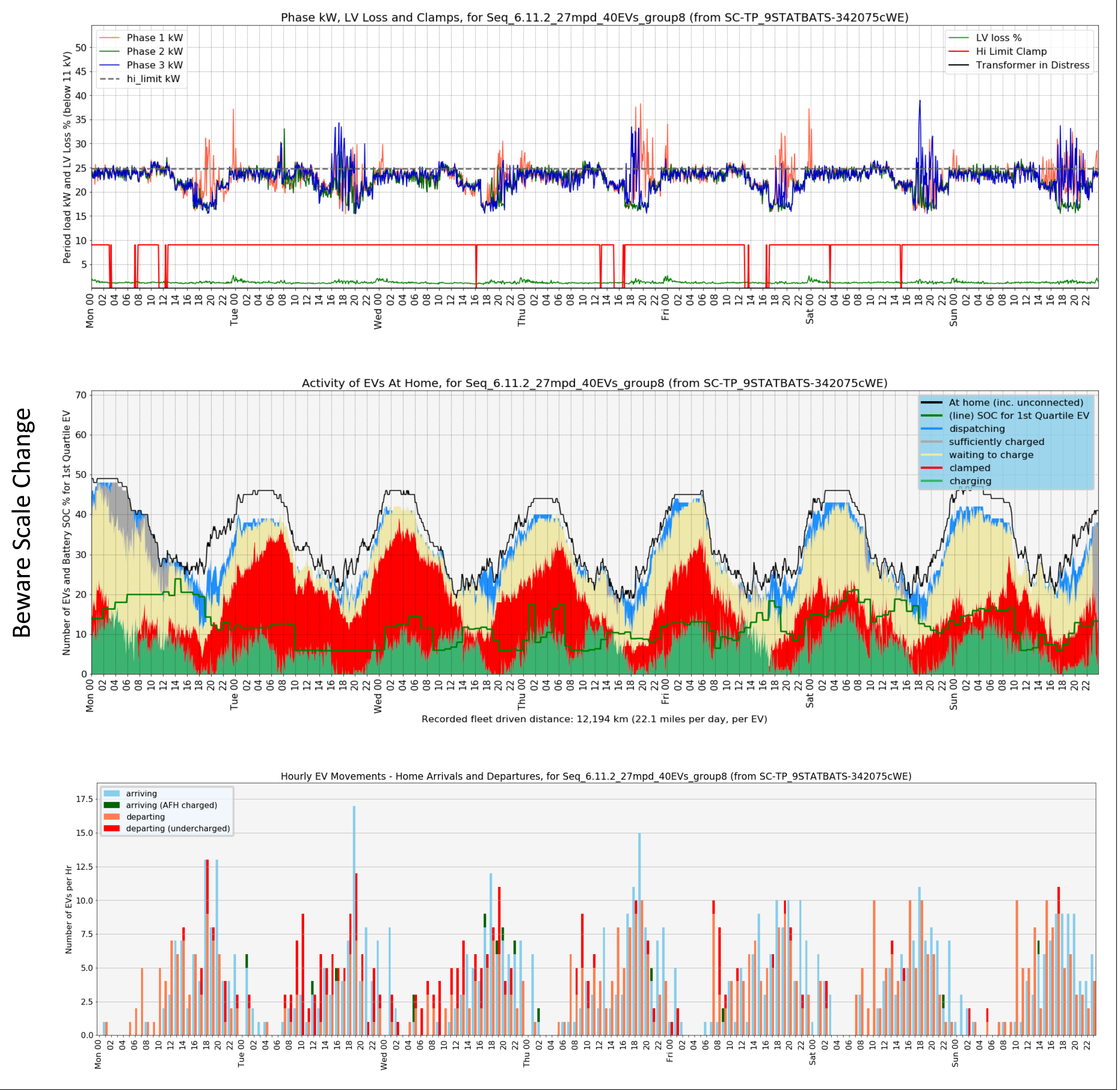
Note that this is a classic case for ex-EV battery “second life” use.

V4-2.94.1 Seq_6.11.2 Outcomes

The reduction of the hi_limit attempted is too severe.

V4-2.95 Seq_6.11.2 Feeder and EV Plots

V4-2.95.1 Seq_6.11.2: 27mpd 40EVs



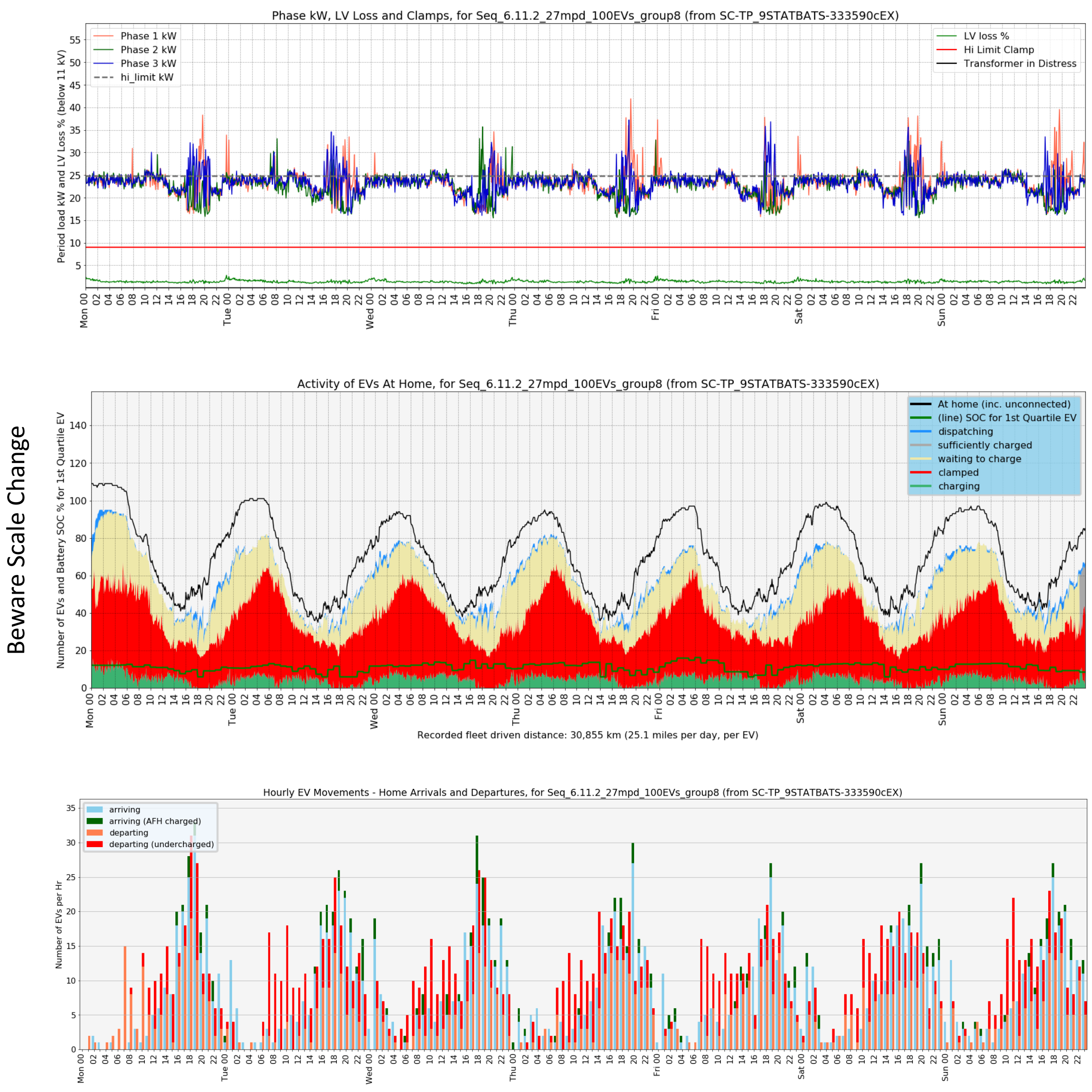
EoW stats: kWh[b]   EV total: 3,402   Home: 2,928   AFH: 474   V2G: 1,101

Figure 2-71: Seq_6.11.2 27mpd 40EVs group 8 plots. Weekly km: 12,227

The cited V2G kWh includes the output of the Static Batteries. Notes re above plots:

- the Feeder plot shows the residential load exceeding the control limit with long periods of clamping
- (CICD) EVs are severely clamped with much V2G pre-burn
- (Arrive/Depart) has occasional departing undercharged EVs. AFH charging is rare.

V4-2.95.2 Seq_6.11.2: 27mpd 100EVs



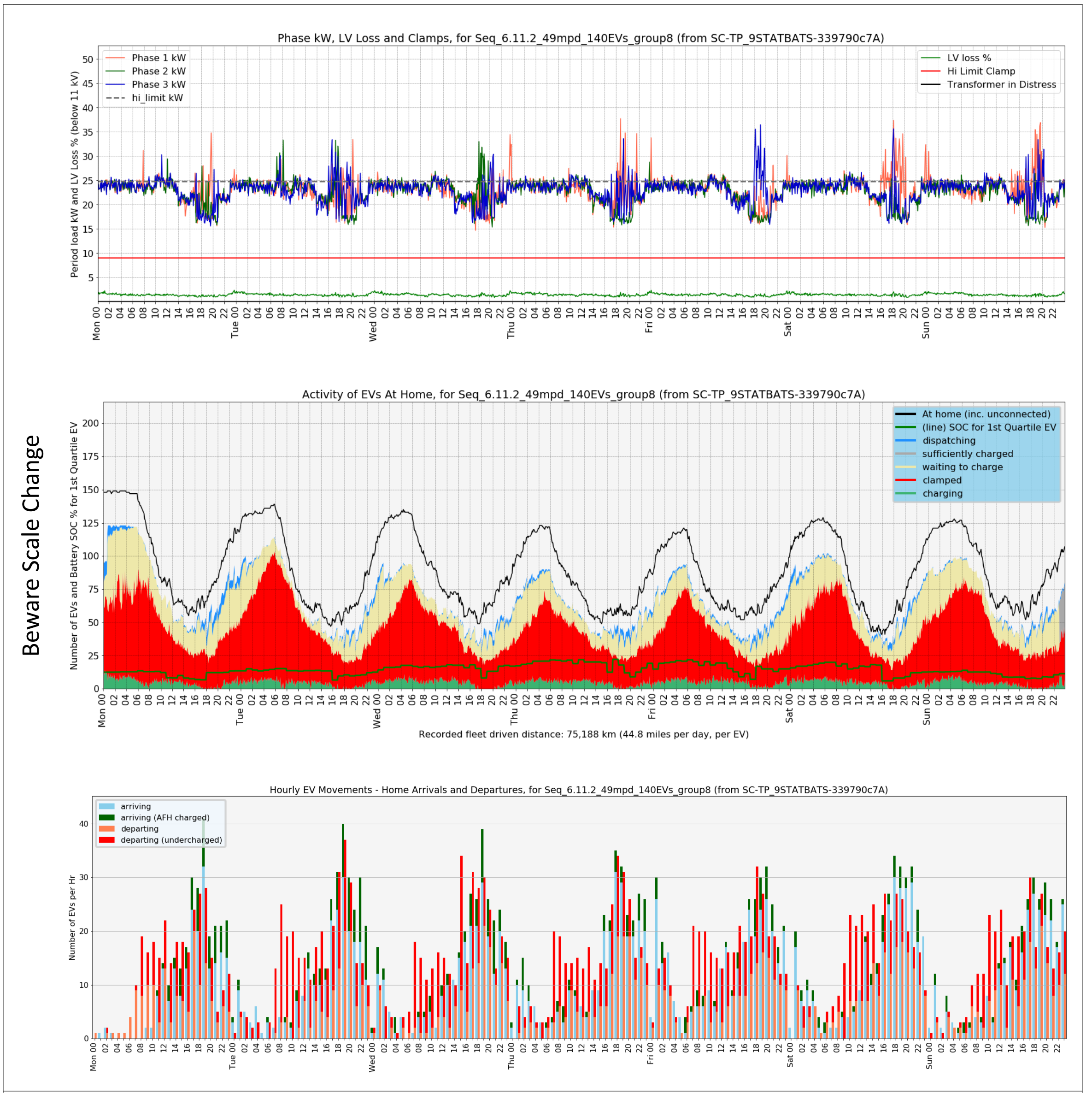
EoW stats: kWh[b] EV total: 6,481 Home: 2,694 AFH: 3,787 V2G: 717

Figure 2-72: Seq_6.11.2 27mpd 100EVs group 8 plots. Weekly km: 30,877

Notes re above plots:

- the Feeder plot shows continuous clamps
- (CICD) SOC is depressed with little charging, major periods of clamping and little V2G (EVs likely have insufficient SOC)
- (Arrive/Depart) has many undercharged departs; AFH charging is now common.

V4-2.95.3 Seq_6.11.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,394 Home: 2,725 AFH: 11,669 V2G: 1,012

Figure 2-73: Seq_6.11.2 49mpd 140EVs group 8 plots. Fleet drives 77,340 km

Notes re above plots:

- the Feeder plot shows continuous clamps
- (CICD) SOC is depressed with little charging, continuous clamping and limited V2G
- (Arrive/Depart) has many undercharged departs; AFH charging has further increased
- embarrassingly, far more charge is now taken AFH then at home.

V4-2.96 Data Tables: Seq_6.11.2

Table 2-183: 6.11.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	3,385	2,664	1,400	1,041	996	1,009	1,046	1,051
	27mpd	3,263	2,380	1,231	1,075	1,050	1,062	1,097	1,103
	38mpd	3,164	2,180	1,208	1,105	1,085	1,098	1,129	1,132
	49mpd	3,075	1,999	1,199	1,123	1,101	1,113	1,140	1,143

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

The lowered hi_limit has caused a notional drop of 12,600 kWh available charge.

This implies that the corrected 6.11.2 span is: [13,662] => [13,743]

Table 2-184: 6.11.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.7	3.3	4.4	9.4	17.3	23.6	28.1	31.2
	27mpd	6.8	8.0	11.8	22.8	31.8	37.8	42.3	45.2
	38mpd	17.5	18.2	27.3	41.7	50.1	57.1	61.1	64.3
	49mpd	35.6	34.3	46.0	60.7	68.9	75.5	80.2	83.3

6.2.2 span: [8.0] => [34.2] and 6.3.2 span: [8.7] => [39.2]

EVs seem to be gaining major amounts of charge AFH.

Table 2-185: 6.11.2 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	0.15	0.19	0.47	0.89	1.22	1.47	1.62
	27mpd	0.30	0.32	0.50	1.02	1.46	1.75	1.98	2.11
	38mpd	0.62	0.65	1.04	1.64	2.03	2.32	2.52	2.64
	49mpd	1.13	1.08	1.55	2.13	2.48	2.75	2.94	3.05

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

The AFH counts do not look too onerous.

Table 2-186: ***6.11.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	1.0	1.1	2.5	7.6	10.7	11.7	12.0	12.0
	27mpd	1.7	1.9	5.0	10.0	11.7	12.1	12.4	12.4
	38mpd	2.4	2.7	7.4	11.2	12.3	12.7	12.9	12.9
	49mpd	3.3	3.6	8.6	11.9	12.7	13.1	13.3	13.3

6.2.2: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

Undercharging is certainly up.

Table 2-187: ***6.11.2 Counts of Severely Undercharged EVs in Week, per EV***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0116	0.0069	0.0187	0.1778	0.3940	0.5614	0.6852	0.7608
	27mpd	0.0090	0.0093	0.1004	0.4233	0.6668	0.8249	0.9454	1.0154
	38mpd	0.0284	0.0204	0.2674	0.7000	0.9244	1.0773	1.1936	1.2612
	49mpd	0.0406	0.0372	0.4563	0.9097	1.1187	1.2722	1.3783	1.4470

6.2.2 span: [0.0015] => [0.1631] and 6.11.2: [0.0209] => [0.3175] (limit: < 0.007)

Severe undercharging is now endemic and unacceptable.

Table 2-188: ***6.11.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	302	425	1,787	4,434	4,945	5,022	5,040	5,042
	27mpd	335	544	2,946	4,675	4,972	5,031	5,040	5,042
	38mpd	384	700	3,451	4,776	5,005	5,036	5,041	5,042
	49mpd	409	818	3,769	4,844	5,007	5,036	5,042	5,042

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 420)

Clamps are unacceptable for all but the lightest load duties. The counts hit their notional peak, being 3 x 1,680 = 5,040. There is a "pre-simulation" period used for setup of -1 => 0; the author suspects clamps are triggered in this period too (this needs be amended).

Table 2-189: ***6.11.2 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	63.1	52.7	46.7	24.1	17.3	16.2	17.0	16.7
	27mpd	64.0	55.9	42.7	21.8	17.9	17.1	18.0	17.8
	38mpd	65.2	59.3	35.0	20.6	17.6	17.1	17.9	17.6
	49mpd	66.4	62.3	32.0	19.6	17.1	16.6	17.5	17.1

6.2.2: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

The V2G dispatch is disappointingly low. As EVs face increasing competition the V2G EVs have insufficient charge for their own trips, let alone any spare to give away.

Table 2-190: ***6.11.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	64.3%	75.6%	92.3%	84.5%	84.5%	86.3%	86.9%	88.7%
	27mpd	65.5%	79.2%	90.5%	85.1%	85.7%	86.3%	88.1%	88.7%
	38mpd	66.1%	82.1%	88.7%	85.1%	86.3%	86.9%	88.7%	88.7%
	49mpd	67.9%	85.1%	86.9%	84.5%	85.1%	86.9%	88.7%	88.7%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

Table 2-191: ***6.11.2 LV Losses kWh (weekly averages)***

9. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	102.2	110.2	135.3	151.3	158.4	163.4	164.2	172.6
	27mpd	103.6	113.3	137.4	150.8	152.6	162.6	162.6	169.5
	38mpd	104.7	115.5	137.6	150.4	153.5	162.1	163.1	168.1
	49mpd	105.6	118.8	137.8	150.2	152.4	161.9	162.0	168.4

Losses are down; however this is not a meaningful exercise.

V4-2.97 Seq_6.11.2 Results Summary

Such a drastically lowered hi_limit is not viable (in this form) to charge EVs.

In retrospect, the Static Batteries need be given their own hi_limit and not be subject to clamps; the simulator is not readily adaptable to do this at this time.

V4-2.98 Sequence 6.12.2

Sequence	**Simulation ID**	**Description**
Seq_6.12.2	(S_AZ)	MCS with standard EV mix (19% dumb, 48% SV1G and 33% V2G), 9 Static Batteries and lowered hi_limit: 32 kW per phase. Pre-Burn V2G ON
Baseline Seq	***Description***	
Seq_6.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON*	

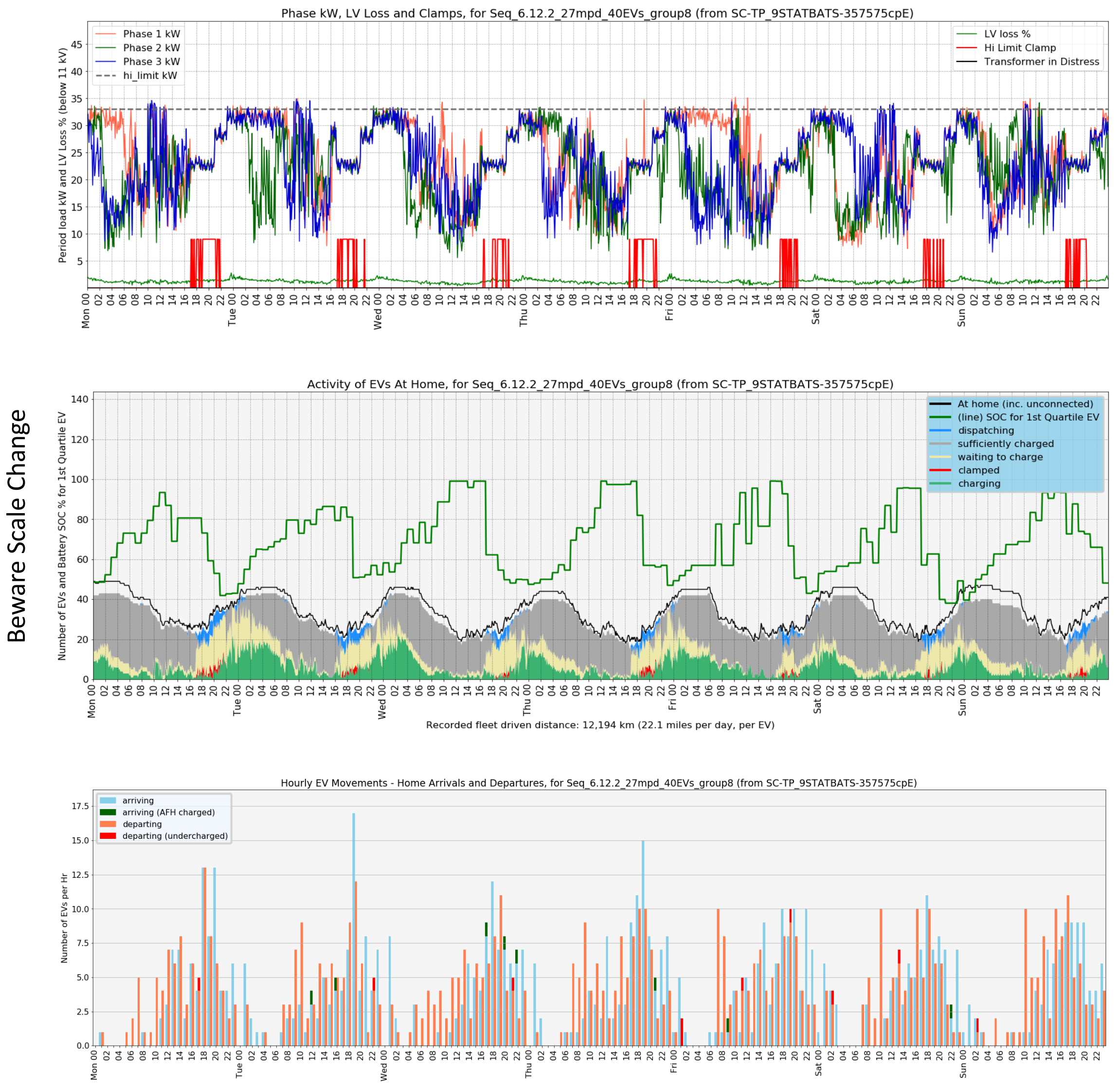
Can large static batteries aid a limit set to 32 kW?

V4-2.98.1 Seq_6.12.2 Outcomes

Loss savings are low with marked impact on EV charging.

V4-2.99 Seq_6.12.2 Feeder and EV Plots

V4-2.99.1 Seq_6.12.2: 27mpd 40EVs



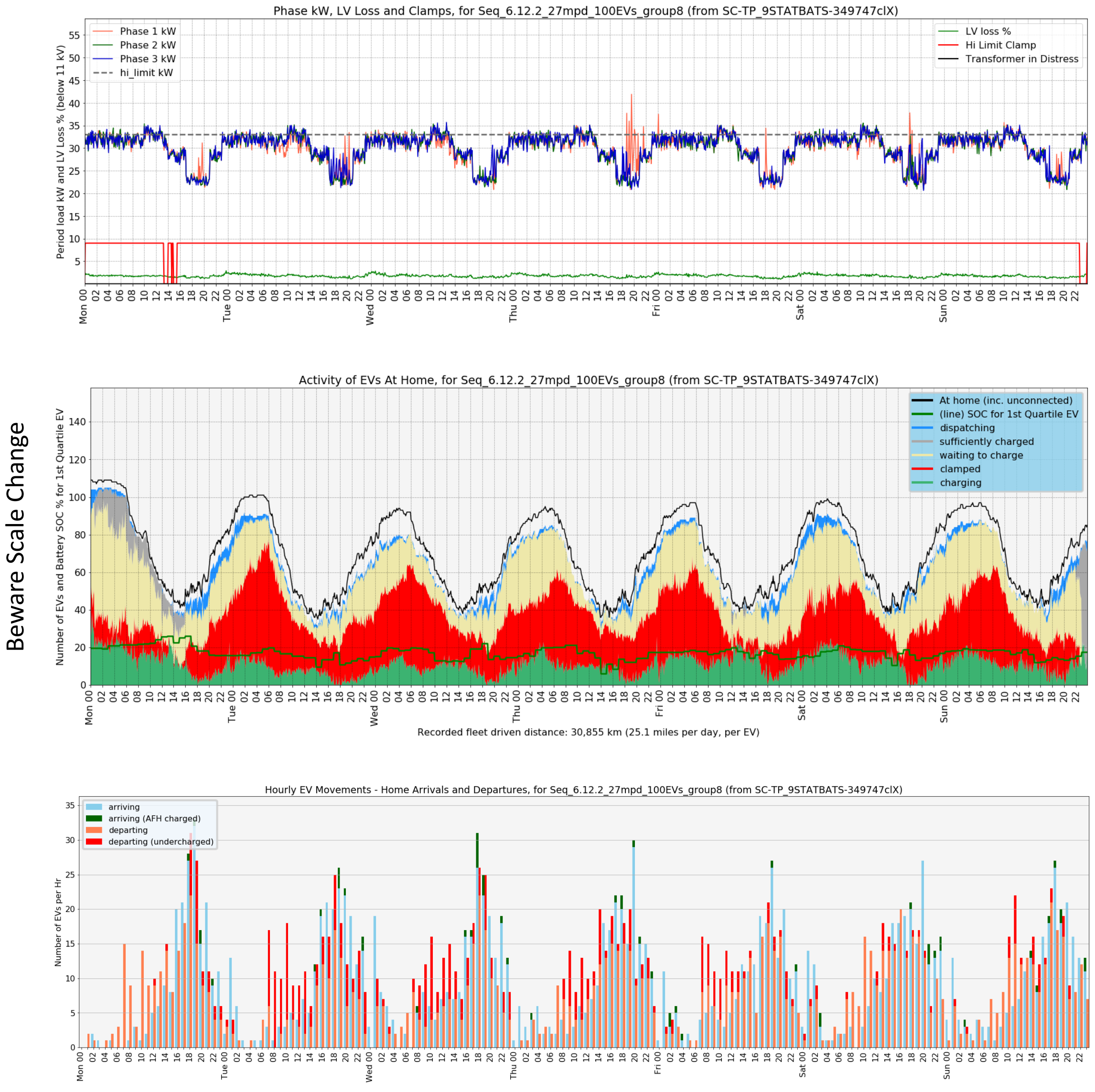
EoW stats: kWh[b] EV total: 2,810 Home: 2,518 AFH: 292 V2G: 480

Figure 2-74: Seq_6.12.2 27mpd 40EVs group 8 plots. Weekly km: 12,227

Notes re above plots:

- the Feeder plot is less dominated by clamping than 6.11.2
- (CICD) plot is less dominated by clamping than 6.11.2 and EVs have good SOC
- (Arrive/Depart) has very little undercharged departs plus some AFH charging.

V4-2.99.2 Seq_6.12.2: 27mpd 100EVs



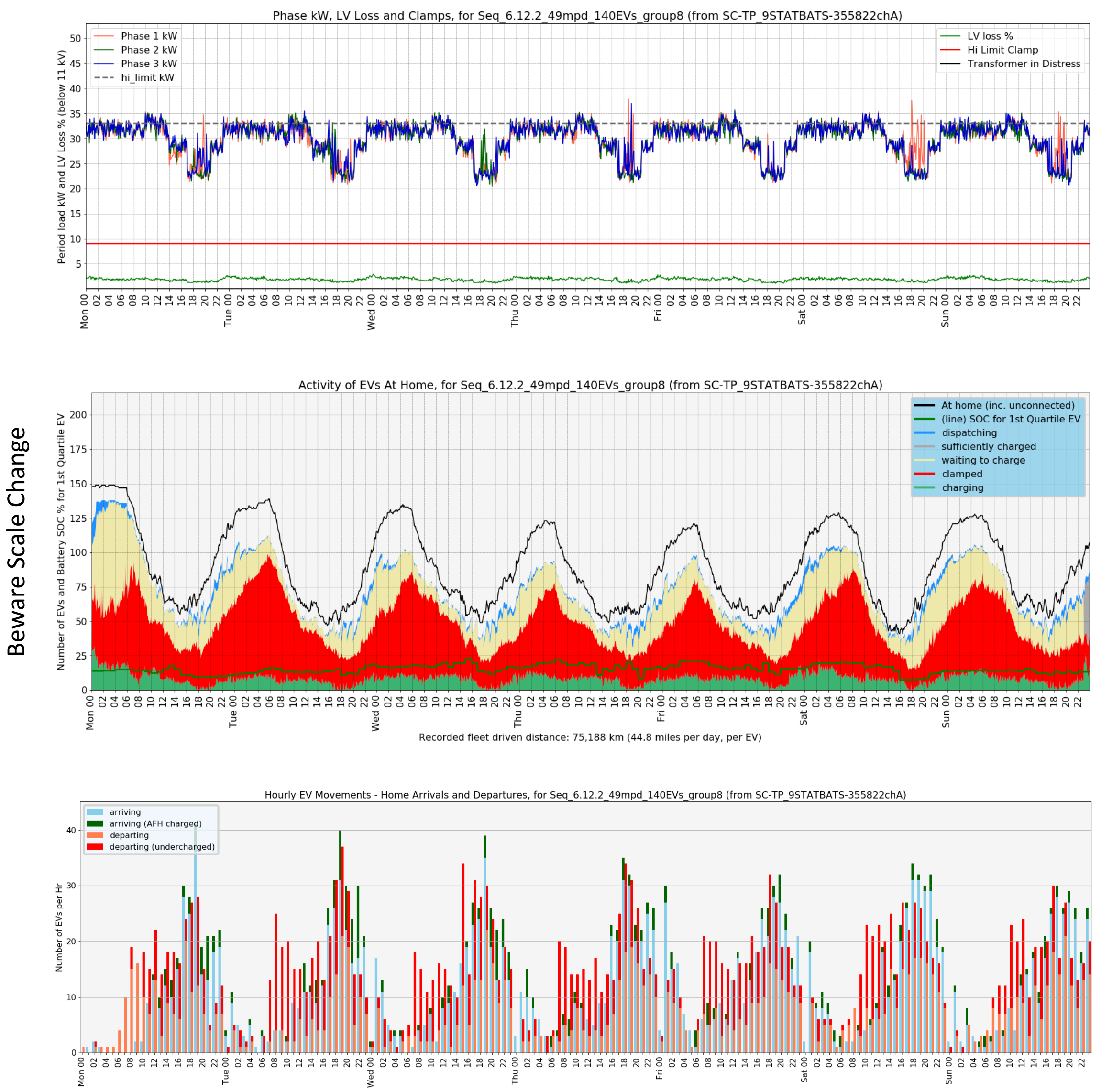
EoW stats: kWh[b] EV total: 6,981 Home: 5,493 AFH: 1,488 V2G: 1,185

Figure 2-75: Seq_6.12.2 27mpd 100EVs group 8 plots. Weekly km: 30,877

Notes re above plots:

- the Feeder plot shows clamps and the onset of saturation
- (CICD) SOC is much down with V2G support. Most EVs are not ready to depart
- (Arrive/Depart) has more undercharged departs; AFH charging is sparse.

V4-2.99.3 Seq_6.12.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 14,422 Home: 5,343 AFH: 9,079 V2G: 1,093

Figure 2-76: Seq_6.12.2 49mpd 140EVs group 8 plots. Fleet drives 77,340 km

Notes re above plots:

- the Feeder plot shows continuous clamps
- (CICD) V2G pre-burn is spares suggesting the EVs cannot spare charge.
- undercharging and AFH charging have to an extreme.

V4-2.100 Data Tables Seq_6.12.2

Table 2-192: 6.12.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7,834	7,185	5,882	4,519	2,951	1,931	1,798	1,792
	27mpd	7,714	6,919	5,326	3,617	1,966	1,837	1,837	1,832
	38mpd	7,611	6,713	4,830	2,732	1,889	1,869	1,869	1,862
	49mpd	7,520	6,533	4,430	2,199	1,893	1,889	1,891	1,882

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

Lowering the hi_limit removed 8,568 kWh. The corrected span is : [10,405] => [10,450]

Table 2-193: 6.12.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	7,834	7,185	5,882	4,519	2,951	1,931	1,798	1,792
	27mpd	7,714	6,919	5,326	3,617	1,966	1,837	1,837	1,832
	38mpd	7,611	6,713	4,830	2,732	1,889	1,869	1,869	1,862
	49mpd	7,520	6,533	4,430	2,199	1,893	1,889	1,891	1,882

6.2.2 span: [8.0] => [34.2] and 6.3.2: [8.7] => [39.2]

AFH charging rises fast in the higher load bands. It is noticeable that as soon as there is > 10% AFH kWh jump, the system seems to be having distress.

Table 2-194: 6.12.2 Per EV AFH N events (average weekly away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.12	0.13	0.13	0.12	0.14	0.21	0.42	0.68
	27mpd	0.28	0.29	0.27	0.29	0.37	0.63	0.96	1.22
	38mpd	0.57	0.57	0.57	0.61	0.83	1.24	1.57	1.83
	49mpd	1.06	0.96	0.91	0.98	1.33	1.74	2.07	2.30

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

With a lowered hi_limit, there is more AFH charging.

Table 2-195: 6.12.2 Counts of Undercharging events per EV (weekly averages)

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.7	0.8	0.8	0.9	1.2	3.0	7.4	10.1
	27mpd	1.3	1.3	1.4	1.5	2.7	7.1	10.2	11.4
	38mpd	1.9	1.9	2.1	2.4	5.8	9.6	11.3	12.1
	49mpd	2.6	2.6	2.7	3.5	7.5	10.6	12.1	12.7

6.2.2: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

Undercharging also rises.

Table 2-196: 6.12.2 Counts of Severely Undercharged EVs in Week, per EV

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0040	0.0024	0.0013	0.0010	0.0011	0.0309	0.1713	0.3212
	27mpd	0.0004	0.0008	0.0011	0.0013	0.0226	0.2191	0.4398	0.5908
	38mpd	0.0082	0.0066	0.0075	0.0104	0.1755	0.4891	0.7081	0.8587
	49mpd	0.0060	0.0064	0.0095	0.0372	0.3587	0.6942	0.9179	1.0654

6.2.2 span: [0.0015] => [0.1631] and 6.11.2: [0.0209] => [0.3175] (limit: < 0.007)

There is great increase in severe undercharing.

Table 2-197: ***6.12.2 MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	81	104	152	199	489	2,665	4,555	4,974
	27mpd	93	127	195	356	2,083	4,183	4,846	5,003
	38mpd	110	159	279	936	3,411	4,538	4,918	5,019
	49mpd	121	183	384	1,578	3,784	4,675	4,959	5,026

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 420)

There is great increase in use of clamps.

Table 2-198: ***6.12.2 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	23.5	18.8	16.6	16.4	26.9	37.3	26.4	20.1
	27mpd	23.9	19.5	18.5	22.5	44.6	28.2	22.2	19.6
	38mpd	24.4	20.6	22.1	35.7	36.4	23.8	21.1	19.2
	49mpd	25.0	21.7	25.8	44.1	32.2	22.2	19.9	18.5

6.2.2: [7.9] => [27.0] and 6.3.2: [5.5] => [21.9]

As demand rises, the V2G EVs become so undercharged as not able to dispatch. The “sweet spot” is clearly the 27mpd, 80 EV ply.

Table 2-199: ***6.12.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	41.7%	48.2%	65.5%	78.6%	88.7%	98.8%	97.0%	96.4%
	27mpd	42.9%	52.4%	72.0%	84.5%	100.0%	97.6%	96.4%	96.4%
	38mpd	42.9%	52.4%	75.0%	91.7%	98.8%	96.4%	96.4%	96.4%
	49mpd	41.7%	53.6%	77.4%	97.6%	98.8%	96.4%	96.4%	96.4%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2: [68.5%] => [85.1%]

***Table 2-200:** 6.12.2 LV Losses kWh (weekly averages)*

9. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	99.8	116.6	143.3	173.9	223.3	268.9	286.4	287.1
	27mpd	101.1	119.8	150.5	198.2	252.2	271.2	283.3	286.4
	38mpd	102.2	122.3	157.0	213.7	255.3	270.6	285.1	285.8
	49mpd	103.2	124.5	166.7	230.6	254.6	270.3	284.7	285.4

This is a loss reduction is (335 kWh - 271.2) kWh = 64 kWh

i.e. (64 / 336) * 100 % = 19 %.

A fairer comparison, given that the parity case is not acceptable, is to calculate the loss reduction for say 27mpd * 60 EVs.

For this case, the difference is (201 - 198) = 3 kWh i.e. 0.9 %, suggesting a profit per million homes of £0.07 * 3 * (10^6 / 100) = £2,100, which for SSEPD is a saving for their likely served population of £2,100 * 2 * 3.8 / 3 = £5,320.

V4-2.101 Seq_6.12.2 Results Summary

Potential savings are low with much degradation of charging performance.

There is found no justification to perform hi_limit reduction in this case, unless it can be simply automated and made an intrinsic feature of a local controller. However this must be flawless; a mistake causes unacceptable EV SOC levels.

V4-2.102 Sequence 6.13.2

Sequence	Simulation ID	Description
Seq_6.13.2	(S_B2)	MCS with standard EV mix (19% dumb, 48% SV1G and 33% V2G), 9 Static Batteries, Winter PV arrays at 2 kW per home average, hi_limit is 39 kW. Pre-Burn V2G ON. The modulation plan is DR-C with FFR.
Baseline Seq	***Description***	
Seq_6.2.2.2	*Typical network, Winter, std. EV mix of 19% dumb, 48% SV1G and 33% V2G, clamps ON (2), pre-burn_V2G ON, 9 Static Batteries*	

Can large static batteries work with PV panels in the Winter? PV records for the week simulated are added as a negative bias per household.

As the week studied is 3 months after the Winter equinox, PV will generate power but has several limiting issues:

- not fitted to every house
- sun rises too late for useful morning contribution (for this week, c. 9am)
- sun sets too early for useful evening contribution (for this week, c. 4:30pm)

However by adding 3 Static Batteries per phase the PV energy is made available in the evening. The system is rigged so the Static batteries are last to charge when other vehicles are present, but always first to dispatch. There are three per phase and mimic standard EV electrics with large batteries (3.5 kW output, 150 kWh per battery). The author supposes this would be an ideal “second life” use of such systems.

Reduction of the hi_limit is performed, to attempt losses reduction.

Data is taken from MetaMeta2.3_Seq_6.13.2.xlsx in the repository.

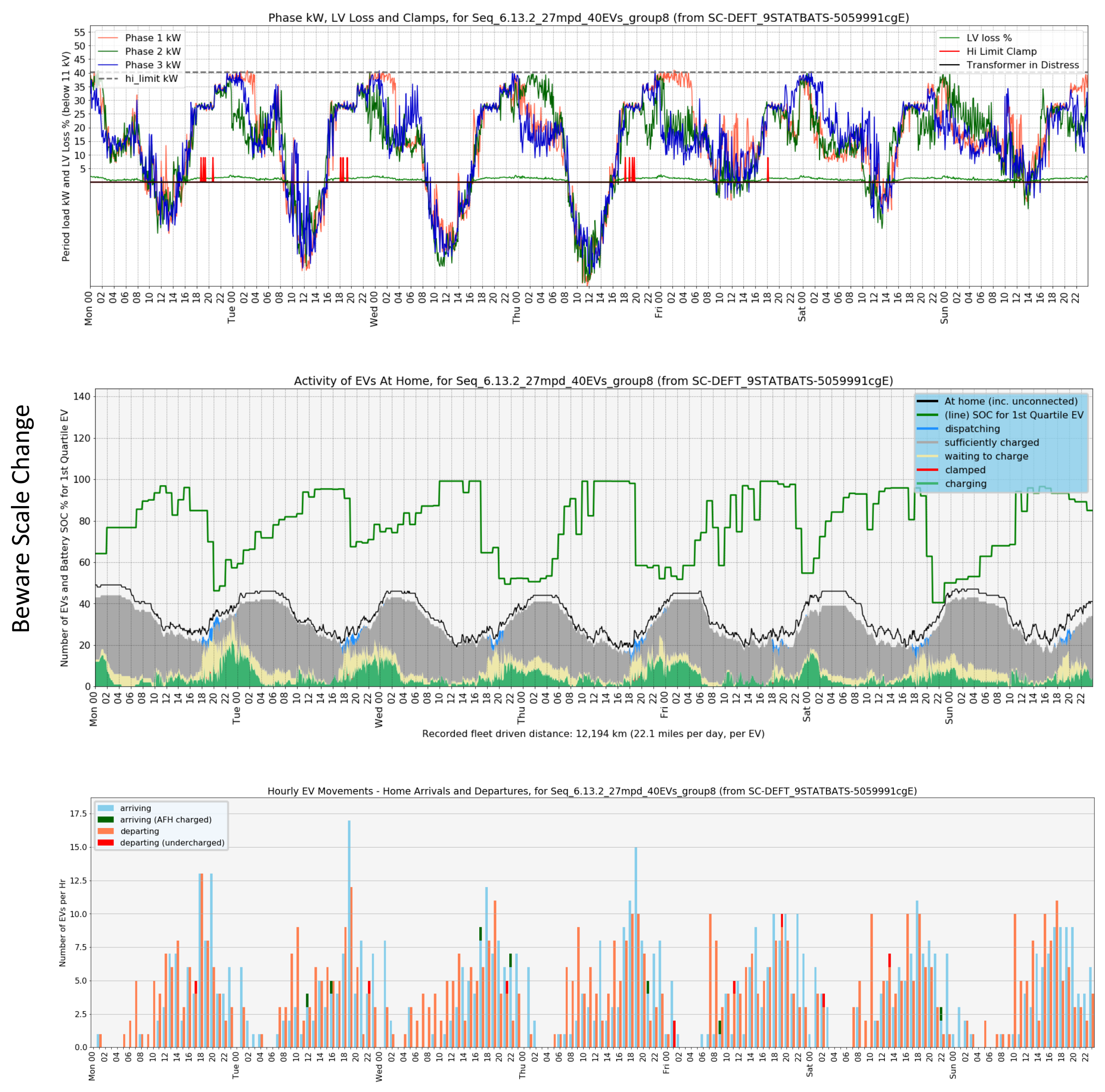
Note a hi_limit of 39 kW is used, similar to the 40 kW runs of 6.9.2, 6.9.2.1, 6.9.2.2 and 6.10.2.

V4-2.102.1 Seq_6.13.2 Outcomes

This approach shows significant improvements, with minimal severe undercharging and use of clamps, plus minimises losses. Significant periods of over-volts were seen.

V4-2.103 Seq_6.13.2 Feeder and EV Plots

V4-2.103.1 Seq_6.13.2: 27mpd 40EVs



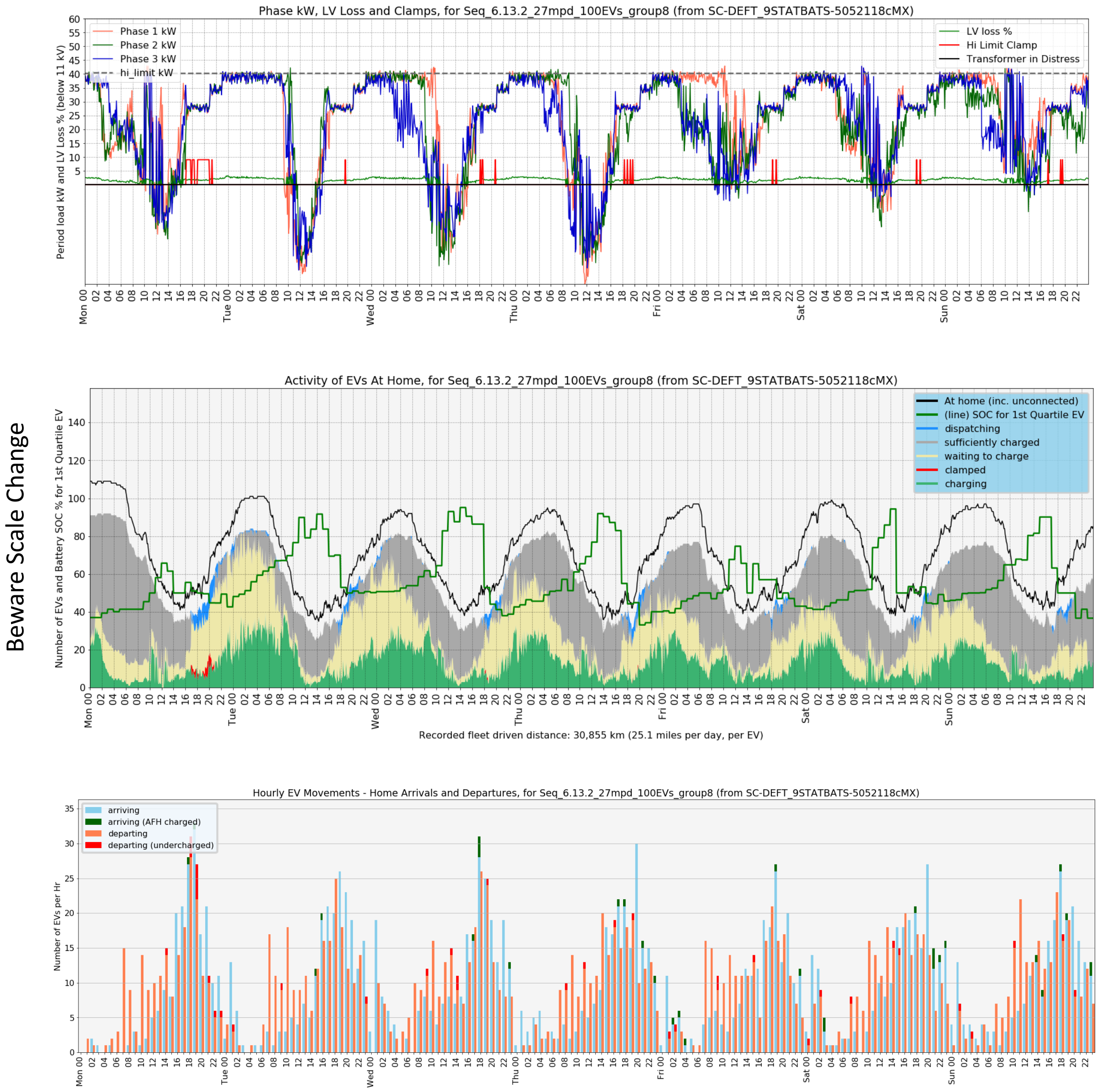
EoW stats: kWh[b] EV total: 2,483 Home: 2,200 AFH: 283 V2G: 166

Figure 2-77: Seq_6.13.2 27mpd 40EVs group 8 plots. Weekly km: 12,227

Notes re above plots:

- the Feeder plot shows negative kW due to PV. Clamps are in use for DR
- (CICD) EVs have exceptional SOC with c. 50% of the week at over 80%. There is some V2G dispatch and most of the EVs are ready to depart; however most have plugged-in on returning home indicating AFH top ups are rare;
- (Arrive/Depart) there are some - rare - undercharged departs. AFH is also rare.

V4-2.103.2 Seq_6.13.2: 27mpd 100EVs



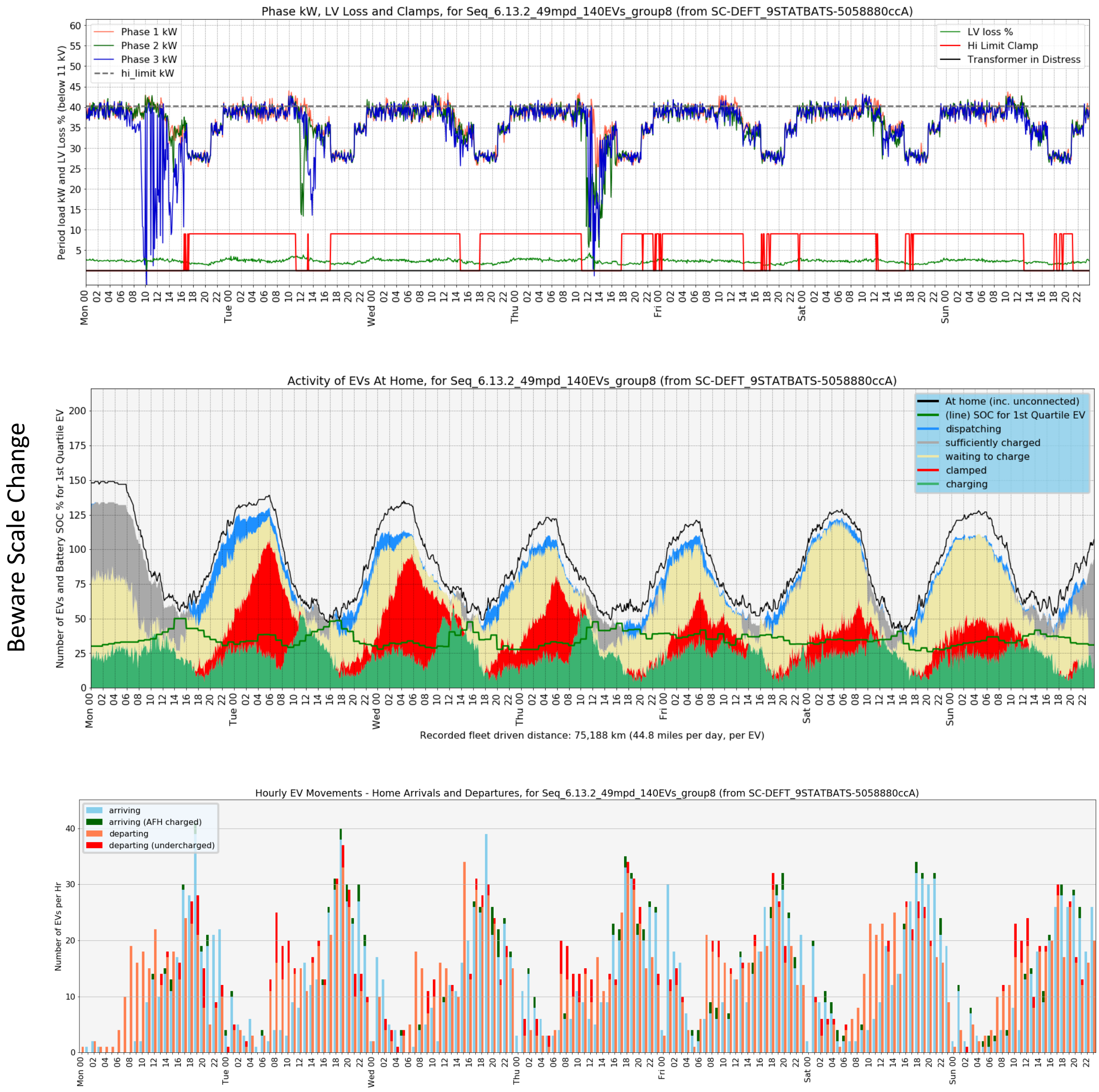
EoW stats: kWh[b] EV total: 6,402 Home: 5,611 AFH: 791 V2G: 498

Figure 2-78: Seq_6.13.2 27mpd 100EVs group 8 plots. Weekly km: 30,877

Notes re above plots:

- the Feeder plot shows PV, with 2.3 hours a week of over-voltage DR / FFR clamps but is unremarkable
- (CICD) SOC is good with significant numbers of EVs ready to depart. Some V2G; less are plugging-in
- (Arrive/Depart) has more undercharged departs particularly on the less sunny days. AFH charging is up; both are low.

V4-2.103.3 Seq_6.13.2: 49mpd 140EVs



EoW stats: kWh[b] EV total: 16,222 Home: 11,691 AFH: 4,532 V2G: 2,656

Figure 2-79: Seq_6.13.2 49mpd 140EVs group 8 plots. Fleet drives 77,340 km

Notes re above plots:

- the Feeder plot shows the DR/FFR signal and almost perfect consumption of PV output. There are no over-voltages.
- (CICD) V2G pre-burn from Static Batteries cannot eliminate clamps, but intensified daytime charging is evident (the Static Batteries consume PV). Few EVs are ready to depart
- undercharging and AFH charging have risen but are not extreme.

V4-2.104 Data Tables

Table 2-201: 6.13.2 Unused kWh (weekly averages)

1. Unused kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	15,709	15,075	13,820	12,538	11,235	9,908	8,609	7,276
	27mpd	15,589	14,814	13,278	11,707	10,128	8,556	6,941	5,180
	38mpd	15,483	14,604	12,795	10,934	9,115	7,179	5,211	3,248
	49mpd	15,392	14,425	12,412	10,358	8,380	6,194	4,036	2,580

6.2.2 span: [10,098] => [4,763] and 6.3.2: [10,239] => [5,747]

Reduction of the hi_limit reduced available kWh by 8,568 kW. Corrected spans are then:

[17,124] => [11,148] i.e. significantly down vs. normal.

Table 2-202: 6.13.2 Per EV AFH kWh Uptake (weekly averages)

2. EV AFH kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	2.4	2.9	3.0	2.9	3.1	3.3	3.3	3.3
	27mpd	6.2	7.2	7.1	7.4	7.9	7.9	7.8	7.7
	38mpd	16.0	16.2	16.6	17.4	17.2	17.7	17.5	18.1
	49mpd	33.5	31.1	30.0	29.7	29.7	29.9	30.6	32.3

6.2.2 span: [8.0] => [34.2] and 6.3.2 span: [8.7] => [39.2]

There is a minor reduction of AFH uptake vs. examples without PV.

Table 2-203: 6.13.2 Per EV AFH N events (weekly average away connects)

3. EV N AFH	N EV	10	20	40	60	80	100	120	140
	19mpd	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.14
	27mpd	0.27	0.28	0.26	0.27	0.30	0.30	0.29	0.29
	38mpd	0.55	0.55	0.55	0.56	0.57	0.58	0.58	0.60
	49mpd	1.03	0.93	0.88	0.87	0.88	0.89	0.92	0.98

6.2.2 span: [0.3] => [1.05] and 6.3.2: [0.34] => [1.26]

Again, a minor reduction of AFH uptake vs. examples without PV.

Table 2-204: ***6.13.2 Counts of Undercharging events per EV (weekly averages)***

4. EV UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9
	27mpd	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5
	38mpd	1.6	1.7	1.8	1.9	1.9	2.0	2.0	2.5
	49mpd	2.2	2.3	2.3	2.4	2.4	2.5	2.7	4.2

6.2.2 span: [1.4] => [5.0] and 6.3.2: [2.0] => [6.6]

With demand low hence proportionately plentiful power, EVs can charge to their fill hence the incidence of undercharging drops.

Table 2-205: ***6.13.2 Counts of Severely Undercharged EVs in Week, per EV (limit: < 0.007)***

5. EV Severe UnChg	N EV	10	20	40	60	80	100	120	140
	19mpd	0.0000	0.0000	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
	27mpd	0.0002	0.0002	0.0004	0.0006	0.0008	0.0009	0.0006	0.0007
	38mpd	0.0016	0.0022	0.0023	0.0025	0.0029	0.0022	0.0024	0.0096
	49mpd	0.0030	0.0027	0.0040	0.0035	0.0054	0.0055	0.0087	0.0781

6.2.2 span: [0.0015] => [0.1631] and 6.3.2: [0.0209] => [0.3175]

Severe undercharging is now experienced by the parity case EVs c. every 2,500 weeks, with only extreme ranges being affected.

Table 2-206: ***6.13.2 Averaged MCS Clamps (weekly averages)***

6. MCS Clamps	N EV	10	20	40	60	80	100	120	140
	19mpd	4	6	14	21	31	40	27	40
	27mpd	6	10	21	35	54	75	73	191
	38mpd	7	15	33	56	95	188	354	1,212
	49mpd	11	19	44	81	171	417	819	2,278

6.2.2 span: [366] => [2,985] and 6.3.2: [244] => [2,370] (limit: < 0.007)

These values have substantively dropped, reflecting the less urgent need to charge.

Table 2-207: ***6.13.2 V2G kWh dispatch per EV (weekly averages)***

7. V2G kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	6.8	5.7	5.5	5.7	6.9	7.9	8.0	9.4
	27mpd	7.1	6.1	6.4	7.2	9.4	11.9	14.0	22.4
	38mpd	7.4	6.8	7.9	9.5	13.6	21.9	31.2	43.4
	49mpd	7.9	7.4	9.1	11.8	19.8	33.8	44.5	45.0

6.2.2 span: [7.9] => [27.0] and 6.3.2 span: [5.5] => [21.9]

These values include output from the static batteries as well as V2G EVs.

Table 2-208: ***6.13.2 DRFFR Percent Effective Hours (weekly averages)***

8. DRFFR %	N EV	10	20	40	60	80	100	120	140
	19mpd	26.8%	33.3%	35.7%	47.6%	54.2%	61.3%	69.0%	78.6%
	27mpd	26.2%	33.3%	38.7%	53.0%	59.5%	69.6%	78.6%	86.9%
	38mpd	29.2%	32.7%	41.7%	58.3%	66.1%	75.6%	84.5%	94.0%
	49mpd	28.0%	32.1%	47.6%	59.5%	72.6%	82.7%	91.1%	98.2%

6.2.2 span: [73.8%] => [98.2%] and 6.3.2 span: [68.5%] => [85.1%]

Response to hi_limit modulation is acceptable.

Table 2-209: ***6.13.2 LV Losses kWh (weekly averages)***

9. Losses kWh	N EV	10	20	40	60	80	100	120	140
	19mpd	58.7	66.8	90.1	121.0	158.9	203.6	251.4	297.5
	27mpd	60.2	72.0	101.7	139.5	186.0	239.5	299.5	357.8
	38mpd	61.4	77.3	109.3	155.1	213.7	280.3	346.6	410.9
	49mpd	62.5	80.3	116.3	171.3	228.8	302.0	377.7	431.8

This is a loss reduction of 100 % * (96 / 336) = 28.6 % giving a notional per Winter saving, at £385 k per 1%, of £11 m.

Does this pay for itself? The author rigged the simulation so the Static Batteries looked like EVs so we are considering “second life systems”. Suitable electrics and battery are likely to be found in any estate or executive class EV. Capital costs though may swamp the benefit of defrayed costs.

However with such £being seen, it may be useful to identify the most lossy networks and see if there is a cost-effective argument for them.

In spot-checks the Static Batteries did not go below 40% charge. This suggests that they have range in hand to mimic BLPs (i.e. operate in the 20 - 80% band).

Table 2-210: ***6.13.2 LV Losses inc. V2G lost energy kWh (weekly averages)***

10.	N EV	10	20	40	60	80	100	120	140
Losses + V2G loss kWh	19mpd	87.4	99.0	133.2	177.0	233.0	303.4	375.9	464.2
	27mpd	89.8	106.7	151.3	210.5	287.2	388.9	518.5	754.3
	38mpd	92.6	116.0	170.5	248.7	361.0	555.9	833.3	1,179.9
	49mpd	95.8	122.6	187.2	288.1	442.5	728.0	1,072.2	1,228.8

Note that the network has not suffered those losses, for they are predominantly lost in the Static Batteries from PV charging. “Might have beens” are not counted; however these are not hypothetical. The lost energy did exist and was radiated as heat.

Rather, the above losses are counter-factual in so far as these kWh were not measured entering from the network thus invisible. However, without the battery / PV system, such losses would be measurable.

Ideally, the PV would be directly charging EVs not intermediate Static Batteries; however the EVs are (for the most part) not on site during the time the Sun is up.

Given that proviso, this is the most successful scheme to minimise network losses so far.

V4-2.105 Seq_6.13.2 Results Summary

Compared to other simulations, the number of plies excluded are:

Table 2-211: Sequence Acceptable EV Penetrations and Ply Exclusions

Sequence	Highest N EVs Tolerated (at 19, 27, 38, 49mpd)	Severe Under - charging	Excessive Clamps
6.9.2	20, 20, 20, 20	15	24
6.9.2.1	60, 60, 40, 20	10	18
6.9.2.2	60, 60, 60, 40	8	13
6.10.2	60, 40, 20, 20	13	20
6.13.2	140, 140, 120, 100	3	3

Per Sequence Acceptable EV Penetrations and Counts of Ply Exclusions (Best, Worst)

The big difference is clearly PV coupled with Static Batteries. Yet, not all homes have PV - and in winter snow will cover many domestic PV systems.

This then is the benefit of Static Batteries and a load monitoring system: together they can take advantage of opportunistic situations.

However DNOs might like to think about some trials of:

- domestic PV on ideal roofs (those which are very high-pitch, due South ±10%)
- and associated Static Batteries.

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V4-3.1 Reflections on Losses Reduction

Lowering the hi_limit setpoint does provide loss reduction hence savings, although there is risk of not being able to service the EVs adequately. As long as that point of risk is known and avoided, then there is potential for savings.

However there is no clear pattern as yet. Can this risk "inflection edge" be identified with what we know now? With clarity: No; but that it exists is hinted at by precursors e.g. noticing that as soon as AFH visits trend up over ±15%, the risk boundary is met:

Table 3-1: ***6.12.2 Per EV AFH N events (count of away connects) in week with difference table.***

N EV	10	20	40	60	80	100	120	140
19mpd	0.12	0.13	0.13	0.12	0.14	0.21	0.42	0.68
27mpd	0.28	0.29	0.27	0.29	0.37	0.63	0.96	1.22
38mpd	0.57	0.57	0.57	0.61	0.83	1.24	1.57	1.83
49mpd	1.06	0.96	0.91	0.98	1.33	1.74	2.07	2.30

The risk zone is on the right of the line i.e. keep at least 1 ply to the left and undercharging will not be met. However determining this line is a function of all our variables (network type, residential loads, EV types, mpd and temperature) so is like to change with time. Rules of thumb cannot be as useful as active data monitoring, yet DNOs may not be able to do so. Conversely, in an actively managed system if the numbers of EVs rises (and usable headroom over the present hi_limit setting exists) then the limit may be raised.

Given a local controller with access to load patterns and the above AFH data (how this is gained is not clear) the machine can speculatively investigate using local data and notionally find the line position. This is a good use of the cpu; most of the time it is idle.

However the AFH line observation is free of deeper understanding and may not always apply. This needs further investigation.

Yet it is worthwhile, in the author's view, to at some point modify the simulator to assess not 500 cases per ply but say 50 and to then scan from (standard hi_limit + 4) kW down to say (standard hi_limit -16) kW so to rapidly explore system behaviour.

This would allow a scenario to be investigated and characteristics vs. hi_limit assessed. This is deferred for now but would make a useful, practical project at some time. The goal would be to identify the risk inflection points and to discover:

- what drives these and
- a general method or technique to predict where the inflection edge will be, for any given system.

V4-3.2 Severe Undercharging Correlation

Plots have been gathered, for deemed viable sequences, of severe undercharging events seen per simple undercharged-on-depart and plotted as below:

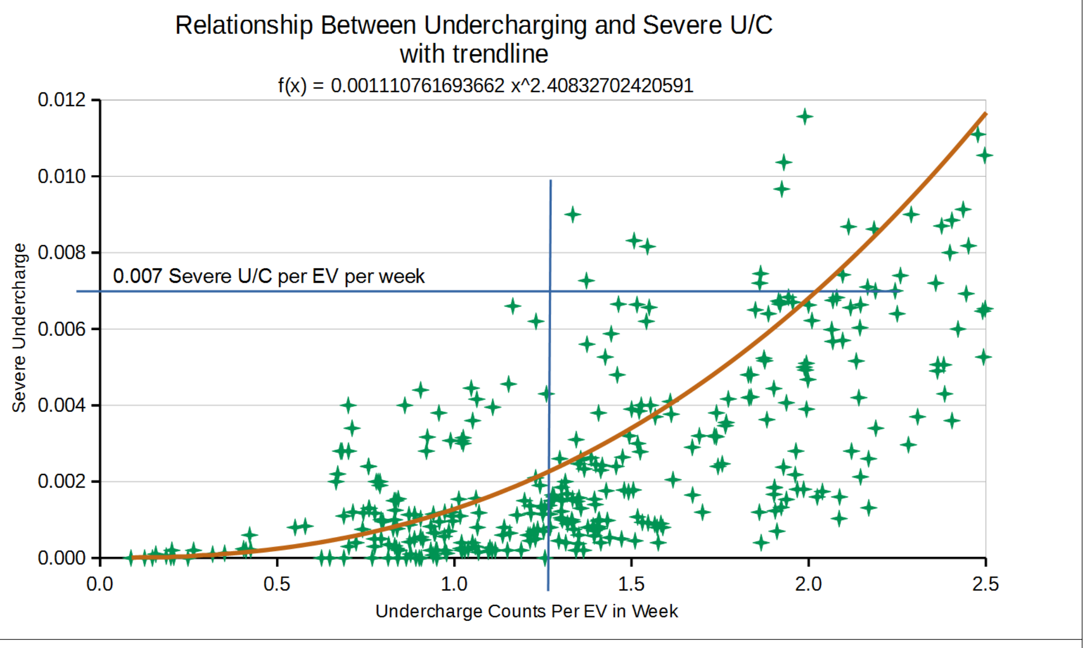

Figure 3-1: Plot of Severe Undercharging vs. Undercharging with Trendline

Rather than use the trendline (brown curve), we wish to avoid severe undercharging rates likely to exceed the "50:50 chance in 10 winters" level, established as 0.007 severe undercharges per EV per week. The vertical blue line, placed by eye, marks a plausible partition with instances on the right exceeding 0.007 severe undercharges. The cross-over so found is at c. 1.25 undercharges per EV per week.

The author imagines a level is needed for bureaucratic intervention prior to this; a rate of 1 undercharge per EV per week seems reasonable (and easy to understand).

Some form of support is suggested for those EVs which encounter 1 U/C per week; perhaps a “Get N free AFH charges per week” card or discounted charging offer. This could be discovered by data analysis (but of who’s data?), the intent being that the DNO can discharge a duty to provide a minimum charging capability, by offering individuals recourse to alternative charge sources.

Is the cross-over found an absolute or a characteristic of the investigations performed? The author has no reason to believe any absolute link, so suggests this is considered a characteristic of a particular situation; the value found might have been different for other network strengths, residential loads and vehicle characteristics. Thus it is suggested that this exercise is re-run for each DNO network situation (or, the range of worst-case to best-case the DNO sees on their networks).

Note that the planet is going into a period of climate change. Winters are not guaranteed to be warmer then historic averages; rather, chaos is likely to increase. This includes occasions of very hard and persistent winters.

Some form of insurance might be needed e.g. a contract which pays out claims given the possibility of such a severe and persistent winter that DNO efforts cannot cope. A DNO might find themselves sued / picking up the bill for thousands of ruined car batteries (replacement values for South of England EV fleet c. 10 m * 0.454 * £8,000 = £36 bn, which, if 10% became damaged, would be a problem).

Dialogue with an actuary may be warranted.

Bibliography

Note there is a complete Bibliography in the main Thesis.

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