

# Vehicle-to-Grid (V2G): Research Overview

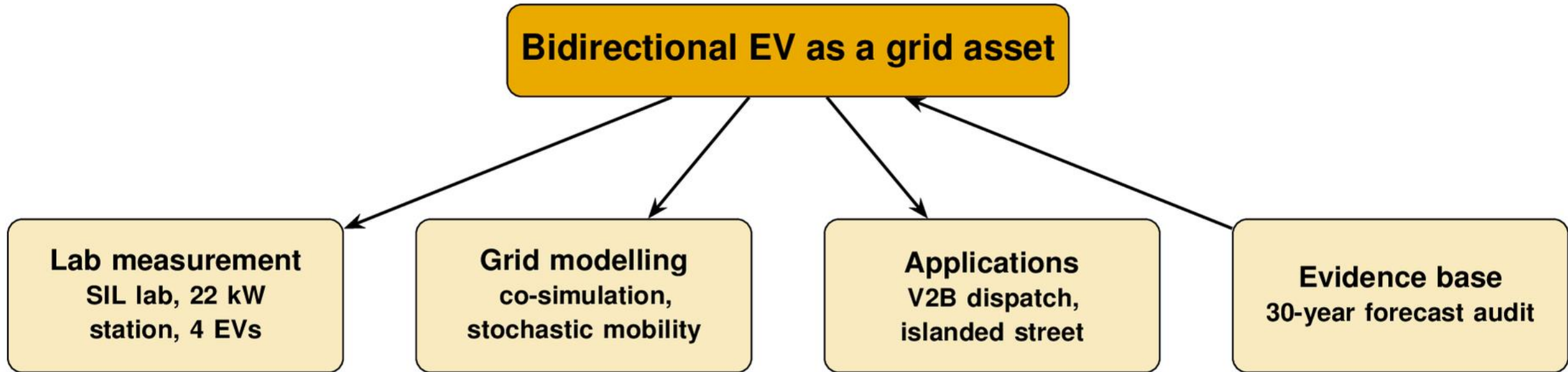
From hardware measurements to distribution-grid models

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# What This Talk Covers



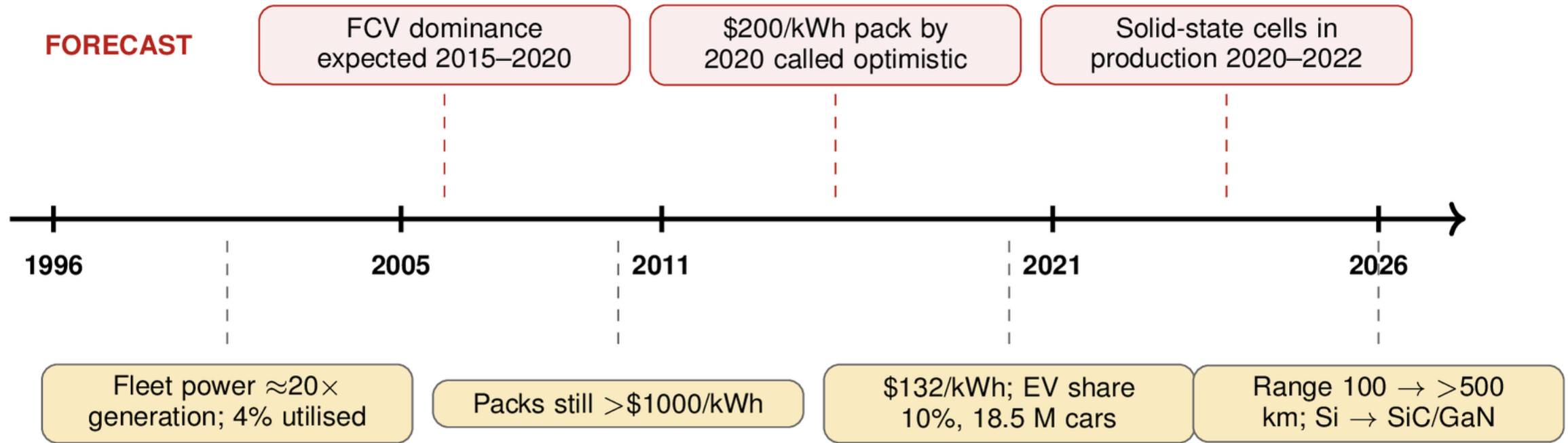
One claim, carried through the whole talk:

**Idealised V2G models understate grid stress because they ignore the charger hardware and the driver. We measured both and put them into the model.**

PART 1

# **Why V2G, Why Now**

# Thirty Years of Forecasts (1996–2026)



Our retrospective review traced 31 numeric claims in the enabling-technology sections back to their cited sources:  
**6 confirmed, 4 reworded, 5 removed** — no source in the corpus reported them.

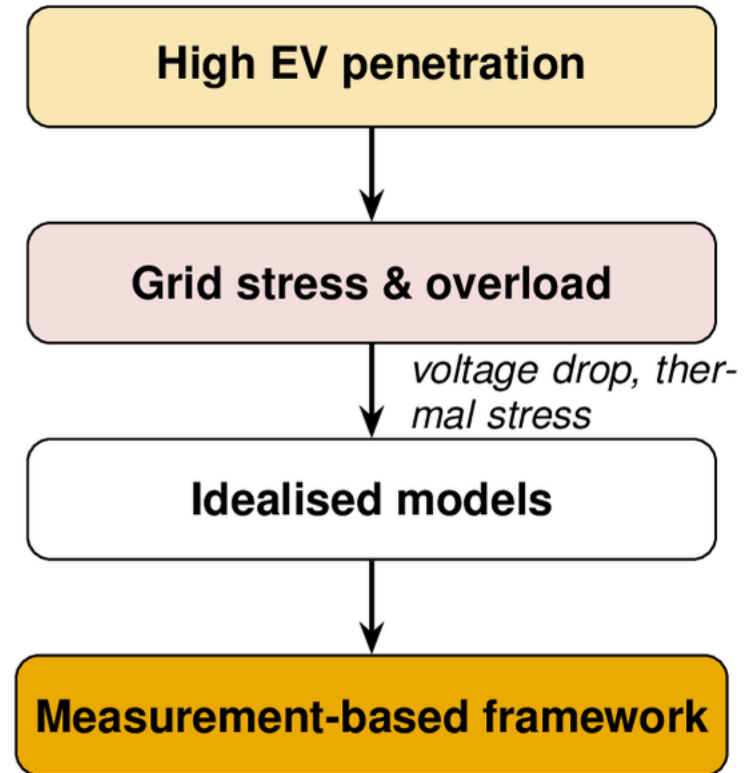
# The Constraint Is the Low-Voltage Feeder

## What uncoordinated charging does:

- 10% local EV penetration → **+17.9%** peak demand; 30% → **≈+53%**.
- Voltage unbalance up to **4.9%** against a 2% planning limit; line loading to **164%** of rating.
- Transformer life reduced by up to **29.7%**.
- Slovak LV feeders have high  $R/X$  → voltage reacts to real power, not just reactive.

## The gap this work addresses

Standard studies model the vehicle as a symmetric, instantaneous source. Real hardware is neither.



PART 2

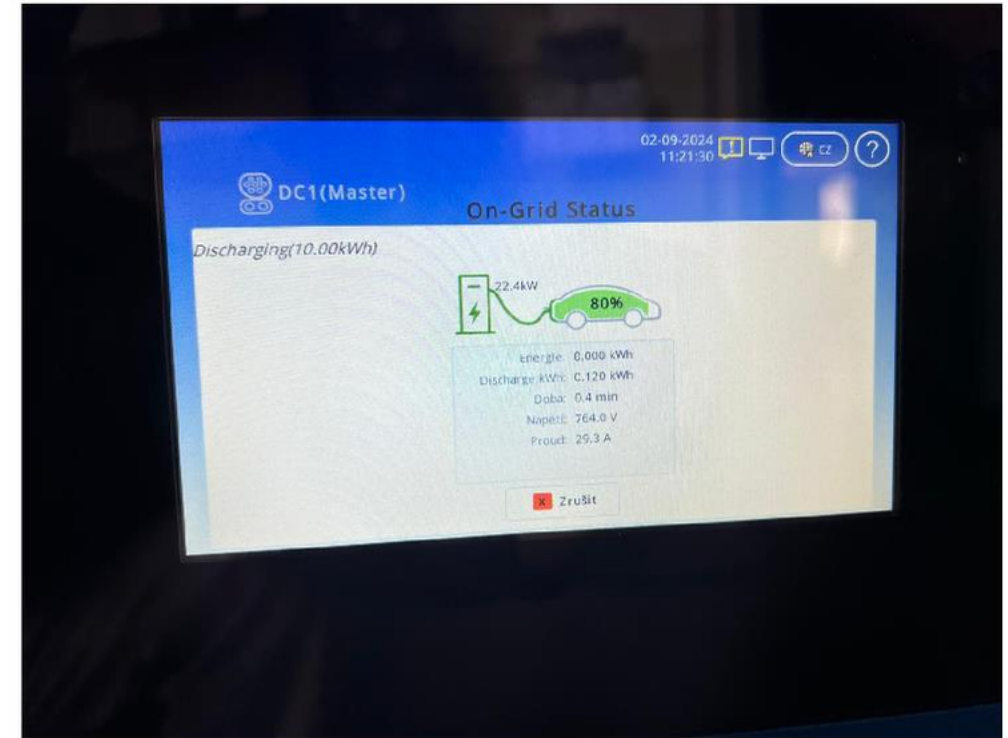
# Measurement

# Smart Industry Lab: the Test Bench

## Bidirectional power-flow test area



## Infypower 22 kW off-board charger



ISO 15118-20 / OCPP 2.0.1 · CCS2 and CHAdeMO · measurements taken at the AC boundary with a PQube analyser.

# How the Measurements Were Taken

## Vehicles under test

- Kia EV6, Kia EV3, Tesla Model 3 — CCS2
- Nissan Leaf — CHAdeMO
- All CCS2 cars share *one* 22 kW Infypower station, so the limits observed are **charger-determined**, not vehicle-determined.

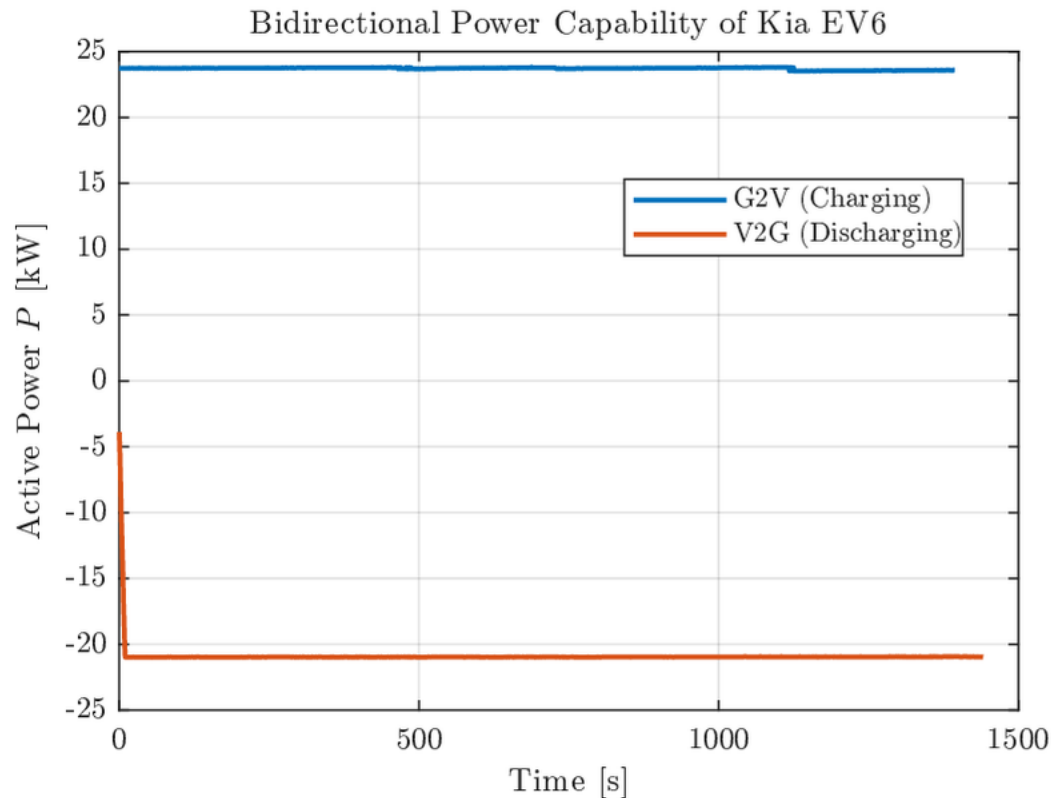
## Instrumentation

- PQube power analyser, AC side of the off-board charger.
- Logging: 0.5 s for the CCS2 vehicles, 1 Hz for the Leaf.
- Aggregated trend export (RMS, power, PF) — no raw waveform, therefore no THD from this campaign.

*Consequence: sub-second phenomena are outside the resolution of this dataset, and are reported as such.*



# Result 1 — The Converter Is Not Symmetric

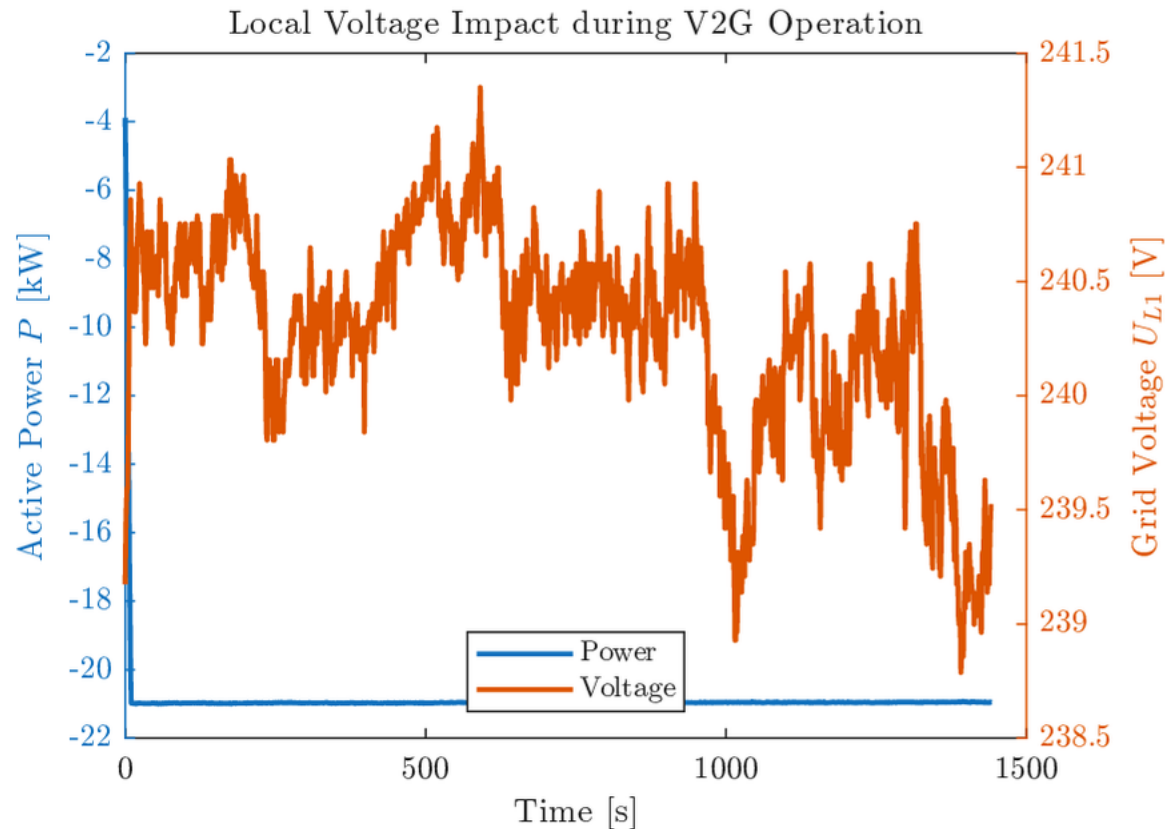


- G2V peak **23.7 kW** vs. V2G peak **-21.0 kW** on the same 22 kW station.
- Charge draw slightly *exceeds* the DC nameplate (rectifier input); discharge stays *below* it (inverter output).
- Consistent with converter efficiencies of 90–95% and with BMS-side safety limits.
- Measured round-trip efficiency **88.4%** at 22 kW.

## Why it matters

A model that assumes  $P_{V2G} = P_{G2V}$  overstates every hour of export the fleet is credited with.

# Result 2 — One 22 kW Unit Moves the Local Voltage



- A single 22 kW injection produces a **2.5 V** change at the point of connection.
- That is one charger, in a laboratory feeder, with no coincident load.
- It confirms the high sensitivity that the  $R/X$  ratio of Slovak LV networks predicts.

## Scaling argument

Voltage support from V2G is a *local* product before it is a system product — the effect is measurable at one unit, which is also why uncoordinated dispatch is a hazard.

# Result 3 — The Time Constants Nobody Publishes

Time-domain parameters measured for ISO 15118-20 / OCPP 2.0.1

**Time to power flow**

**45.33 s**

Session establishment,  
from plug-in.

**Transition delay**

**13.50 s**

Charge → discharge  
reversal.

**Round-trip efficiency**

**88.4 %**

Measured at 22 kW.

*These are protocol and hardware constants, not modelling assumptions.*

# What Those Latencies Rule Out

| Quantity                                                     | Value   |
|--------------------------------------------------------------|---------|
| Activation budget for primary frequency control (literature) | 2–3 s   |
| Measured charge → discharge reversal                         | 13.50 s |
| Measured cold-start session setup                            | 45.33 s |

The activation budget covers the whole chain: frequency measurement → set-point execution.

## Reading of the result

- An *already-active* session reverses power roughly **5×** **too slowly** for an FCR-type product.
- The 45 s cold start decides whether an *idle* plugged-in car can be called at all.
- What this hardware generation does serve: peak shaving, slower restoration-reserve timescales, local voltage support, behind-the-meter V2B.
- Reactive support and coordinated charging (V1G) add *no* battery throughput — the degradation argument applies only to bidirectional real power.

PART 3

# Modelling

# No Single Simulator Covers V2G

- Multi-criteria assessment of 9 simulation environments, scale 1–5.
- C1 grid physics · C2 mobility modelling · C3 optimisation · C4 automation / scripting.

| Simulation tool   | C1       | C2       | C3       | C4       | Total     |
|-------------------|----------|----------|----------|----------|-----------|
| MATLAB/Simulink   | 5        | 2        | 4        | 2        | 13        |
| PyPSA             | 3        | 1        | 5        | 5        | 14        |
| <b>pandapower</b> | <b>5</b> | <b>1</b> | <b>4</b> | <b>5</b> | <b>15</b> |
| <b>datafev</b>    | <b>1</b> | <b>5</b> | <b>3</b> | <b>4</b> | <b>13</b> |
| OpenDSS           | 5        | 1        | 2        | 3        | 11        |

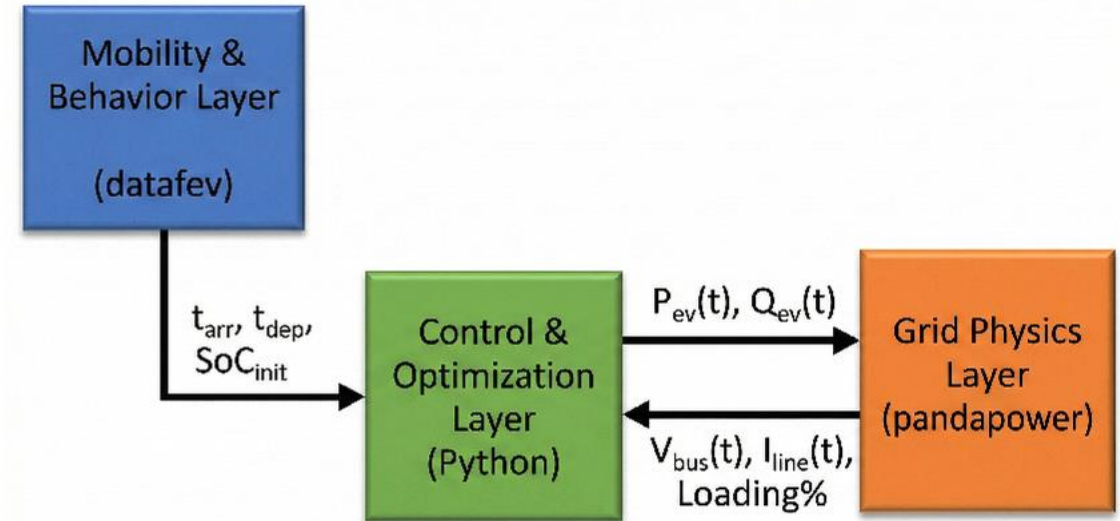
**Result:** grid physics and mobility behaviour are never strong in the same tool. Co-simulation is not a preference here, it is a consequence.

# Proposed Co-Simulation Framework

## Three layers, one Python process:

- 1 Mobility — datafev.**  
Stochastic arrival and departure events; the driver is a distribution, not a schedule.
- 2 Control — Python.**  
Energy management that applies the **measured asymmetry and the measured latencies**, not idealised set-points.
- 3 Physics — pandapower.**  
Bus voltages and line currents checked at every time step.

*The measurement layer is what closes the loop: the SIL constants parameterise the control layer.*



# Proof of Concept: Static vs. Stochastic

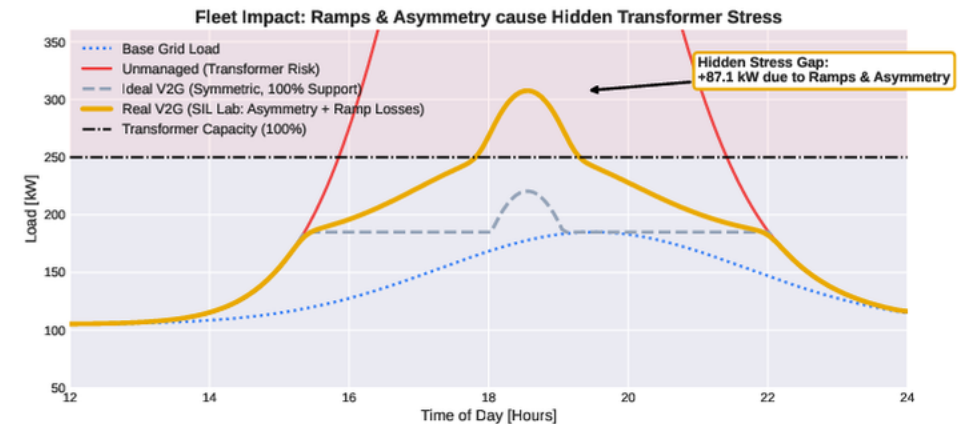
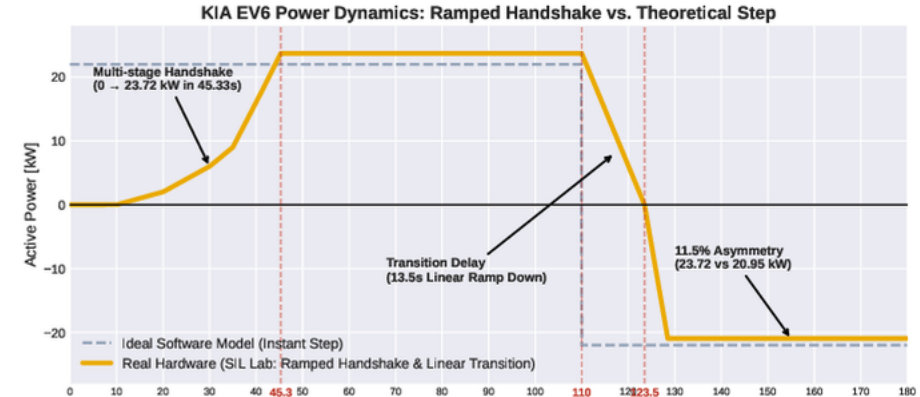
## Two ways to load the same feeder:

- **Static case** — aggregated load profiles, the conventional approach.
- **Stochastic case** — the proposed co-simulation stack, driver behaviour sampled.

## Key finding

Neglecting user stochasticity **understates grid stress and peak loading by 10–15%.**

That is the margin a planner would have believed they had, and did not.



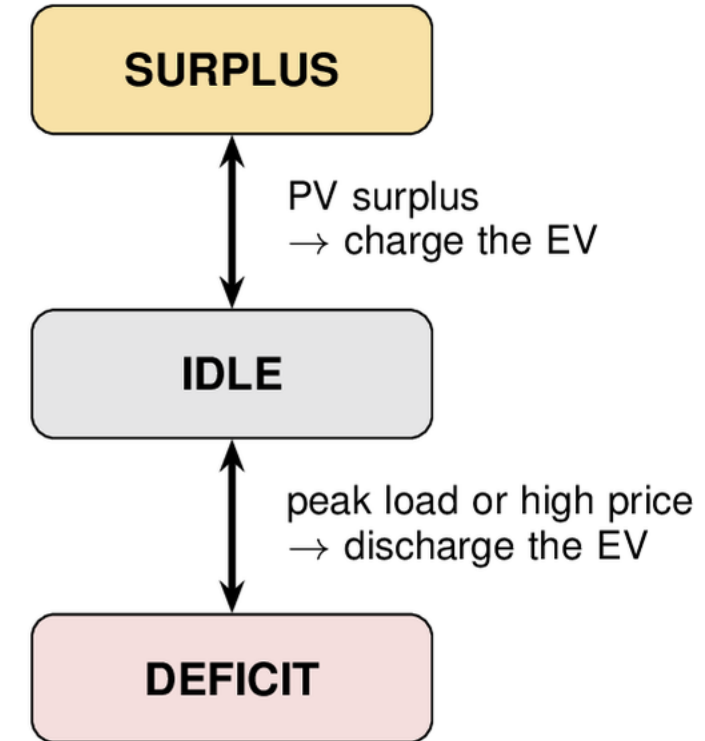
PART 4

# Applications

# Behind the Meter: V2B Dispatch

A state-based dispatch algorithm inside a building energy management system, designed for deployment rather than for a clean simulation:

- Three operating states driven by PV surplus, building deficit and price.
- A **state-transition debouncer** stops the controller oscillating on noisy forecasts.
- **Exponential backoff** keeps dispatch safe when the charger link drops — the failure mode the measured 45 s setup time makes real.
- Battery cost enters the objective directly: cycling throughput *and* calendar ageing away from a resting SOC.



*every transition passes the debouncer;  
departure SOC is a hard constraint*

Published, SAMI 2026.

# Islanded Operation: PV + BESS + V2X Smart Street

Grid-forming BESS, rooftop PV and V2X chargers serving a street section that must survive loss of supply. Frequency nadir after the disturbance:

| Strategy                   | Nadir           |
|----------------------------|-----------------|
| Proposed adaptive shedding | <b>49.50 Hz</b> |
| No buffering               | 48.78 Hz        |
| Conventional static UFLS   | 48.48 Hz        |
| No shedding                | 47.33 Hz        |

The V2X fleet is treated as a buffer with the measured ramp and the measured power limit — not as an ideal source.

## Under review

The corresponding frequency traces are part of a manuscript currently under review and are not reproduced in this recording.

PART 5

# Outlook

# Three Things to Take Away

**1. A bidirectional charger is neither symmetric nor instantaneous.**

23.7 kW in against 21.0 kW out, 13.5 s to reverse, 45.3 s to start. Measured, not assumed.

**2. A model that ignores this understates grid stress by 10–15%.**

The error is systematic and it is in the optimistic direction.

**3. So the order matters: measure the hardware, then model the fleet.**

Hardware constants → stochastic co-simulation → conclusions for the distribution operator.

# Where This Goes Next

## In progress

- Extending the hardware dataset: more vehicles, more charger types, mapped in the SIL lab.
- Unified co-simulation testbed on real **VSD distribution feeders** in the Košice region — a digital twin with measured constants.

## Collaboration

- Óbuda University, Budapest — machine-learning prediction of V2G availability.
- Východoslovenská distribučná (VSD) — field data and feeder models.

## Open questions

- Does the 13.5 s reversal shrink with the next charger generation, or is it protocol-bound?
- How much of the asymmetry is converter, how much is BMS policy? The two scale differently.
- What does a DSO actually procure from a fleet whose availability is a distribution, not a contract?

# Publication Record Behind This Talk

- **Three Decades of Electromobility: A Retrospective and Prospective Review of Forecasts, Technical Breakthroughs, and Grid Constraints** — survey, 1996–2026.
- **Comparative Assessment of Simulation Tools and a Proposed Co-Simulation Framework for Vehicle-to-Grid Integration** — CANDO EPE 2026.
- **Design of Black-Start and Islanded Control for a Resilient Smart Street with Integration of Photovoltaics, Battery Storage and V2X Infrastructure.**
- **A Resilient, State-Based Dispatch Algorithm for Vehicle-to-Building (V2B) Integration** — SAMI 2026.

**Thank you for your attention.**

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