# Modelling and (Co-)simulation of power systems, controls and components for analysing complex energy systems

Workshop on Software Tools for Power System Modelling and Analysis

University College Dublin – 11th October 2013

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# About Co-Simulation

# Co-Simulation Motivation

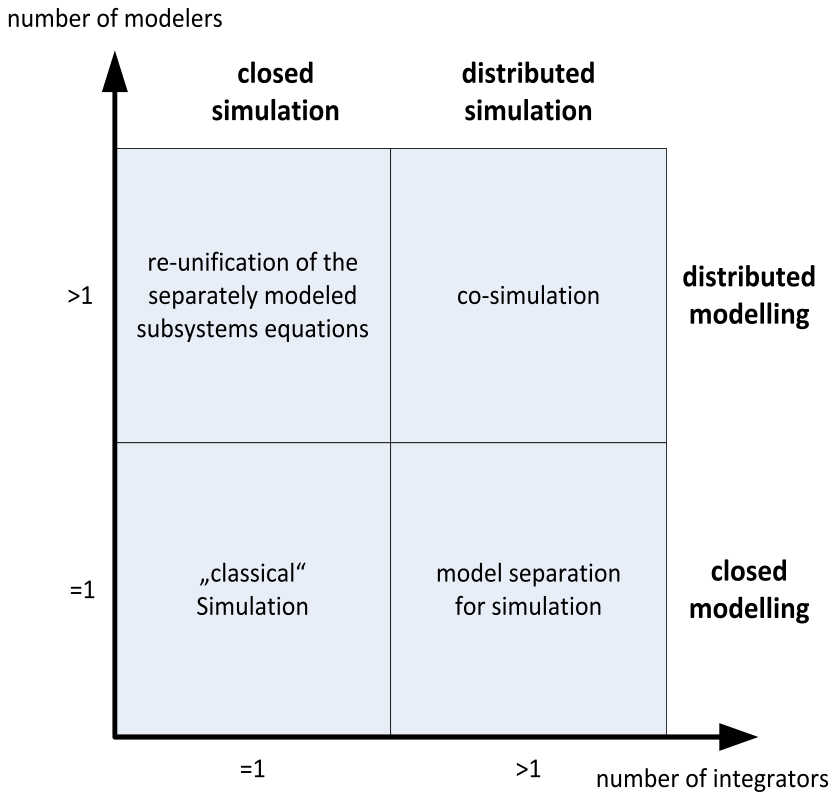
- Multi-domain problems not covered in one tool
  - Electrical power system
  - Communication system
  - Controls / SCADA
- Different simulation time steps
- Different concepts: continuous time and discrete event time systems
- Use existing highly complex and detailed models
- Integration of real components
- Scalability and flexibility

→ **Combine** different **dedicated** simulation tools and domains

→ **Analyse** different **subsystems** and their interactions

# Co-Simulation Overview

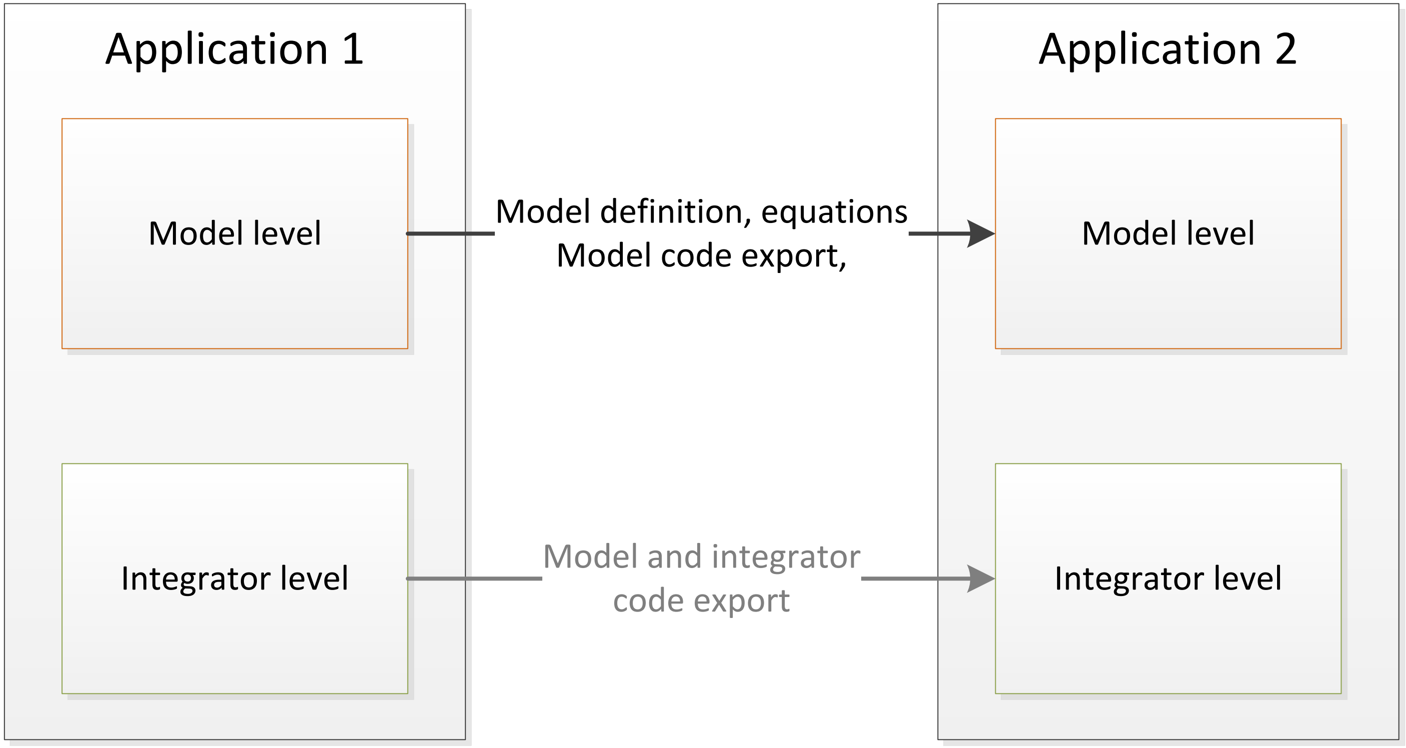
- Various types of modelling and simulation:




Source: M. Geimer, T. Krüger, P. Linsel, *Co-Simulation, gekoppelte Simulation oder Simulatorkopplung?* Simulation 2006.

# Co-Simulation (1)

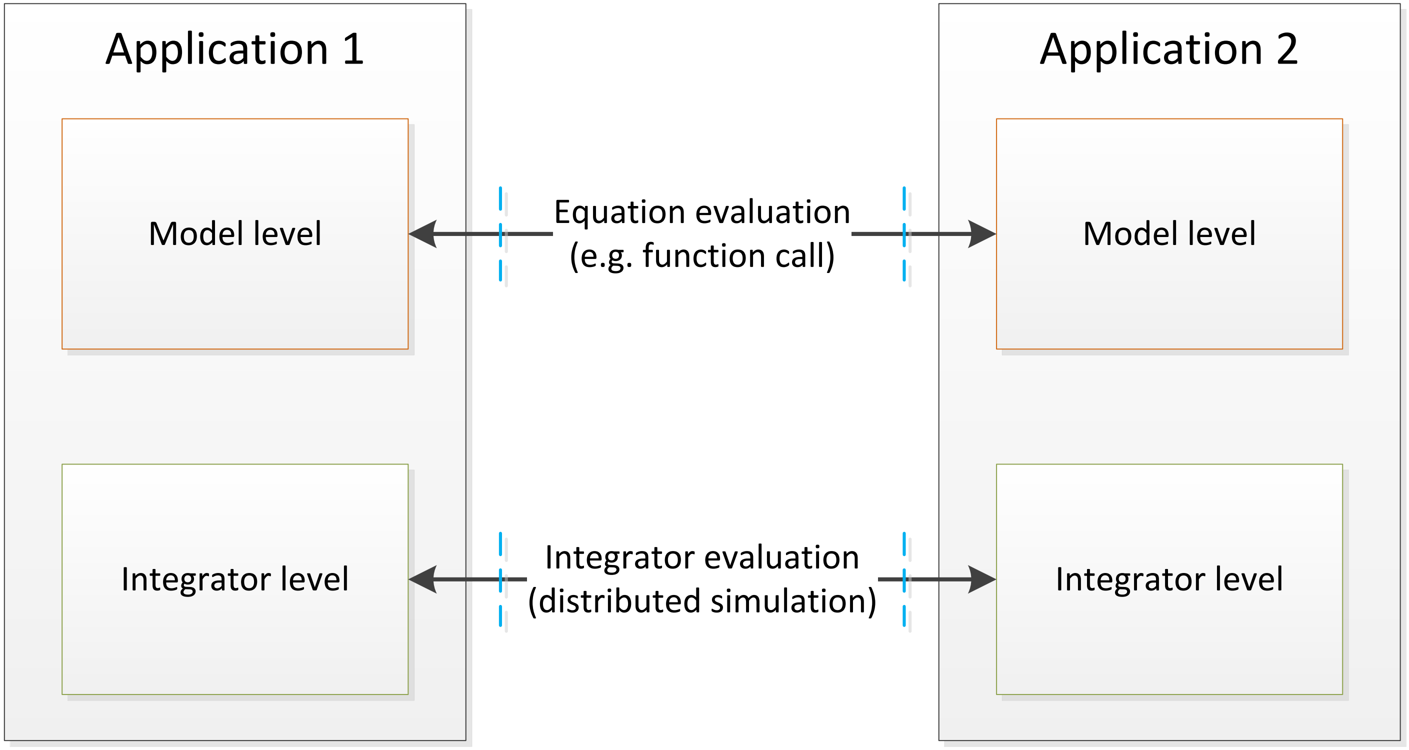
- Coupling on model level




Source: M. Geimer, T. Krüger, P. Linsel, *Co-Simulation, gekoppelte Simulation oder Simulatorkopplung?* Simulation 2006.

# Co-Simulation (2)

- Coupling on integrator level

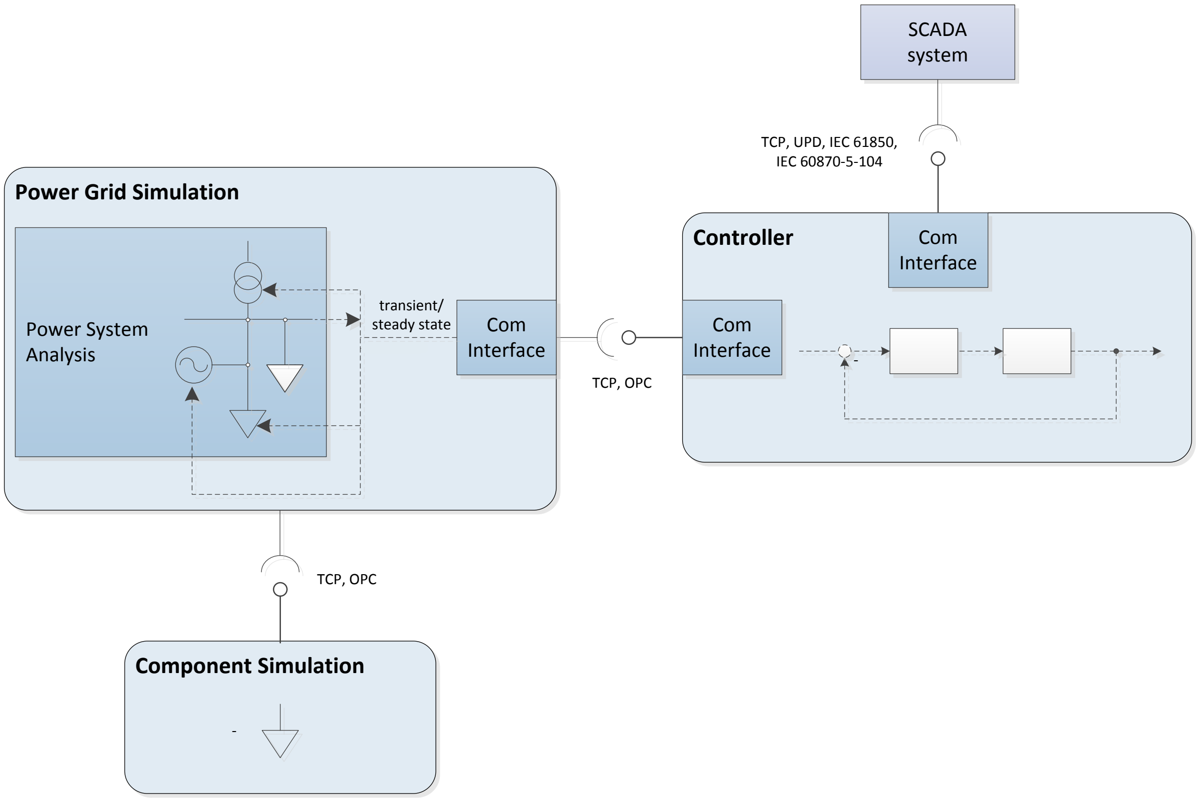



Source: M. Geimer, T. Krüger, P. Linsel, *Co-Simulation, gekoppelte Simulation oder Simulatorkopplung?* Simulation 2006.

# Simulation challenge: power system and controls

System with controller to fulfilll certain functionalities: e.g., voltage control task consists typically of the following parts:

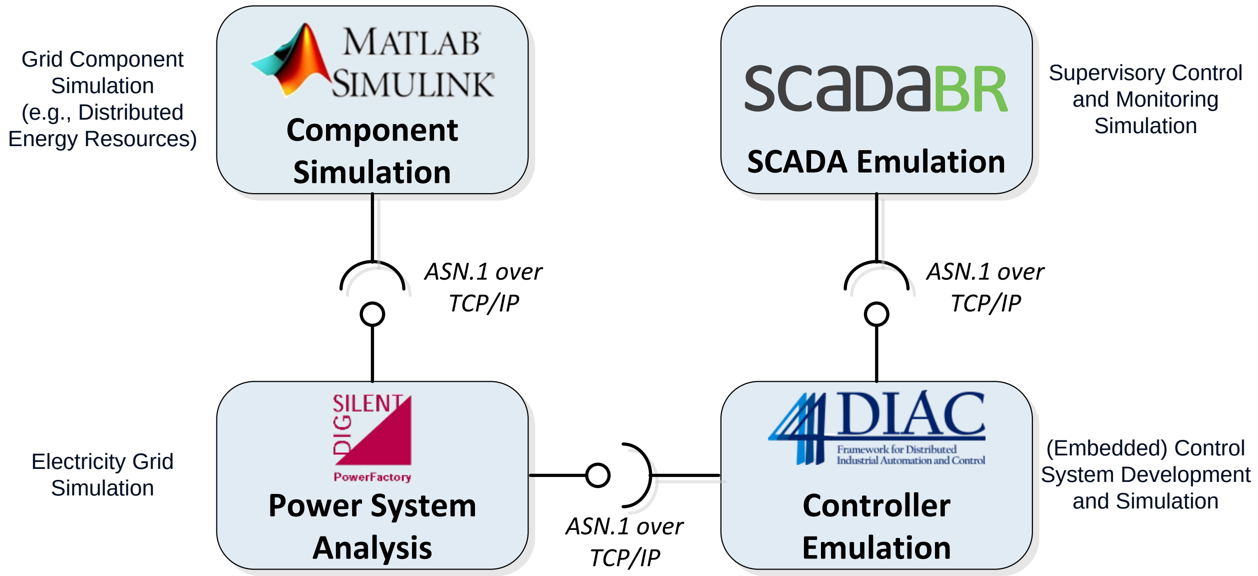
- Power system model
- Component models
- Controller /
- SCADA



# Co-Simulation approach

In this simulation coupling, the individual simulators run in real time and parallel, exchanging results and set-points.

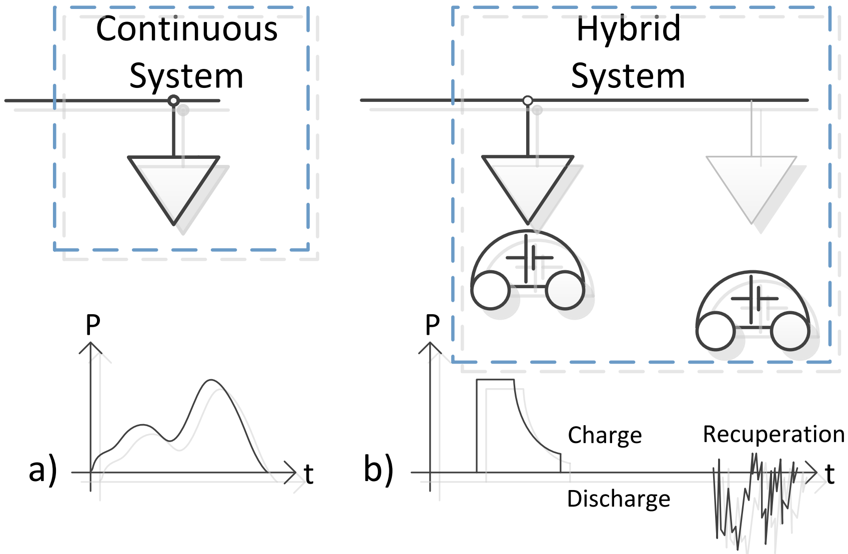
- PowerFactory ←→ Matlab / SimPowerSystem
- PowerFactory ←→ 4DIAC (distributed control system)
- 4DIAC ←→ ScadaBR



# Simulation challenge: dynamic EV charging

Need for simulation of :

- impact of the electric vehicle energy demand
  → energy depends on trip length, temperature, etc.
- test charging management strategies
  → charging power is **not static**




→ Hybrid system: discontinuity taking place at discrete events

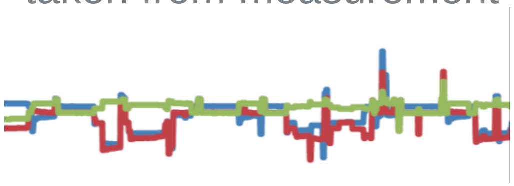
→ Need for simulation of the EV trip to get the energy needed to recharge

→ **Combine** the **power system** simulation with the simulation of the **discharging**

# Simulation challenge: dynamic EV charging

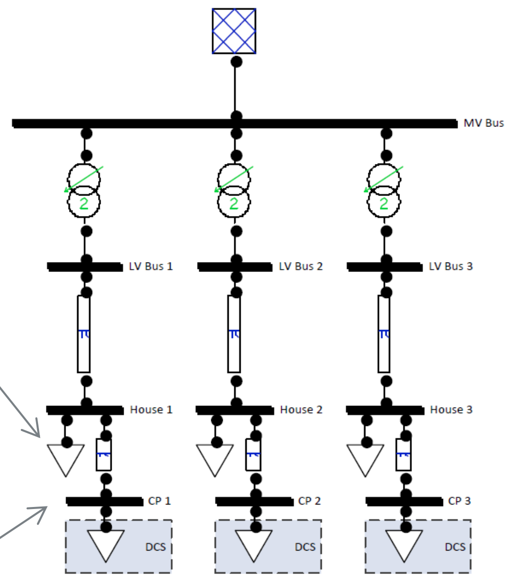
**household load profiles**

taken from measurement



**small scale distribution grid**

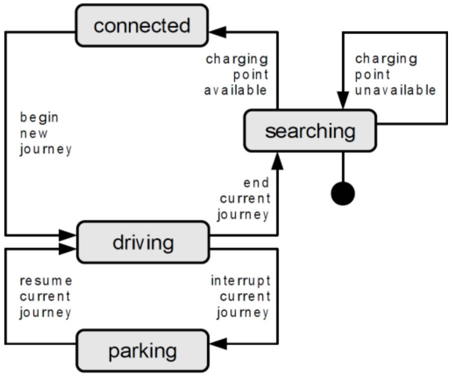
medium/low voltage network with consumers




**realistic battery model**

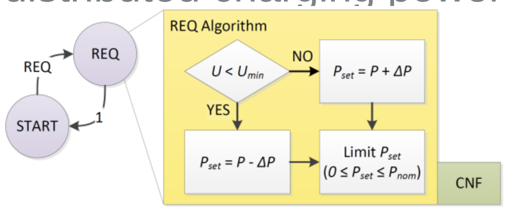
**stochastic driving patterns**

derived from real data




**charging control algorithm**

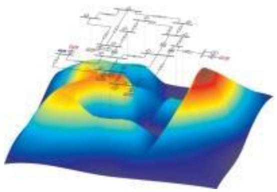
distributed charging power



# Simulation tools

## Modelica

- dedicated *multi-domain* (physics) simulation language
- supports *event handling*
- *acausal simulation* (continuous time-based simulation)



## PSAT

- Power system analysis toolbox
- Matlab/Simulink and Octave
- *continuous time-based* simulation

## 4Diac / Forte

- framework for distributed control systems
- intended for *event based* controls in *real time*
- open source IDE and Runtime

## GridLAB-D

- multi-agent based power system simulation
- includes various energy-related modules
- *discrete event-based* simulation

**Main challenge**

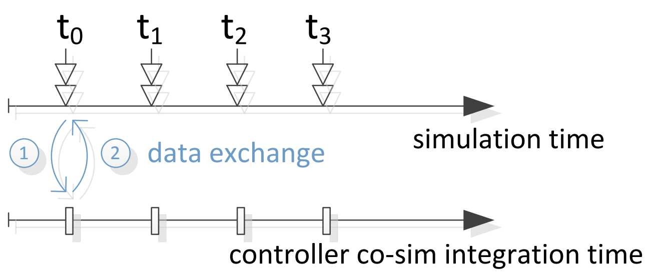
→ coupling discrete event-based simulation with continuous time-based models.

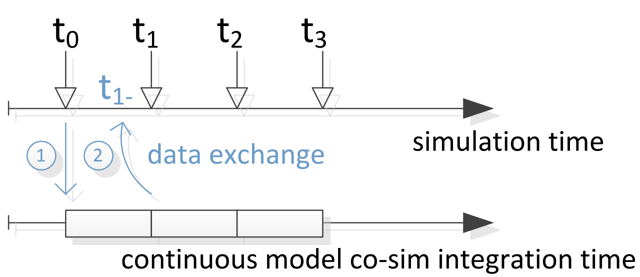
# Co-Simulation Interfaces and Mechanisms

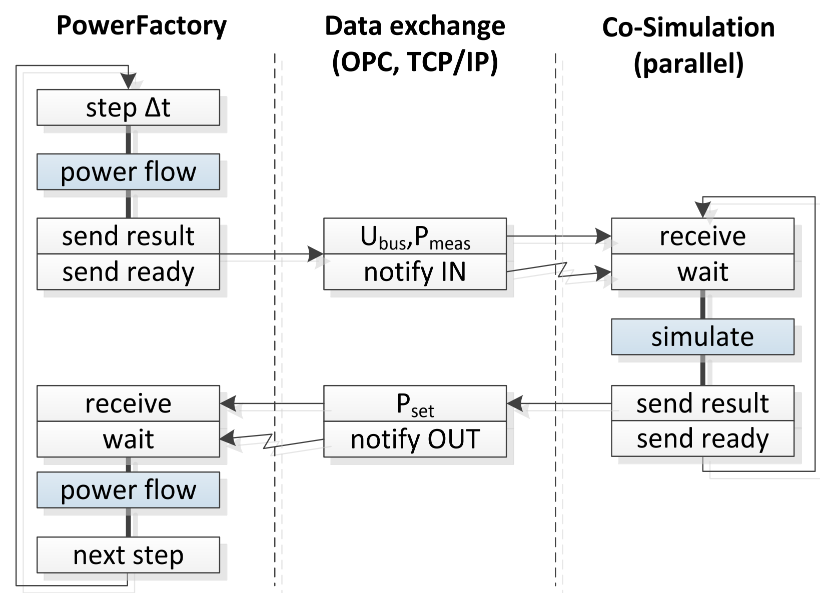
# Co-Simulation: synchronous, sequentially

- Co-Simulation run sequentially and blocks until the results are available

- simulate same time step twice



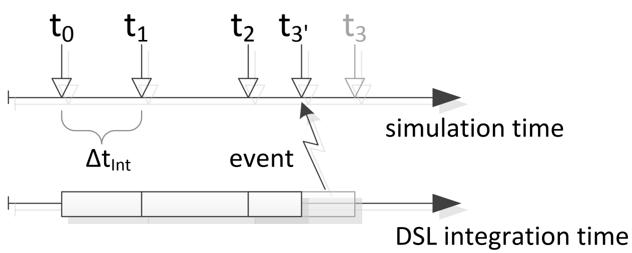



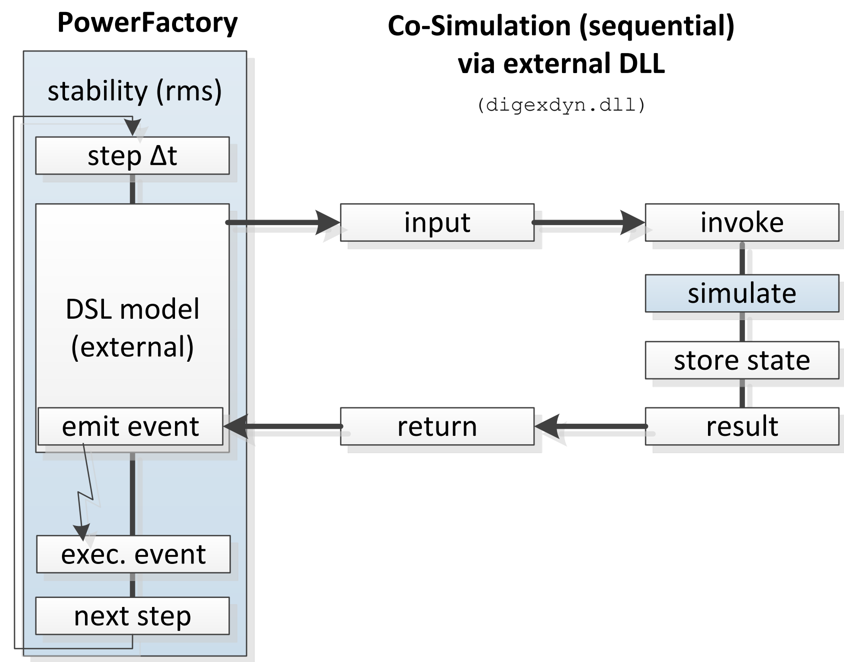

- simulate at next time step

M. Stifter, R. Schwalbe, F. Andrén, and T. Strasser, "Steady-state co-simulation with PowerFactory," in Modeling and Simulation of Cyber-Physical Energy Systems, Berkeley, California, 2013.

# Co-Simulation: asynchronous, parallel

- Co-Simulation via external DLL

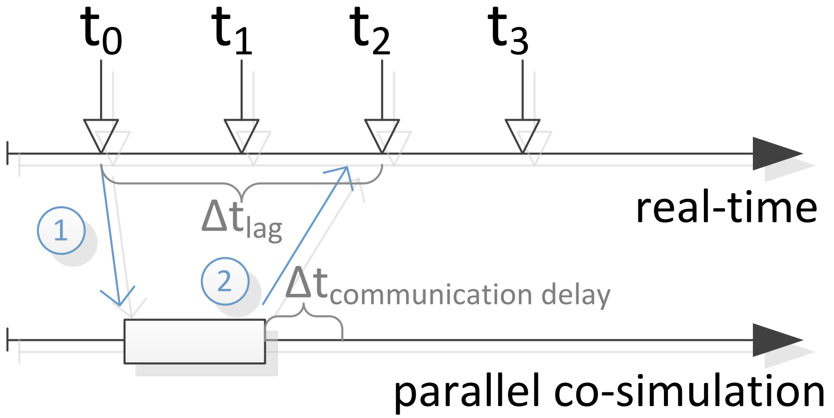



M. Stifter, R. Schwalbe, F. Andrén, and T. Strasser, “Steady-state co-simulation with PowerFactory,” in Modeling and Simulation of Cyber-Physical Energy Systems, Berkeley, California, 2013.

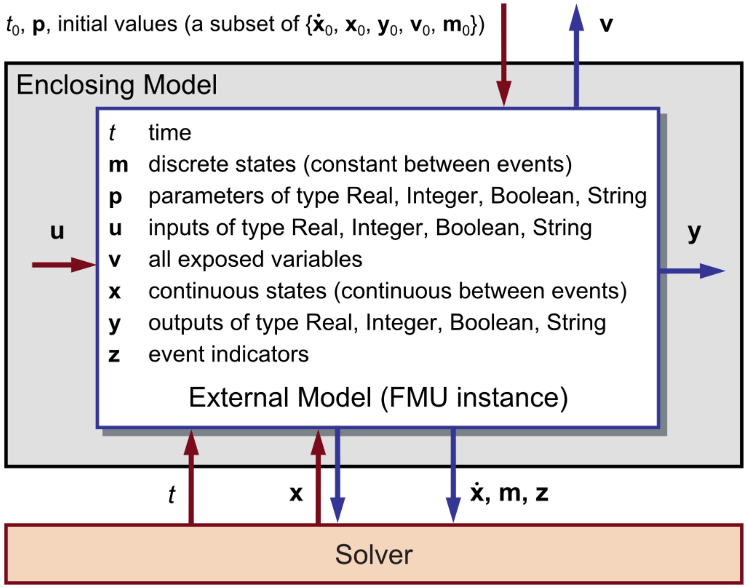
# Co-Simulation: real time synchronisation

- Dynamic behaviour
  - C-HIL / Regler
  - Filters
- Synchronisation with system time / scaled time base



# Functional Mock-Up Interface for Model Exchange

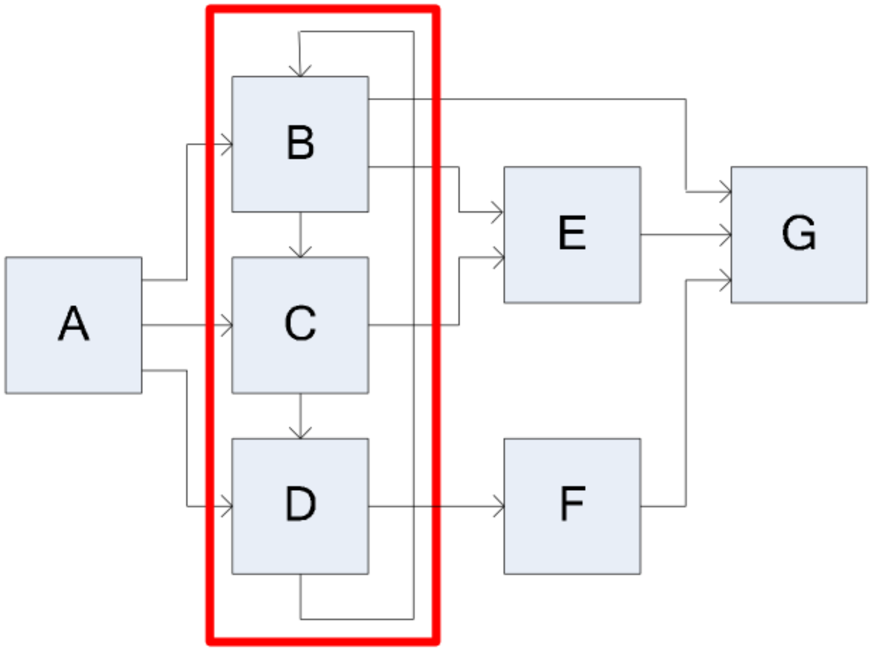
- FMI: A standarized API for describing models of DAE-based modeling environments (Modelica, Simulink, etc)
- Functional Mock-Up Unit
  - model *interface* (shared library)
  - model *description* (XML file)
- Executable according to C API
  - *low-level* approach
  - most *fundamental* functionalities only
  - tool/platform *independent*




- Gaining popularity among tool vendors
  - CATIA, Simulink, OpenModelica, Dymola, JModelica, SimulationX, etc.

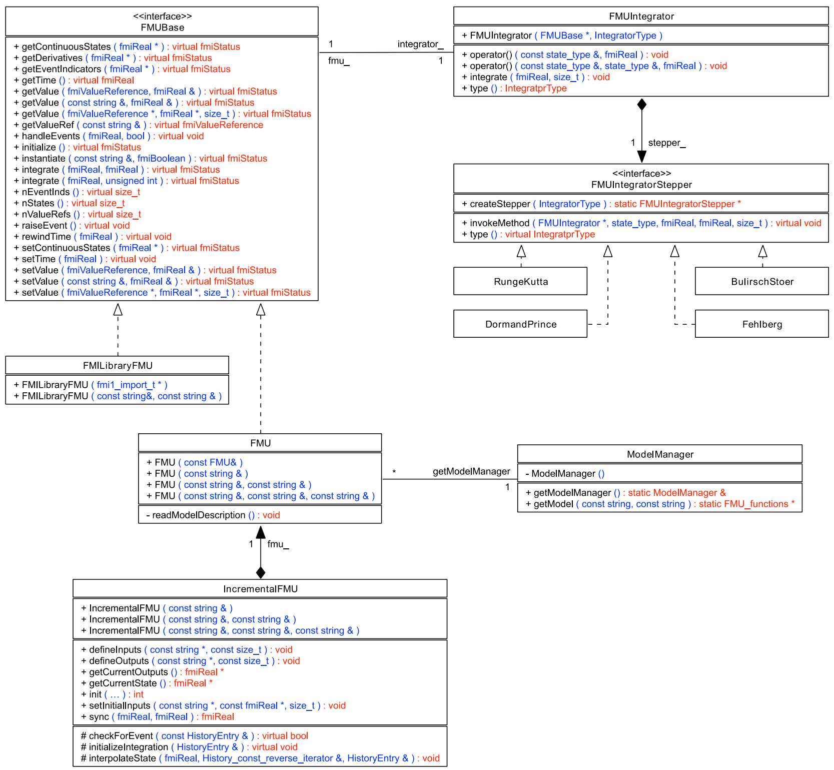
# Simulation environment for FMI for Model Exchange

- Simulation *master algorithm* not covered by FMI specification
  - tool independence
- Requirements
  - initialization
  - numerical integration
  - event handling
  - orchestration
- Well suited for simulation tools focusing on *continuous time-based* modelling
- What about plug-ins for *discrete event-driven* simulation tools?



# The FMI++ library

- High-level **access** to FMUs
  - model initialization, get/set variable by name, etc.
- High-level FMU **functionalities**
  - integrators, advanced event handling, rollback mechanism, look-ahead predictions, etc.
- **Open-source** C++ library
  - tested on Linux and Windows (MinGW/GCC and Visual Studio)
  - available at [sourceforge.net](sourceforge.net)

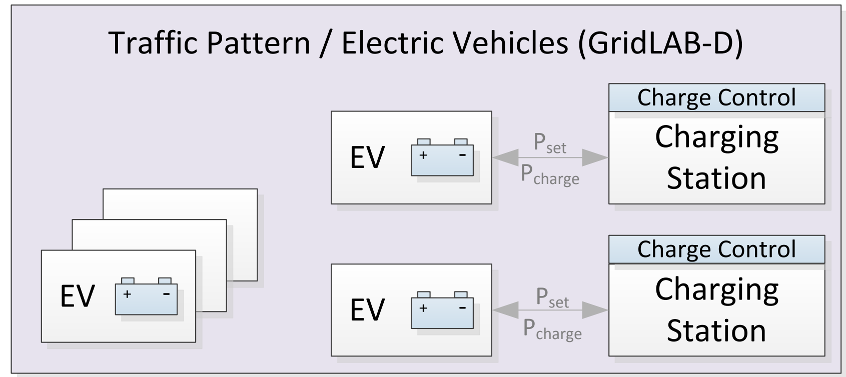


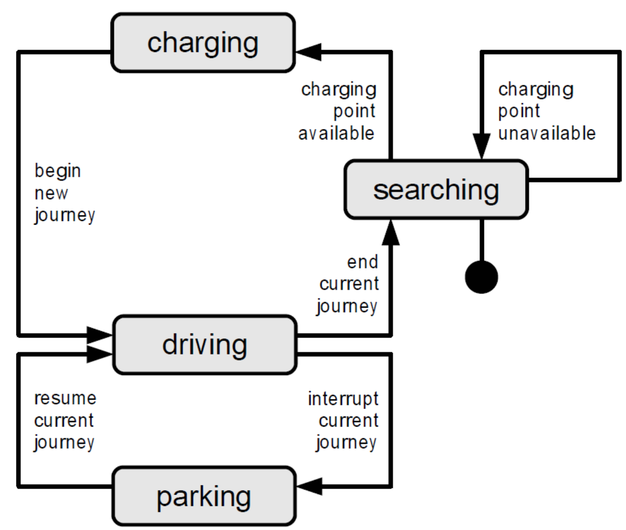

→ **synchronous interaction** between **discrete event-based** environment and a **continuous equation-based** component

# Example Application: Controlled Charging

# GridLAB-D as co-simulation master

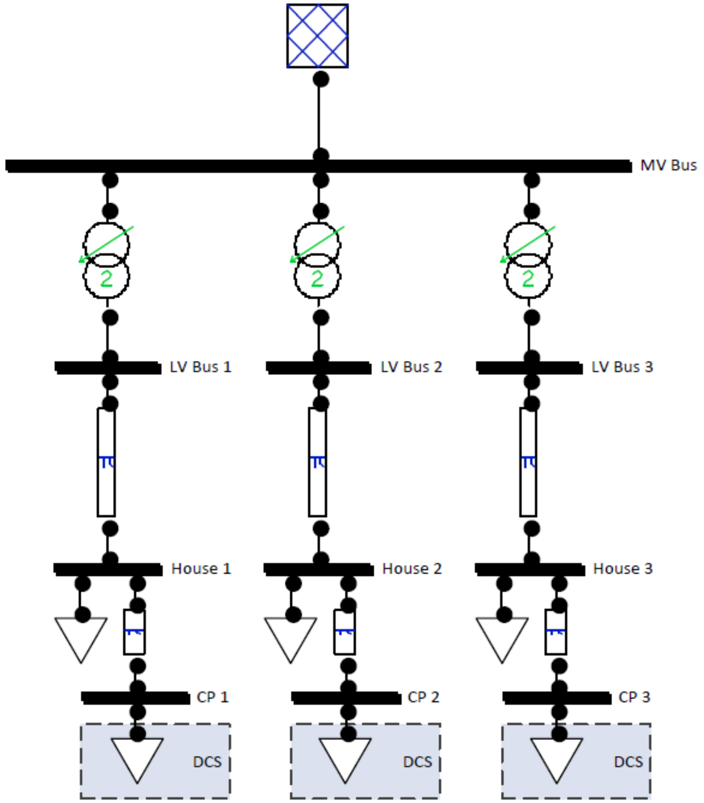
- **Discrete event-based** simulator as **co-simulation master**
  - GridLAB-D's core functionalities deployed as master algorithm
- EV model:
  - agent based behavior over time (individual driving patterns)
  - energy demand due to the trip
  - charging station handling
- Interface
  - plugin validated tools and continuous models via standardized interface (FMI & FMI++, etc.)



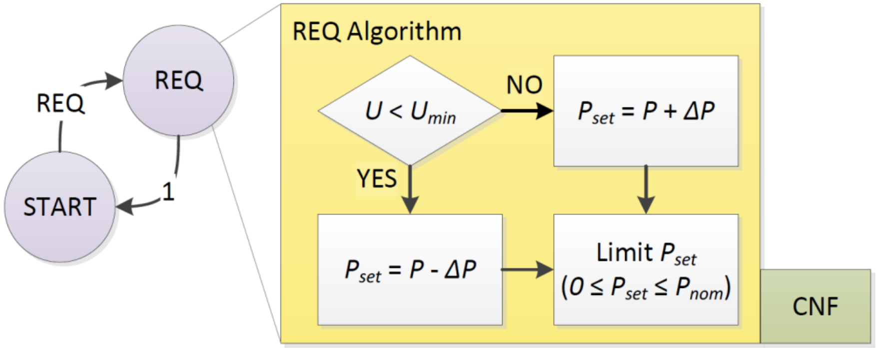
# PSAT (Octave)

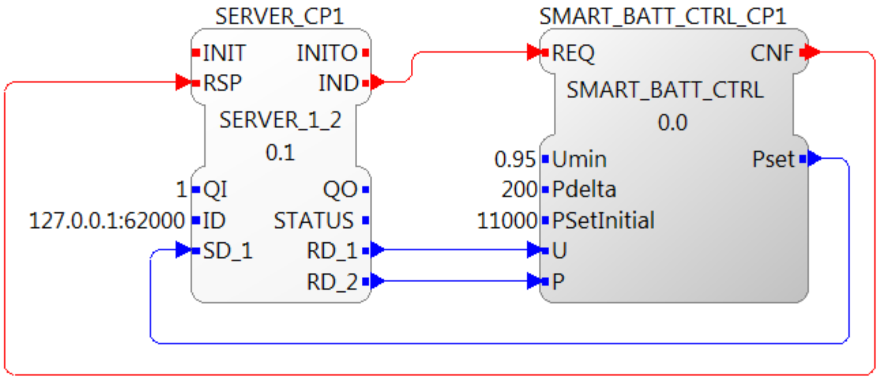
- **Power system analysis**
  - power flow to determine bus voltages
- Network model:
  - medium voltage network with low voltage networks
  - load presenting household and charging station
- Interface:
  - Connect to GridLAB-D via Octave API
  - + thin wrapper to access C arrays instead of data types



# 4Diac / FORTE

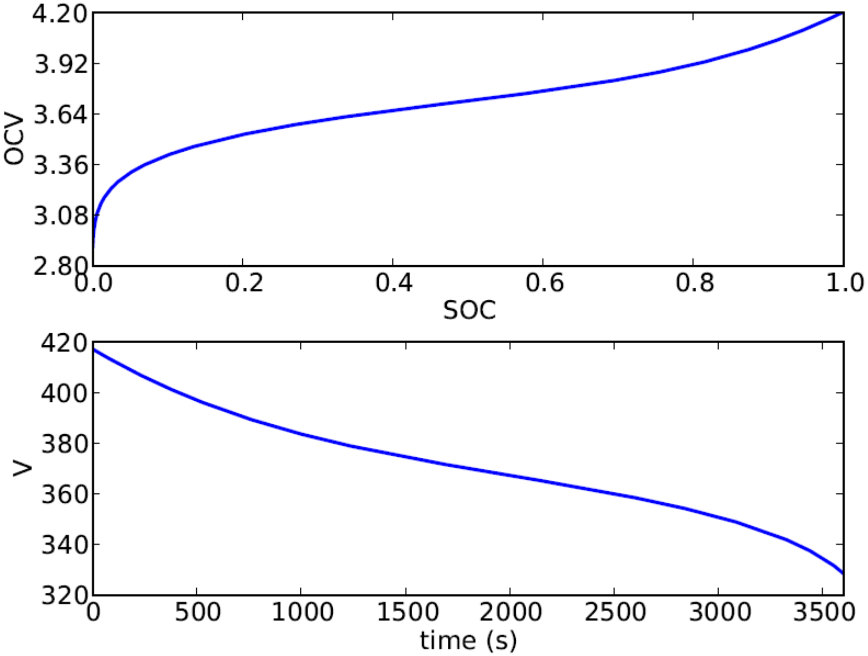
- **Distributed control system**
  - IEC 61499 reference model for distributed automation
- Model / control
  - Local voltage control (anxilliary service) → keep voltage limits
- Interface:
  - TCP/IP socket communication (ASN.1 format)
  - suitable for embedded system environments



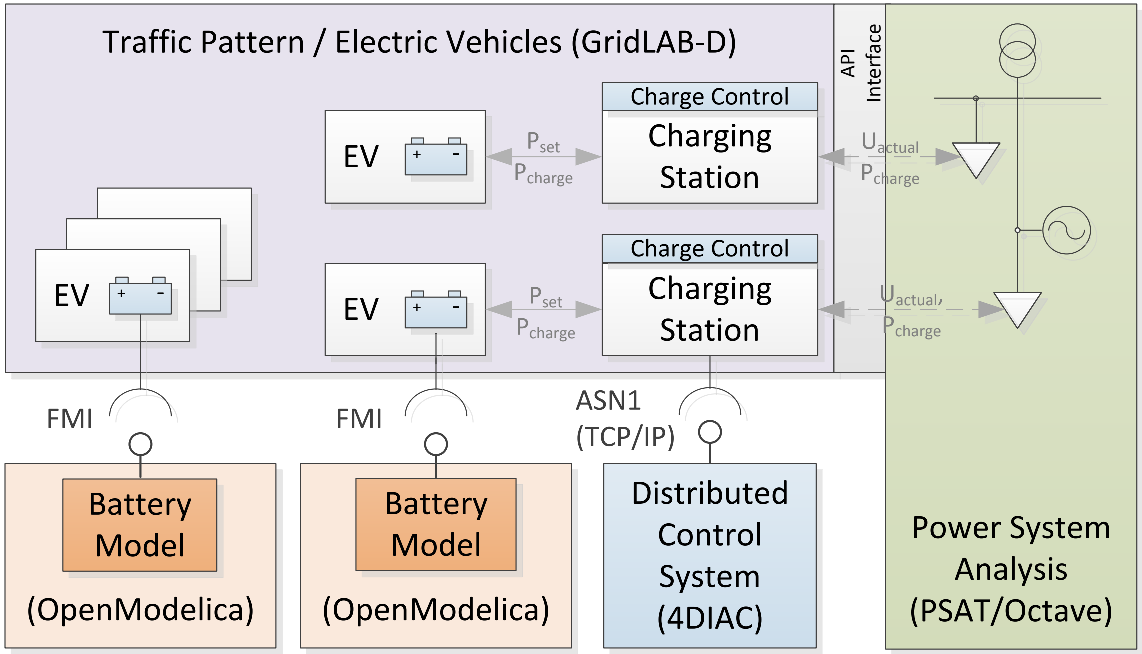
# OpenModelica

- **multi-domain** (physics) simulation language
  - supports event handling
  - acausal simulation (continuous time-based simulation)
- Model
  - Industry proofed library for a detailed Li-Ion battery model
  - constant current / constant voltage charger
- Interface
  - plug-in *continuous time-based* models **via FMI++**



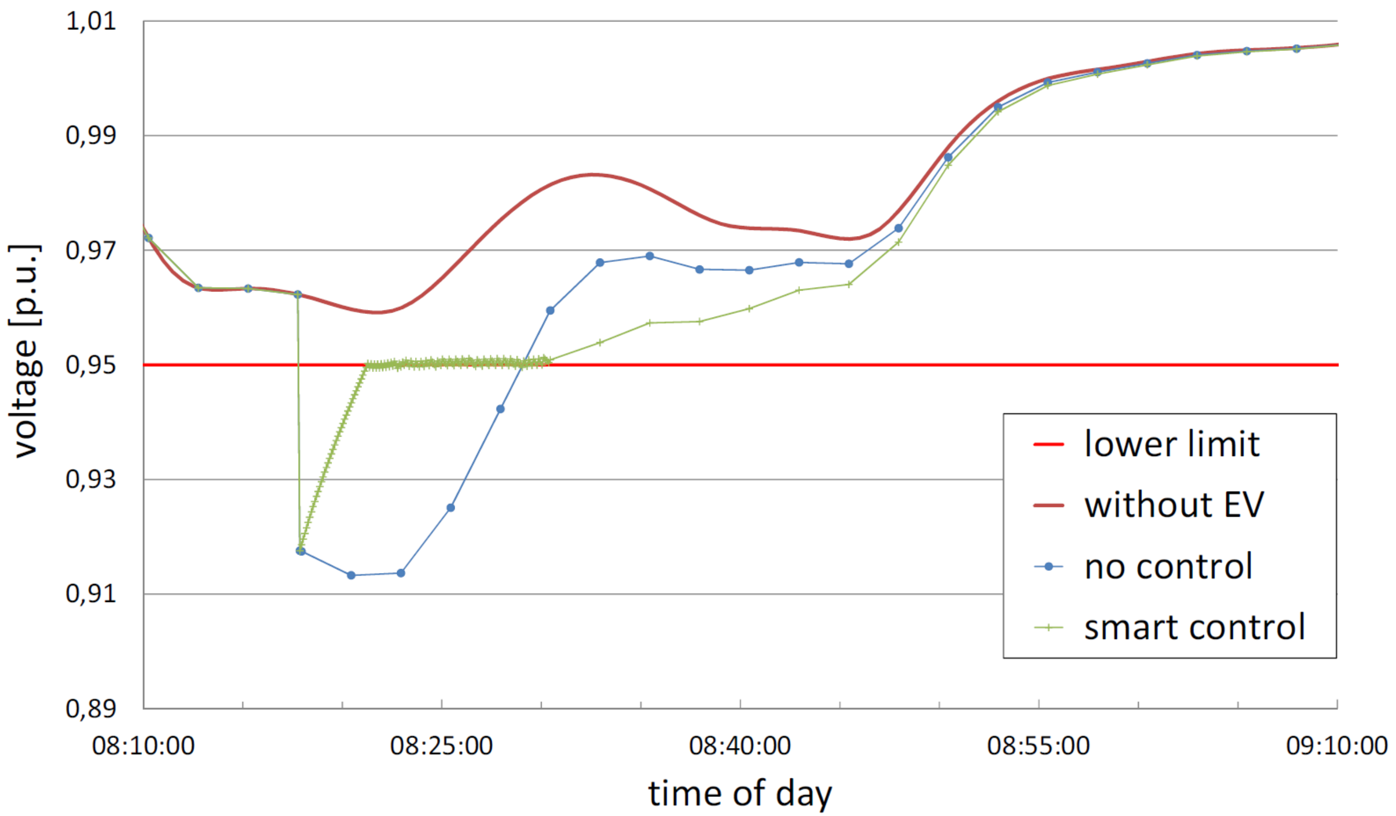
# Co-Sim Power System, EVs, Components and Controls

- Open source based approach of electric vehicle energy management for voltage control



# Results

- Voltage during charging process



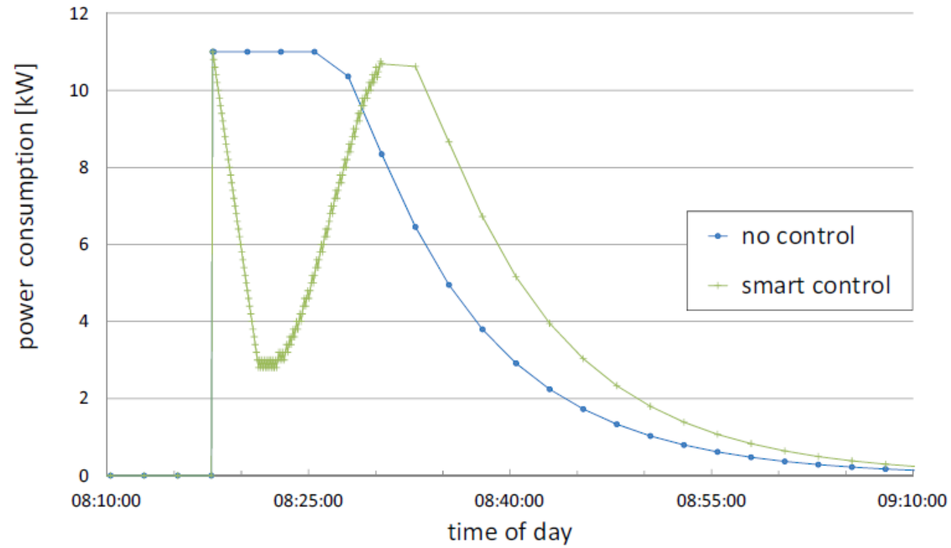

Simulation time step varies with time due to updates of control algorithm

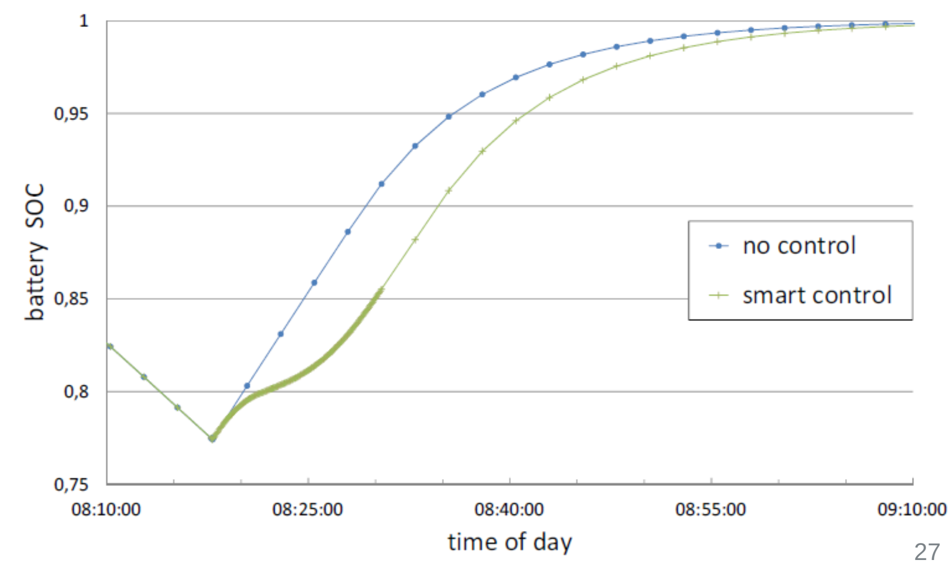
# Results

- Reduced charging power has impact on battery's SOC

**Increased number of updates**
controller notifies the simulation core more frequently, thus increasing the simulation step resolution.

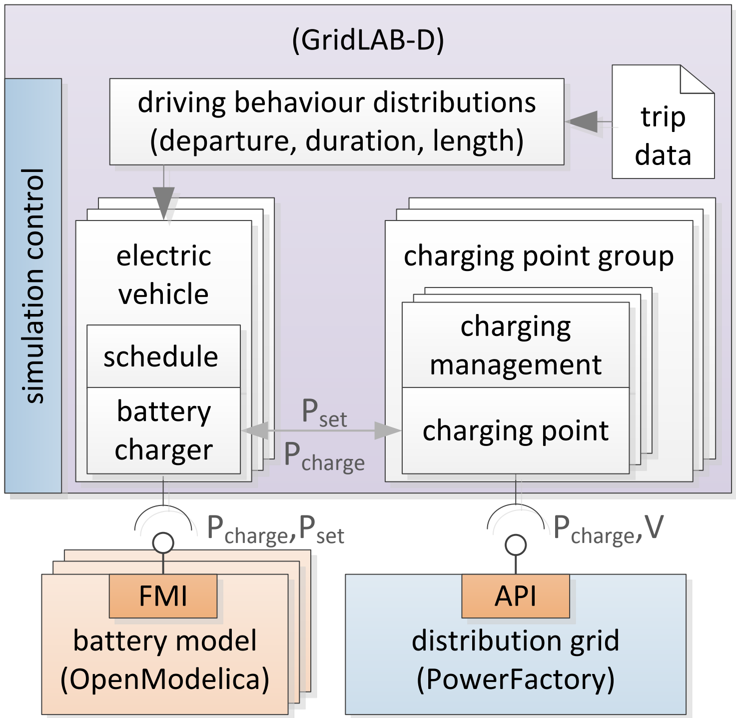
→ Investigate interesting dynamic effects more precisely.

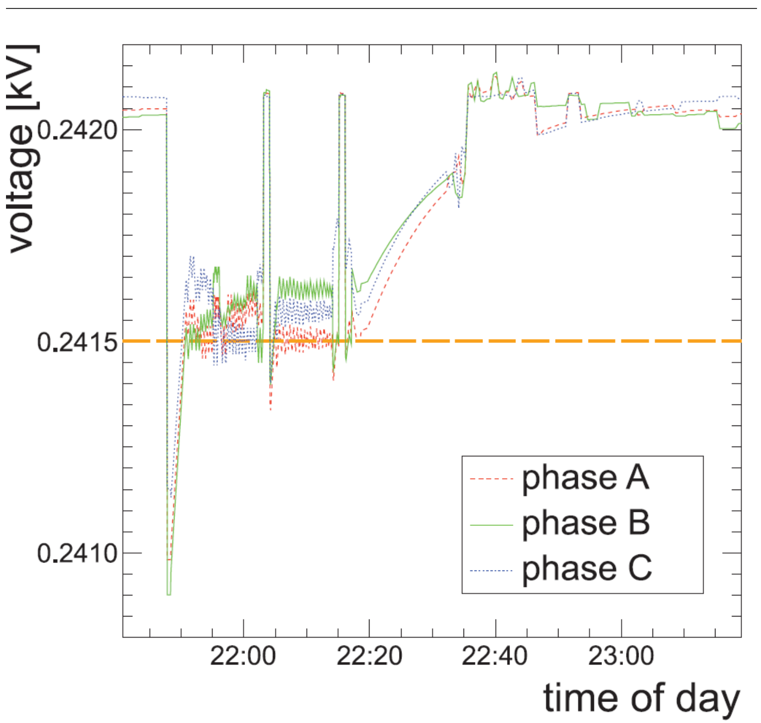


# Co-Sim Power System and Control

- Electric Vehicle charge management for voltage control



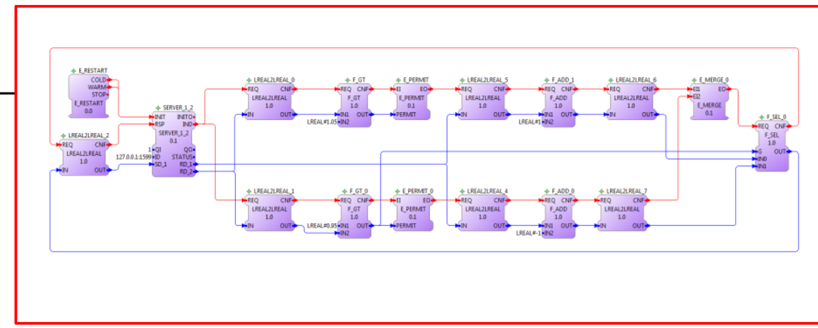




P. Palensky, E. Widl, A. Elsheikh, and M. Stifter, "Modeling intelligent energy systems: Lessons learned from a flexible-demand EV charging management," *Smart Grids, IEEE Transactions on (accepted)*, 2013.

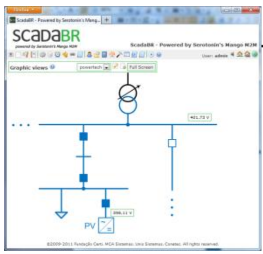
# Co-Sim Power System, Components and Control System

- Detailed battery model based on chemical equations + Energy management
- Power Flow for every time step

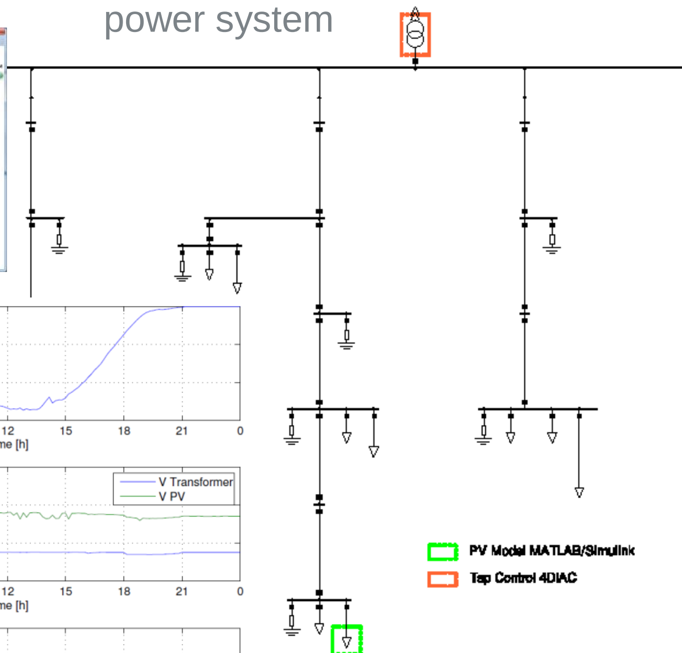
control system

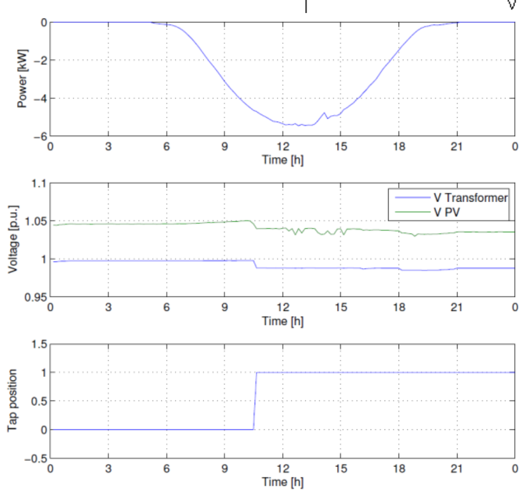


SCADA



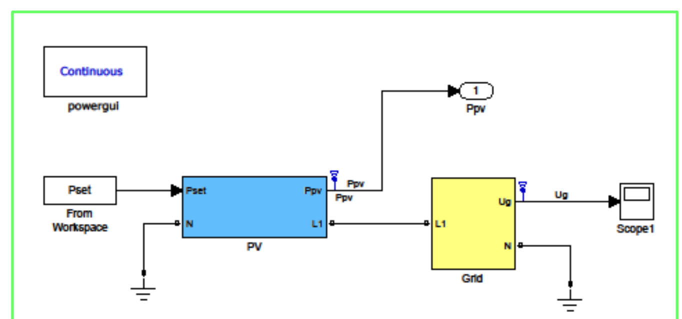

power system



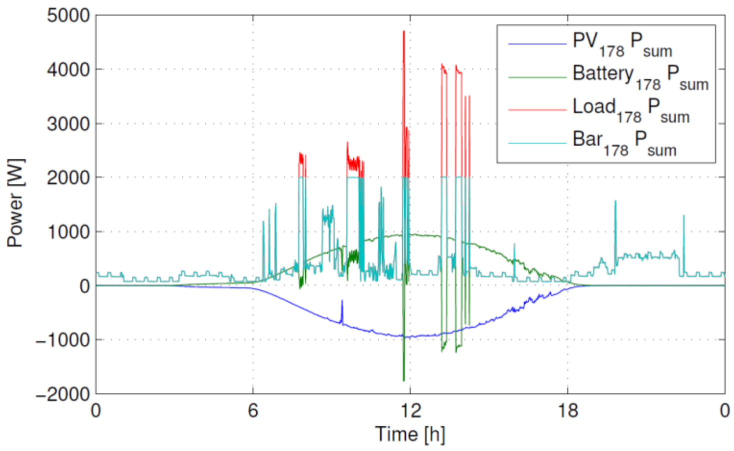

simulation results

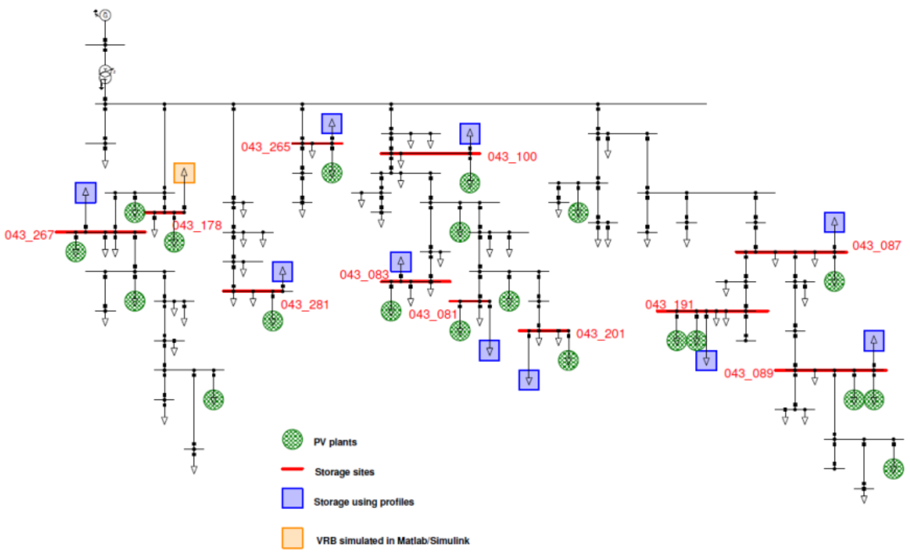
PV system + inverter



# Co-Sim Power System with Electrical Energy Storage

- Detailed battery model based on chemical equations + Energy management
- Power Flow for every time step

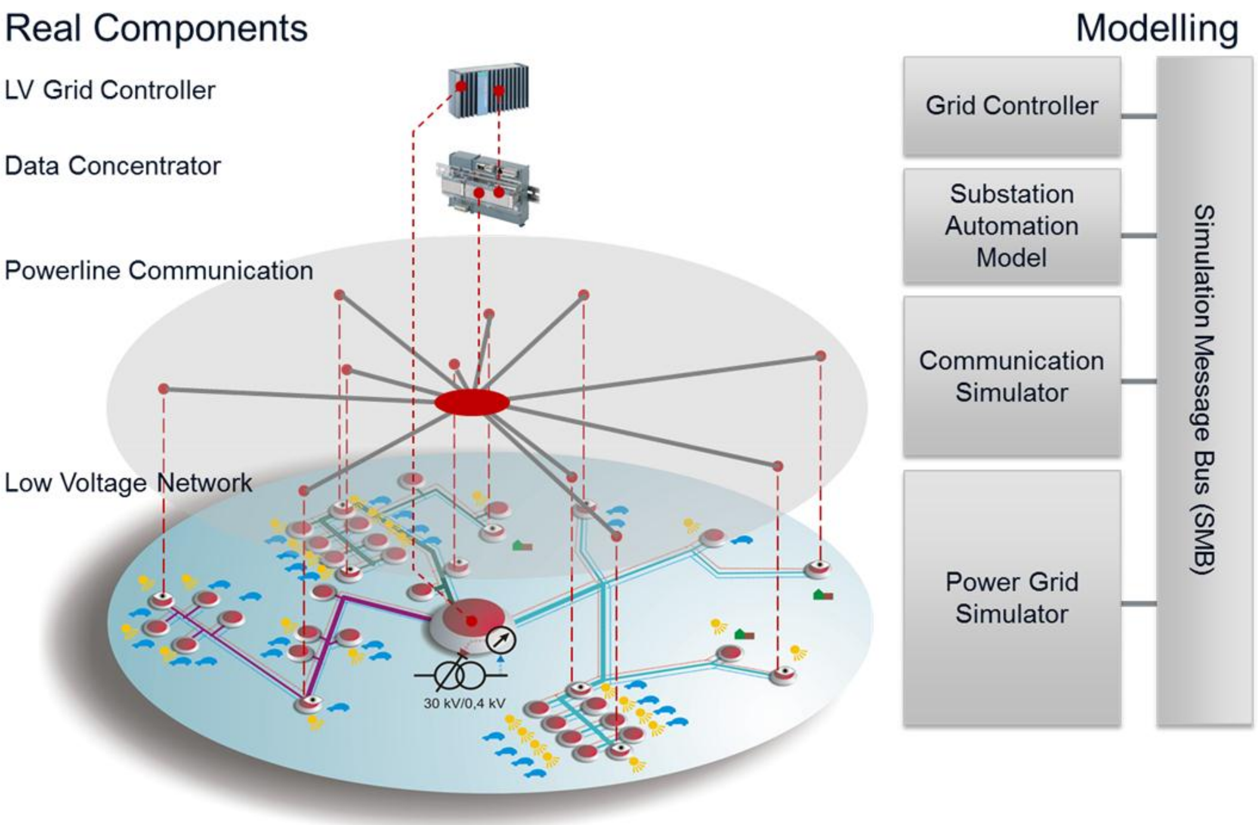



F. Andrén, M. Stifter, T. Strasser, and D. Burnier de Castro, "Framework for co-ordinated simulation of power networks and components in smart grids using common communication protocols," in IECON 2011 - 37th

# Co-Sim Power System, Communication and Control

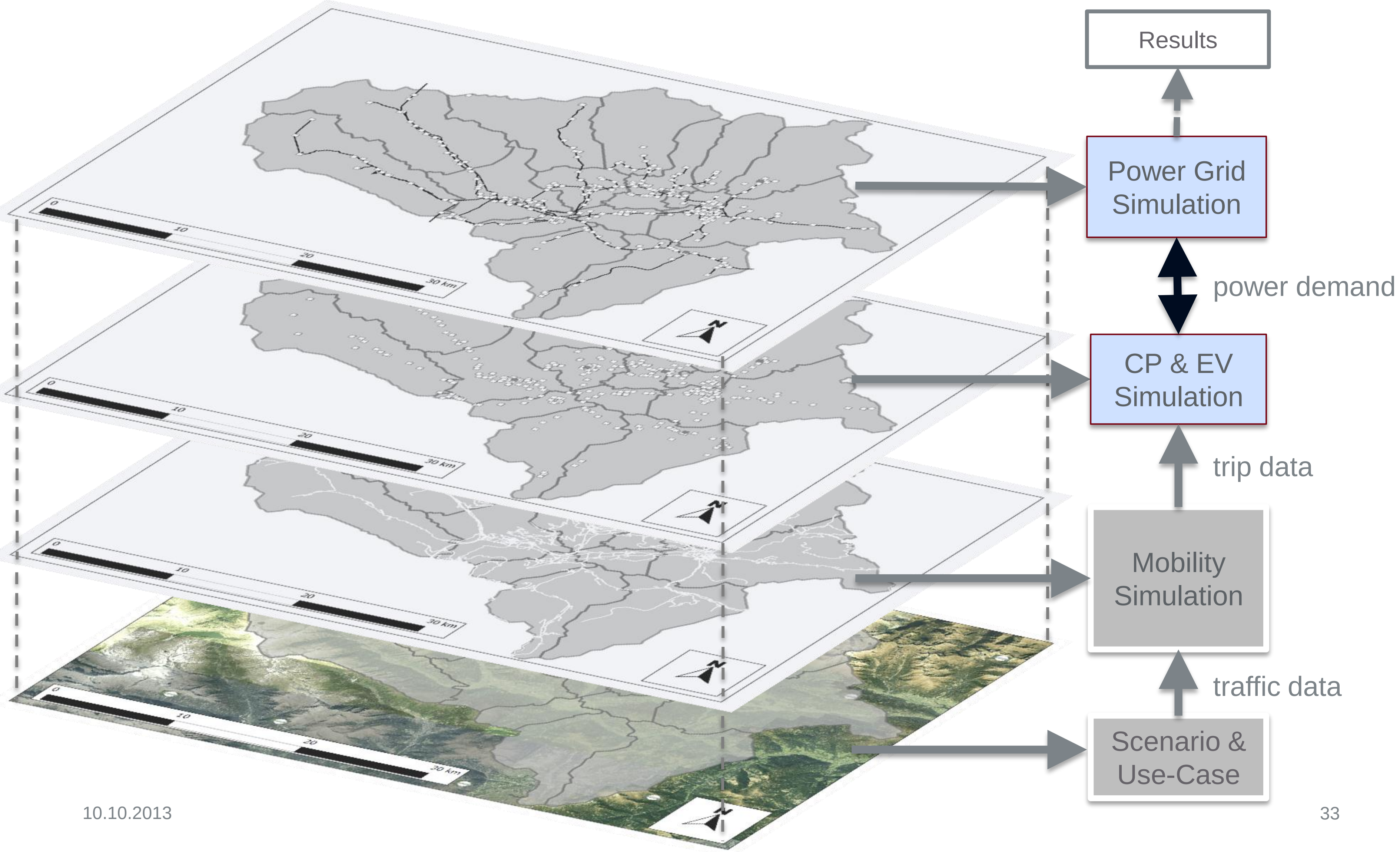
- Co-Simulation with PowerFactory API: Loose Coupling via Message Bus




M. Ralf, K. Friederich, F. Mario, and S. Matthias, "Loose coupling architecture for co-simulation of heterogeneous components – support of controller prototyping for smart grid applications," in *submitted to IECON 2013 - 39th Annual Conference on IEEE Industrial Electronics Society*, Vienna, Austria, 2013.

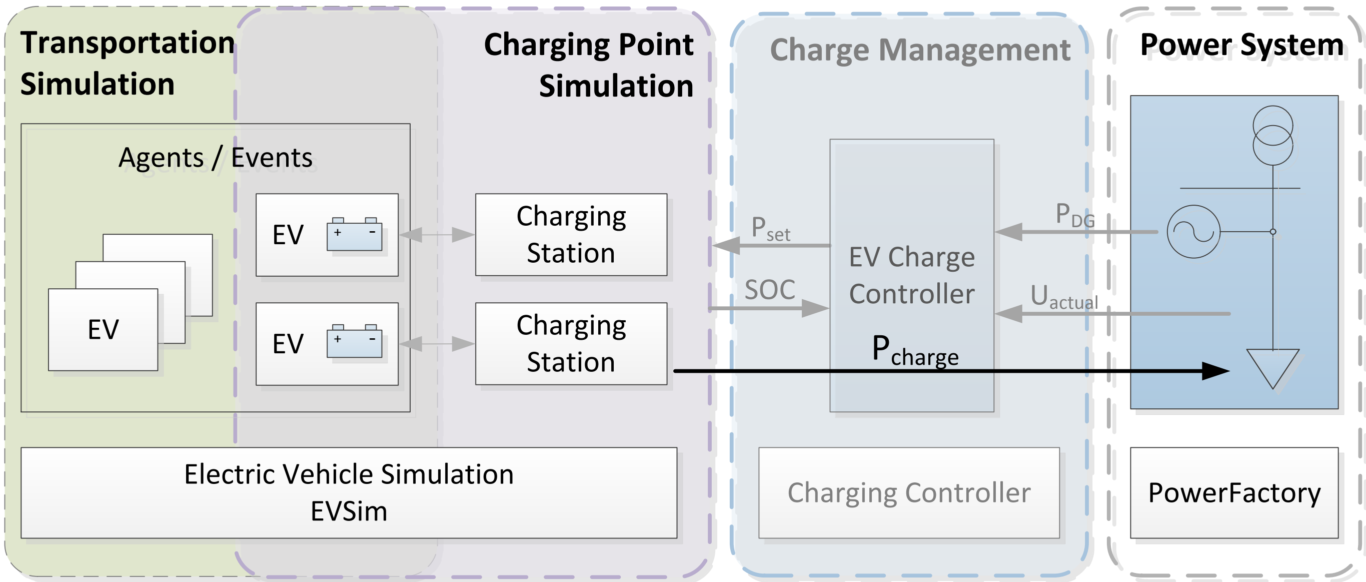
# Electric Vehicle Simulation Environment

# EV Simulation Environment



# EVSim - Architecture

## Architecture




**Specification** for the simulation scenario

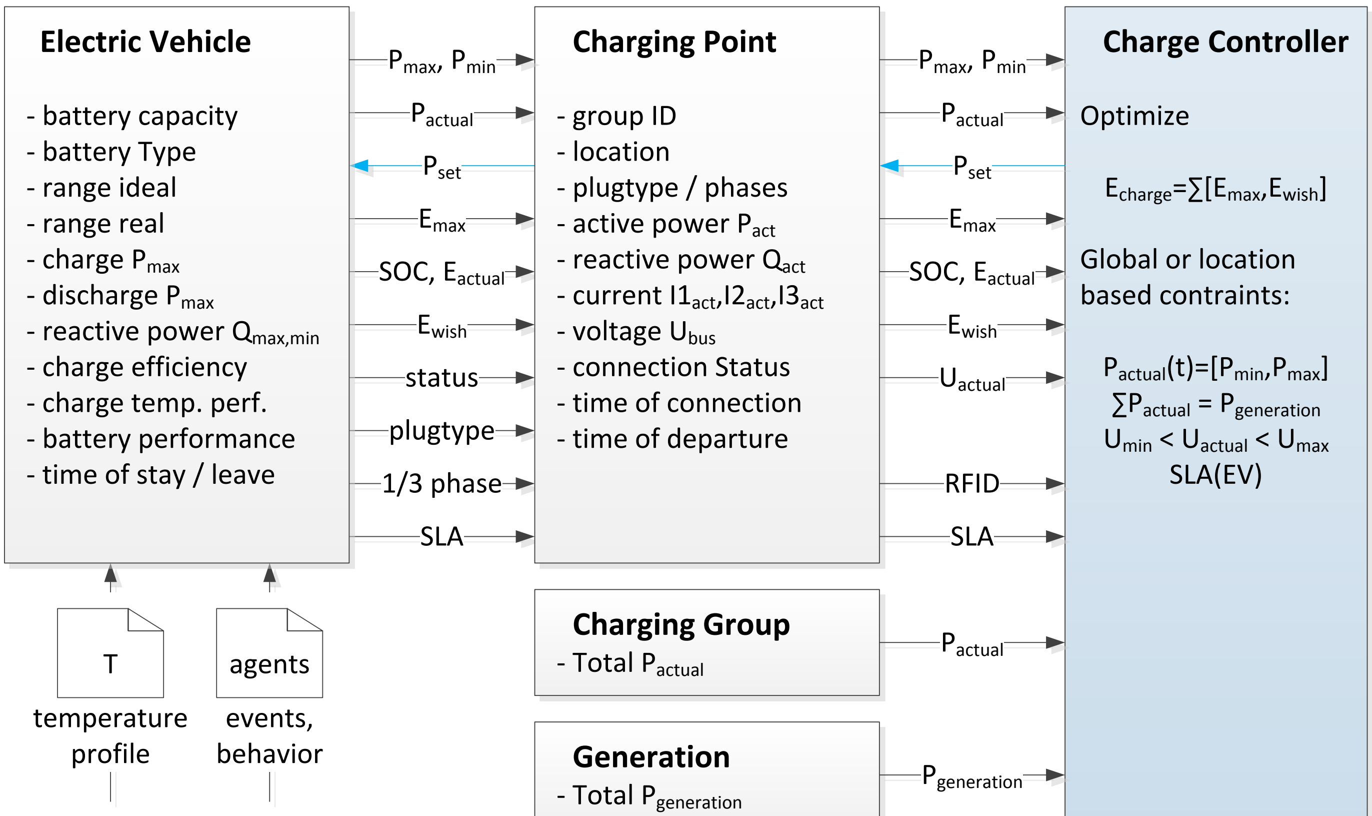
- EV + battery, plug types including efficiency (temperature, losses)
- locations and charging points
- distributed generation (location based)

# EVSim - Functionality

- **Configuration**
  - simulation time: start / stop / step-size / loop / real-time
  - temperature dependency / performance of the battery
- **Output** (csv)
  - SOC, power
- **Interfacing** / co-simulation
  - OPC
  - OCPP (Open Charge Point Protocol)
- **Behaviour**
  - connection / disconnection handling, authorisation
  - time to plug / unplug
  - charging noise
- **Charging algorithm**
  - G2V, V2G, matching with local generation

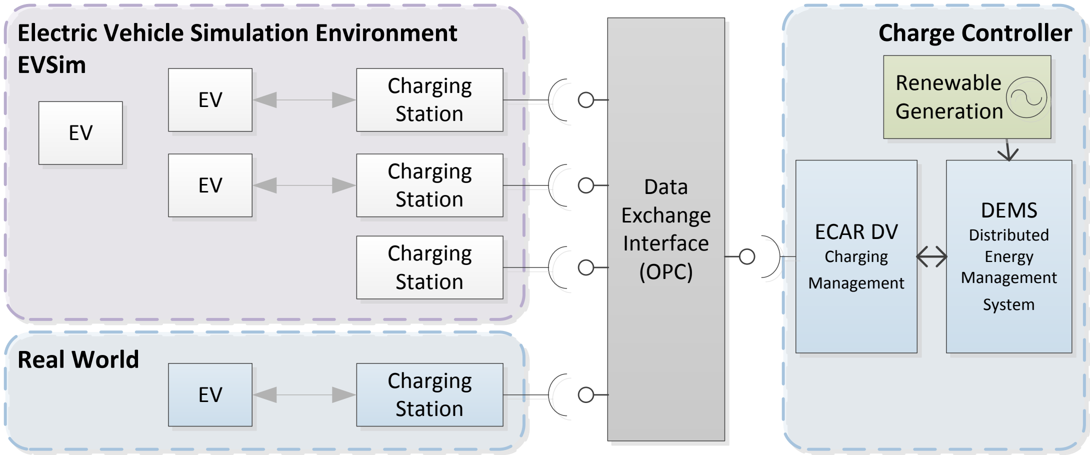
# EVSim – Parameters and Interface

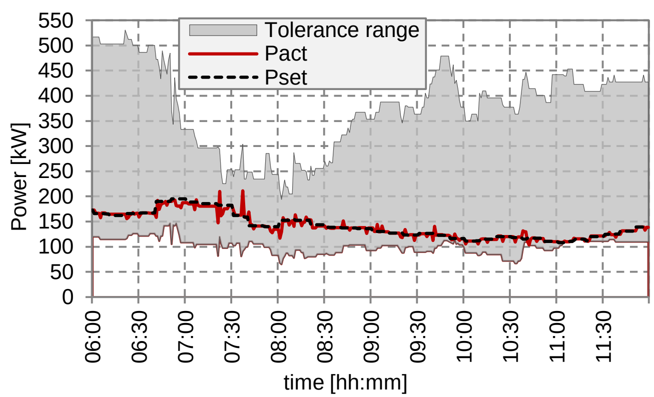
## Internal variables and parameters

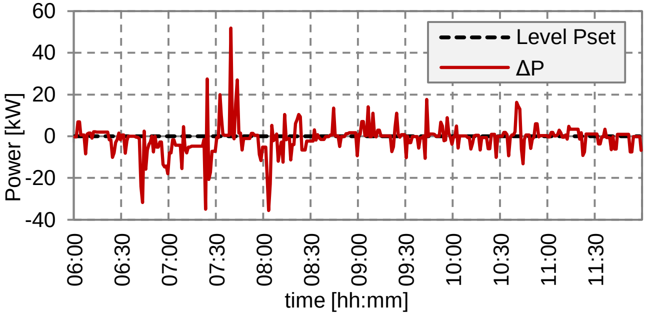


# Validation of charging management

- Real and simulated EVs for charging management validation



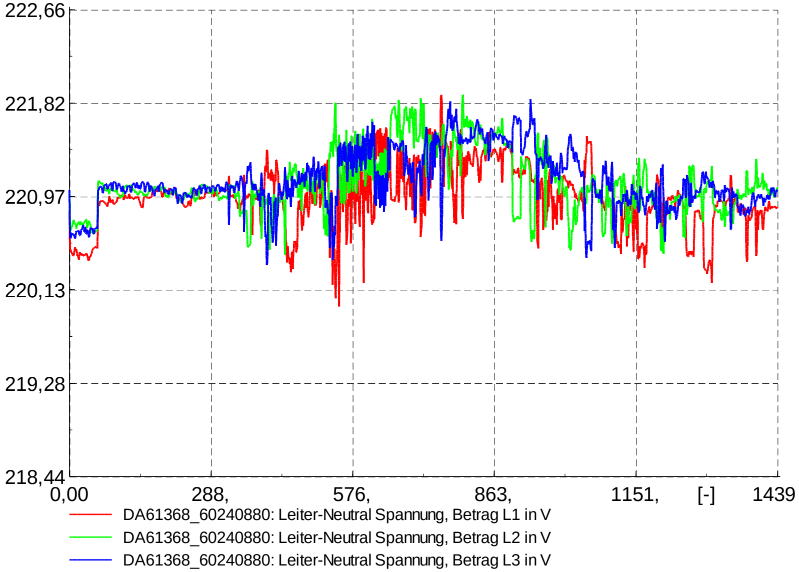



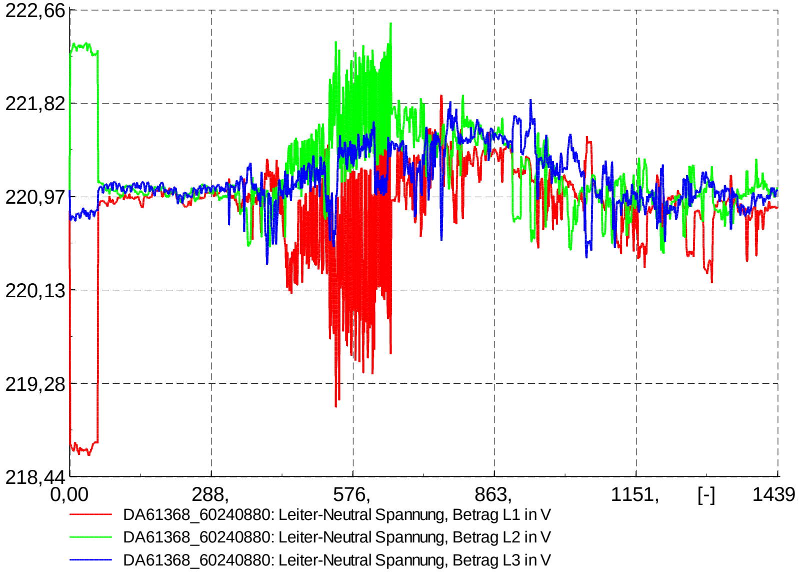

Tolerance range, $P_{set}$ and $P_{act}$ during simulation and deviation

# Simulation of EVs and power system

- Impact of unbalanced charging in low voltage networks



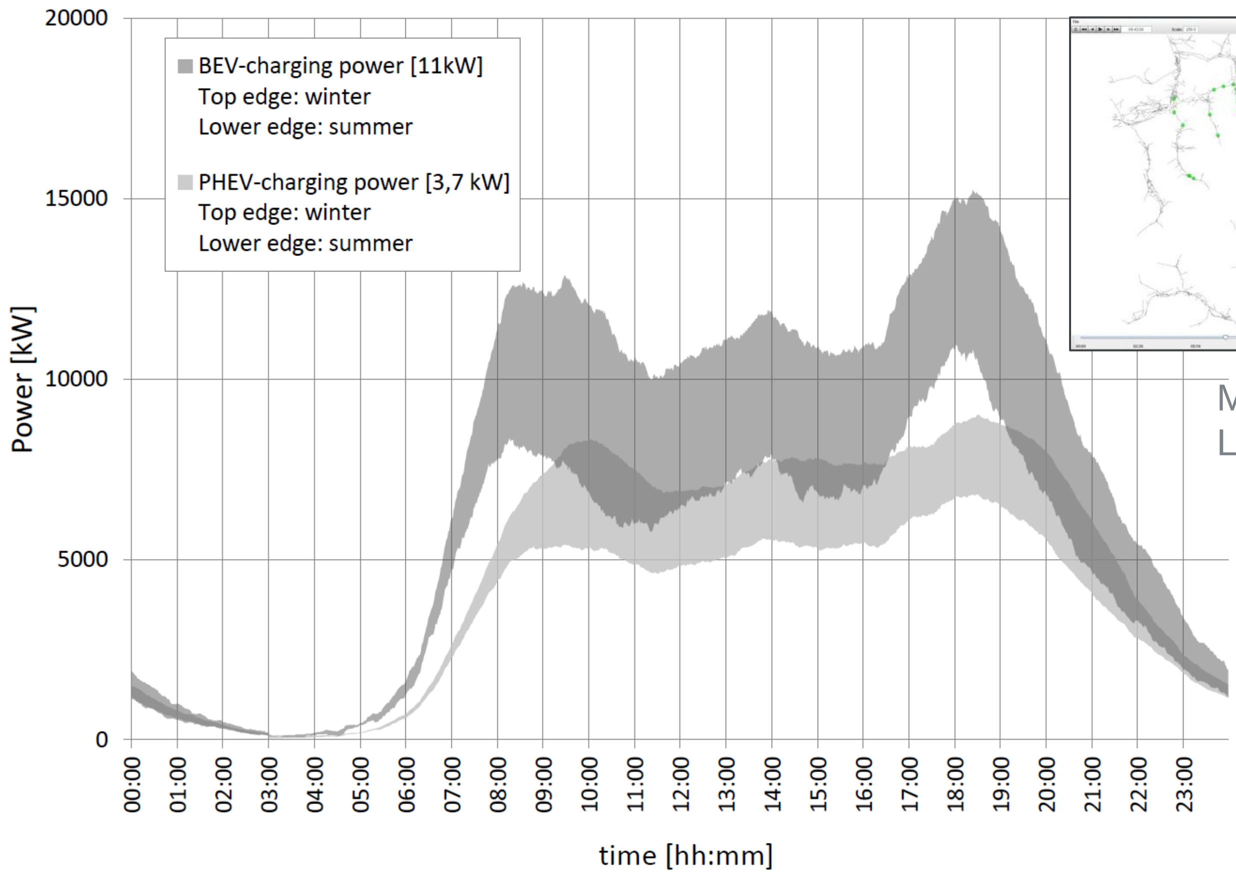

Voltages a the charging point for symmetrical loaded phases (3 times 3.68kW). Note the voltage rise due to PV generation

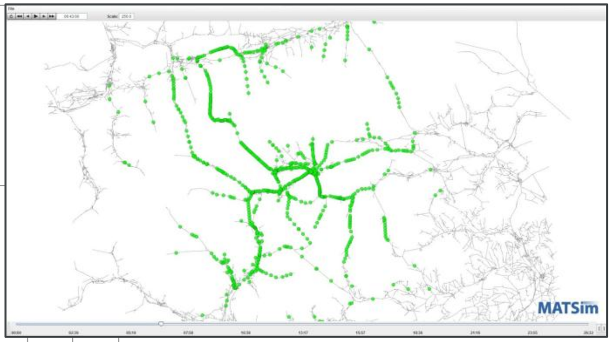



Voltages for unsymmetrical loaded phase (red: 11.04kW). Note the rise in the other phase (green) due to neutral point displacement.

# Temperature dependency

- Region Lungau (Upper Austria) – approx. 6000 EVs



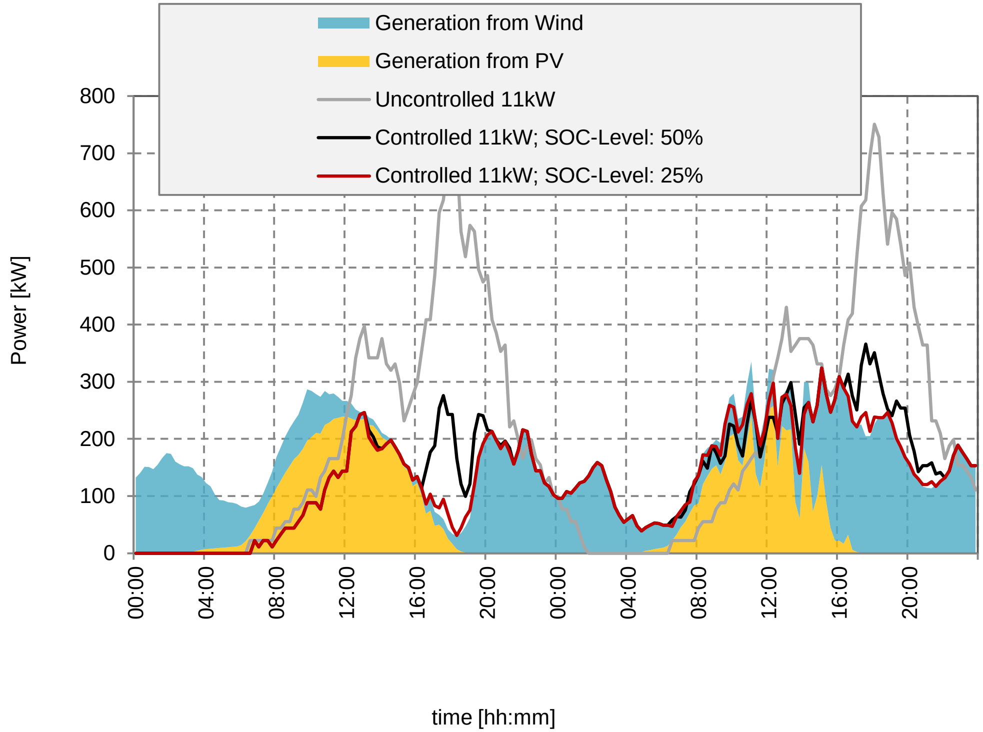




Micro-simulation of region Lungau, generating trip data

Charging power for opportunity charging on a winter and summer day

# Simulation of EVs, control and power system

- Local supply - demand match in medium voltage networks




Uncontrolled and controlled charging of 306 EVs with 11 kW during two sumer days.
Note: wind is accumulated on top of PV generation

Two days simulation in summer

| Charging Mode | empty EVs | P-peak [kW] | Charged Energy [kWh] | DER Energy [kWh] | DER Coverage [%] |
|---|---|---|---|---|---|
| uncontrolled 11kW | 15 | 751 | 9964 | 8079 | 54% |
| controlled 11kW/SOC50 | 55 | 366 | 6832 | 8079 | 89% |
| controlled 11kW/SOC25 | 66 | 324 | 6229 | 8079 | 99% |

Two days simulation in winter

| Charging Mode | empty Evs | P-peak [kW] | Charged Energy [kWh] | DER Energy [kWh] | DER Coverage [%] |
|---|---|---|---|---|---|
| uncontrolled 11kW | 135 | 883 | 12613 | 3971 | 26% |
| controlled 11kW/SOC50 | 197 | 552 | 7267 | 3971 | 50% |
| controlled 11kW/SOC25 | 218 | 353 | 5051 | 3971 | 71% |

# Summary

- **Multi-agent based** simulation tool, time-continuous **multi-physics** simulation, **controls** and **power system** simulation, e.g.: GridLAB-D, OpenModelica, PSAT, 4Diac, PowerFactory

  → **Open source software** can be used for co-simulation environments

- A **number of interfaces** possibilities exist to couple simulation tools.

  → Model and integrator based coupling can be realised.

- **Proprietary interfaces** are light-weighted but not very general, not usable for other tools, no simulation time step synchronisation

  → **Functional Mockup Interface** for model exchange + co-simulation.