FRONIUS ENERGY MANAGEMENT OF TODAY AND TOMORROW

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SELF-CONSUMPTION RATE AND SELF-SUFFICIENCY

E.g. 4-person household in Austria - consumption 5000 kWh/year (8000 kWh/year with heat supply)

	only PV	PV + EM	PV + battery	PV + Ohmpilot
PV power	5 kWp	5 kWp	5 kWp	5 kWp
Battery storage			5 kWh	
Heat storage, EV		heat pump, EV		500 l
Self-consumption	**up to 30 %**	**40–50 %**	**60–70 %**	**70–80 %**
Self-sufficiency	**up to 30 %**	**35 %**	**60 %**	**25–40 %**

more PV !

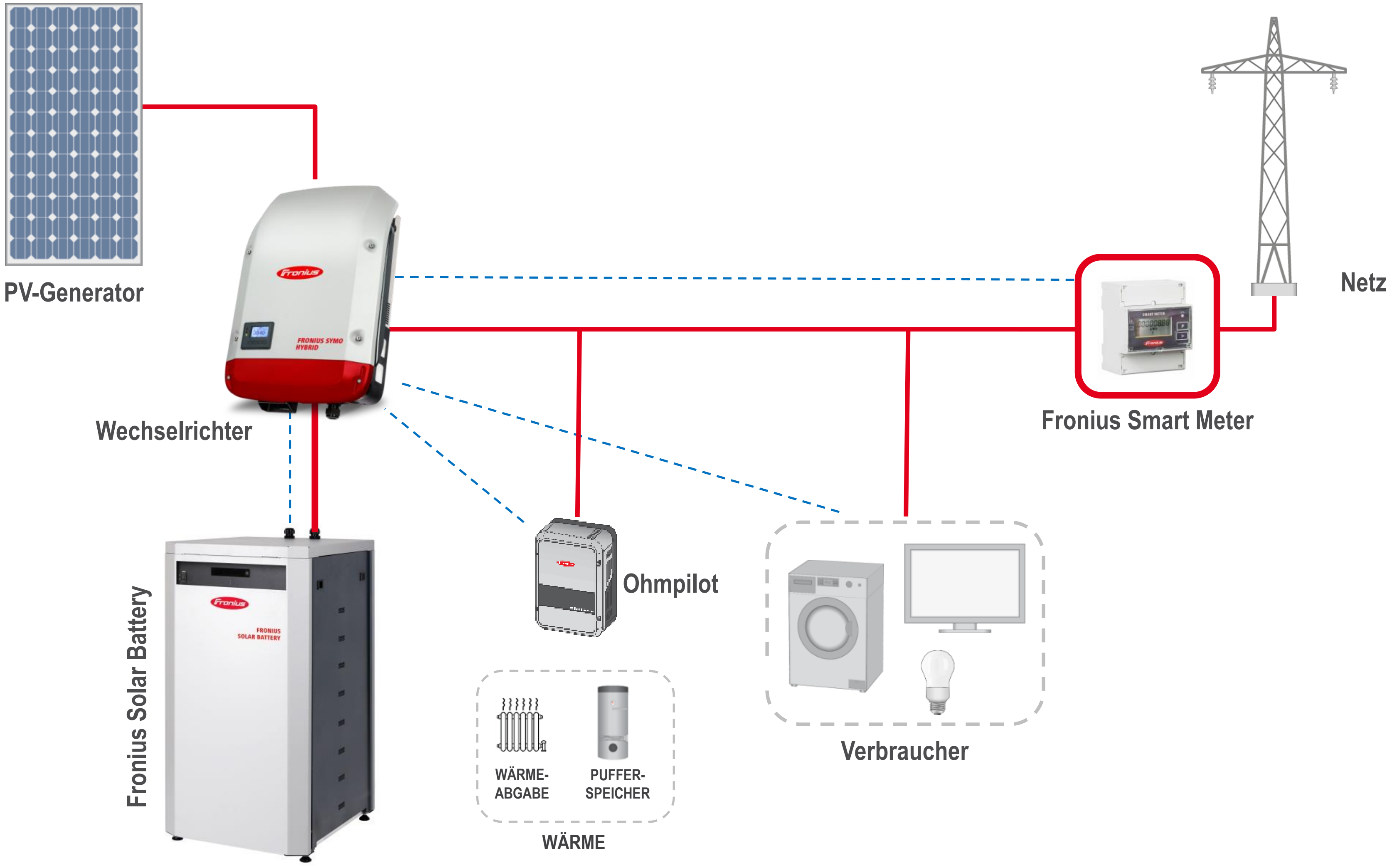
Source: Volker Quaschning – Berlin

STATE OF THE ART: ENERGY MANAGEMENT SYSTEMS

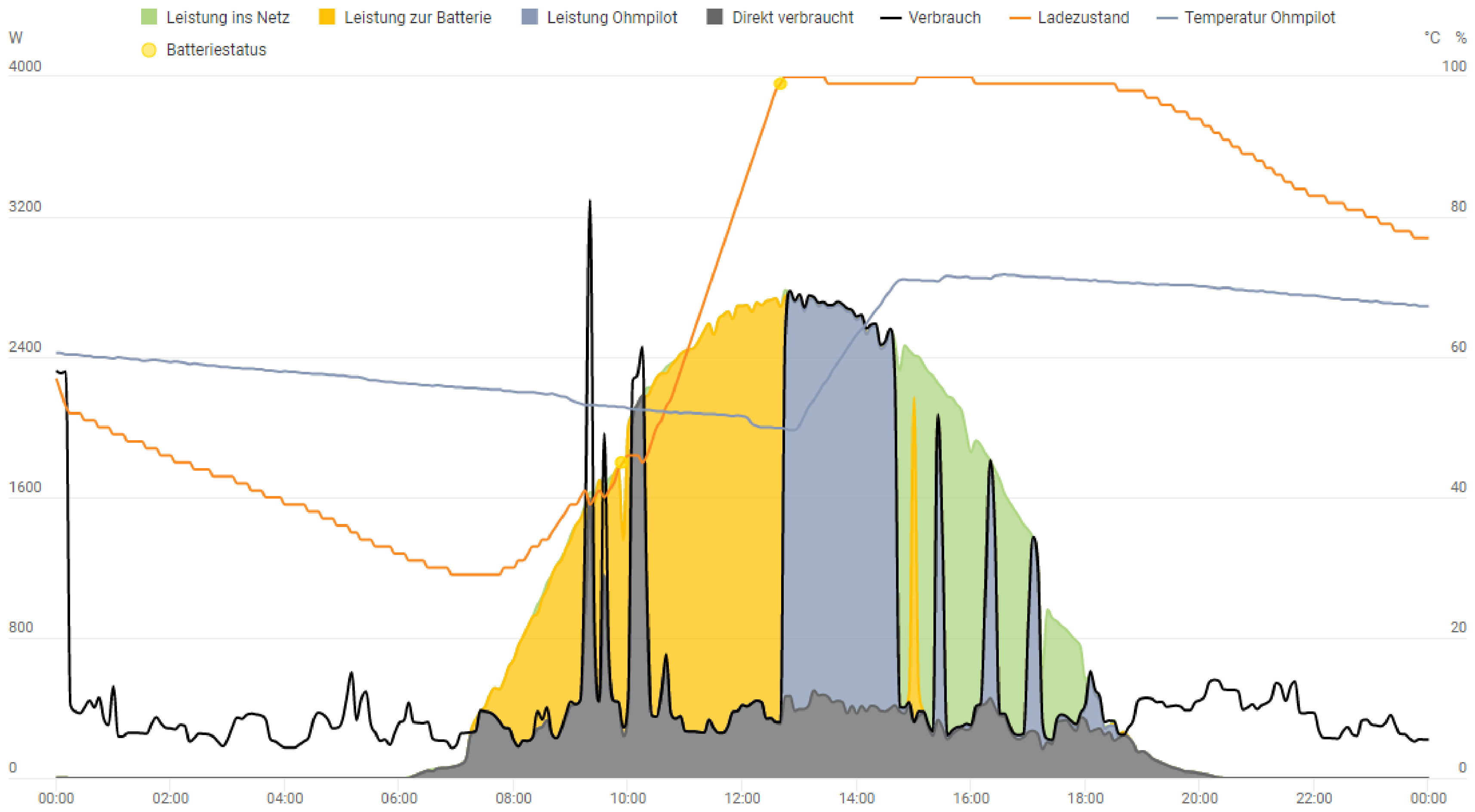
- Most Energy Management Systems are developed by Experts
  - E.g. Rule-based Logics
- They often use controllers whose computation and execution is computationally exhaustive
  - E.g. Model Predictive Controls [1-4]
- There are high maintenance efforts due to difficulties in adapting to changes in the system:
  - Controllers (like in MPCs) often contain a fixed simulation model
  - Makes it hard to adapt to changes in the system → also the simulation model needs to be adapted
- Different strategies on how to manage/optimize a system:
  - Current Fronius Energy Management System:
    Self-consumption optimization of the energy generated from renewable energy resource like a PV power plant & load management
  - Future Fronius Energy Management System:
    Cost-optimization of the overall energy usage

Current Energy Management System

FRONIUS ENERGY MANAGEMENT SYSTEM – OVERVIEW

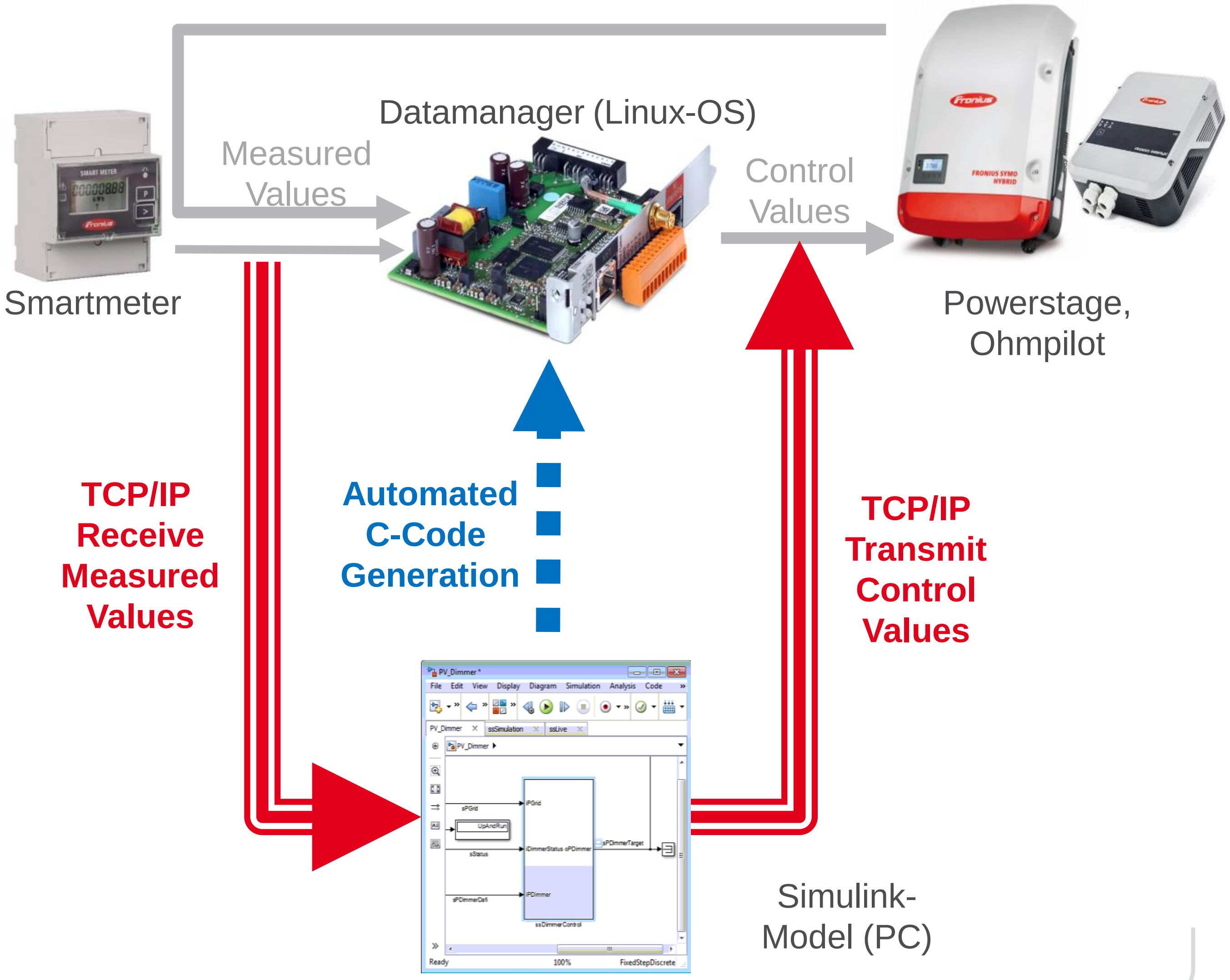


FRONIUS SELF CONSUMPTION OPTIMIZATION



FRONIUS ENERGY MANAGEMENT SYSTEM

- Runs directly on the Fronius inverters → they control e.g. Battery (if supported) and Ohmpilot
- Optimization of the household energy consumption with Battery and Ohmpilot
  - Increase own consumption and self sufficiency
  - Use cheaper night tariffs
  - Avoid expensive power from the grid
- Intelligent power distribution between Battery and Ohmpilot
- Creation of a battery usage roadmap using PV and load forecasts



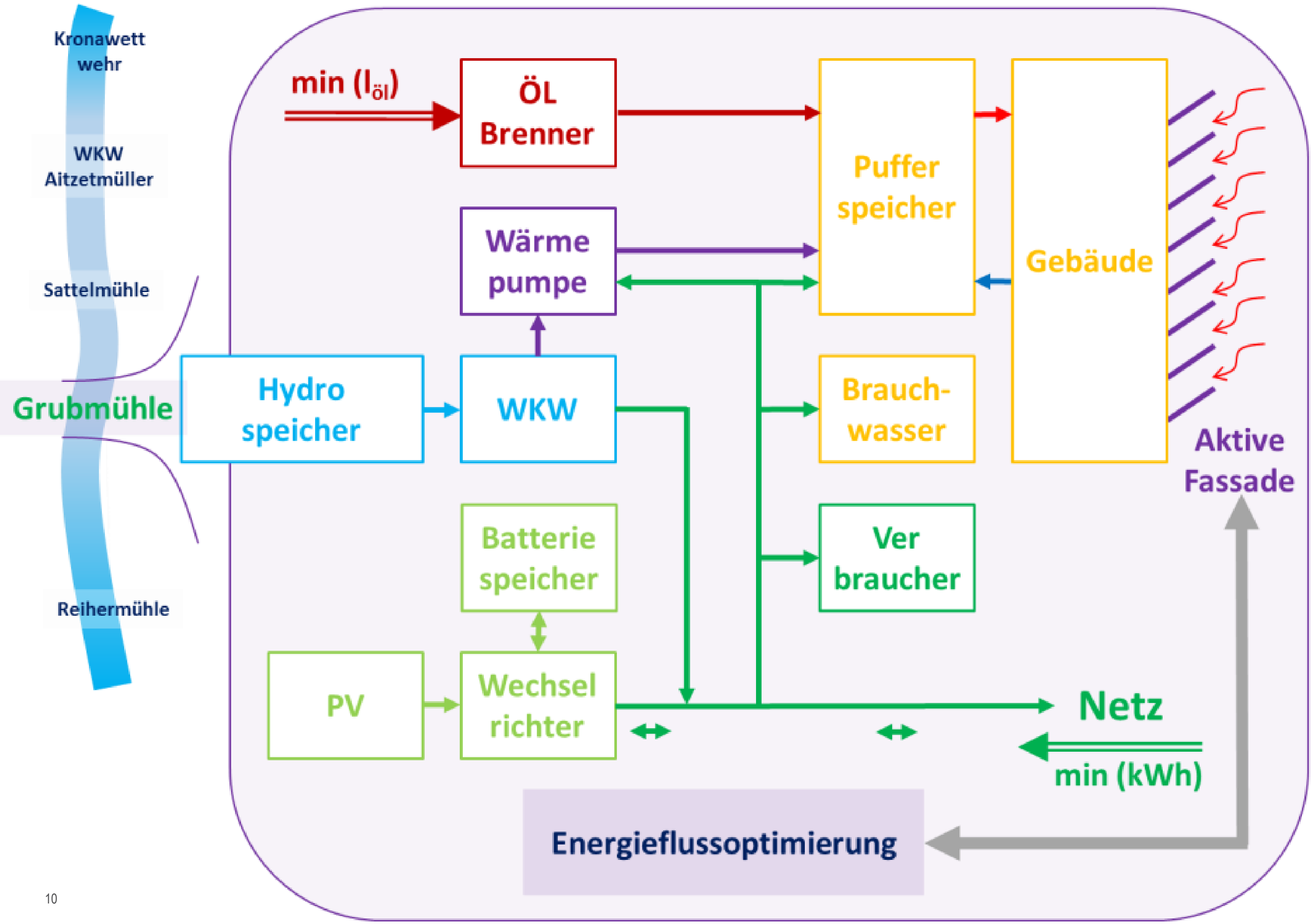
Tomorrow‘s Energy Management System

GENERAL REMARKS

- Developed in the course of the EFRE-funded research project ***Learning Energy***
  - Partners: FH Upper Austria (ASIC – Austria Solar Innovation Center in Wels and HEAL – Heuristic and Evolutionary Algorithms Lab in Hagenberg), Thermocollect
- **Goal:** Development of a combined numeric/heuristic controller algorithms energy management systems used in complex thermally-electrically coupled systems
  - Algorithms should be developed without expert knowledge
  - Should be scalable to other systems
  - Should use only little computing power (at least during execution)
- **Real-World Testing Environment**: Schule an der Alm in Lungendorf (between Vorchdorf and Pettenbach, Upper Austria)

Europäische Union Investitionen in Wachstum & Beschäftigung. Österreich.

SCHULE AN DER ALM



GENERAL OPTIMIZATION APPROACH

- Simulation-based optimization using MATLAB Simulink and the optimization framework HeuristicLab
- Genetic Programming to perform Symbolic Regression
- 2 stages of optimization:
  - Simplified Model: contains just the PV system + battery storage for a single family household
  - „Schule an der Alm“ Model: contains (nearly) all thermal and electric components of the real world system
- Evaluation currently done in Simulation, real world test in the „Schule an der Alm“ at the end of the project

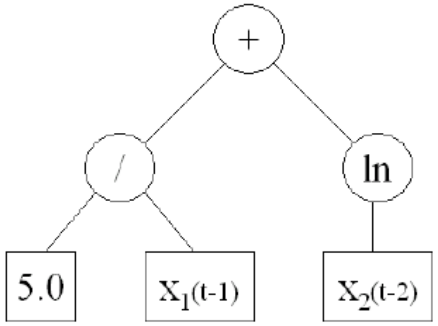
EXCURSION: GENETIC PROGRAMMING

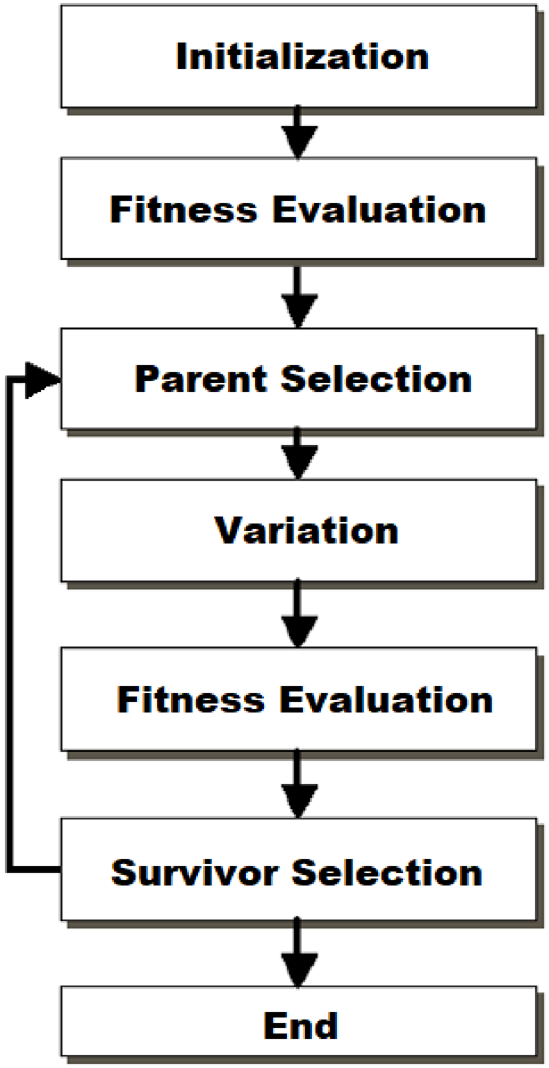
- Inspiration: Natural, biological selection process
  →"Survival of the Fittest Individual"

- Very performant in final execution, but learning the controls is very computation-intensive

- Genetic programming is used to calculate symbolic regression:
  - Structure of a syntax tree that can be interpreted as a mathematical formula.
  - Formula = Controller that optimizes the respective parameter

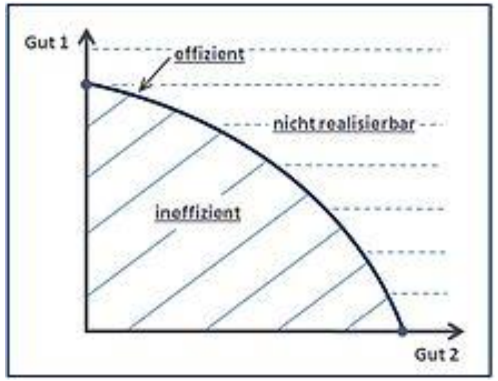
$$y = \frac{5.0}{X1(t-1)} + \ln(X2(t-2))$$





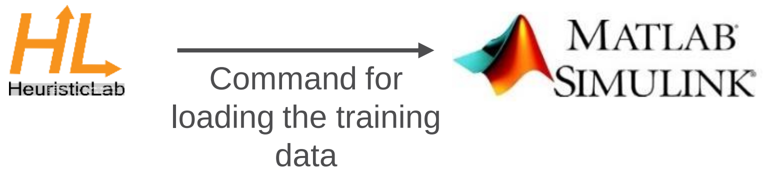
USED GENETIC ALGORITHMS

- OSGA: single objective, maximizes balance
  - Offspring (new solution candidate) is only accepted if it has a better fitness than one of the two parents
  - Expectation: better results as more offsprings have to be generated by high selection pressure to get the required number of accepted offsprings → Probability to get individuals with better performance is higher!
- NSGA II: multi objective, maximizes balance and simultaneously minimizes complexity of formula
  - Pareto Front = line on which those results lie that are optimal depending on the weighting of the optimization goals.
    - Gut 1 = maximum fitness function,
    - Gut 2 = minimum complexity; both goals cannot be fully optimized at the same time if one goal is very well approached, the second goal is less well achieved at the same time

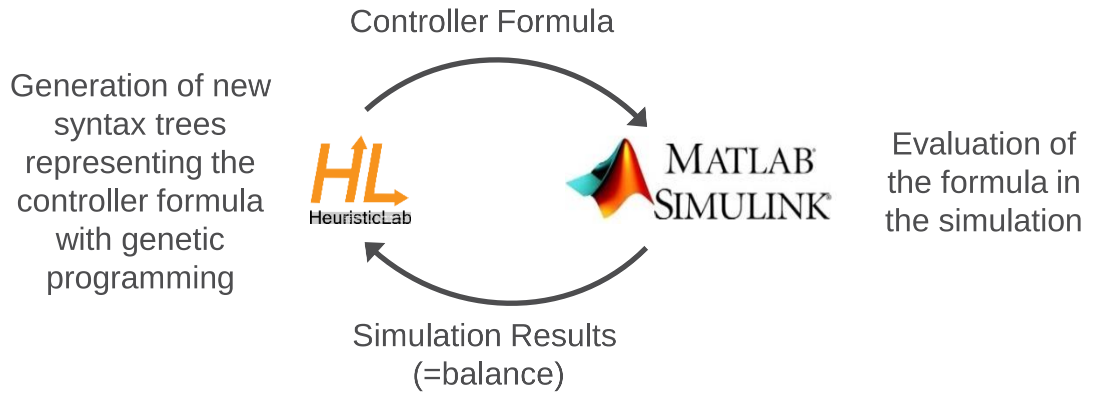


TRAINING PROCESS

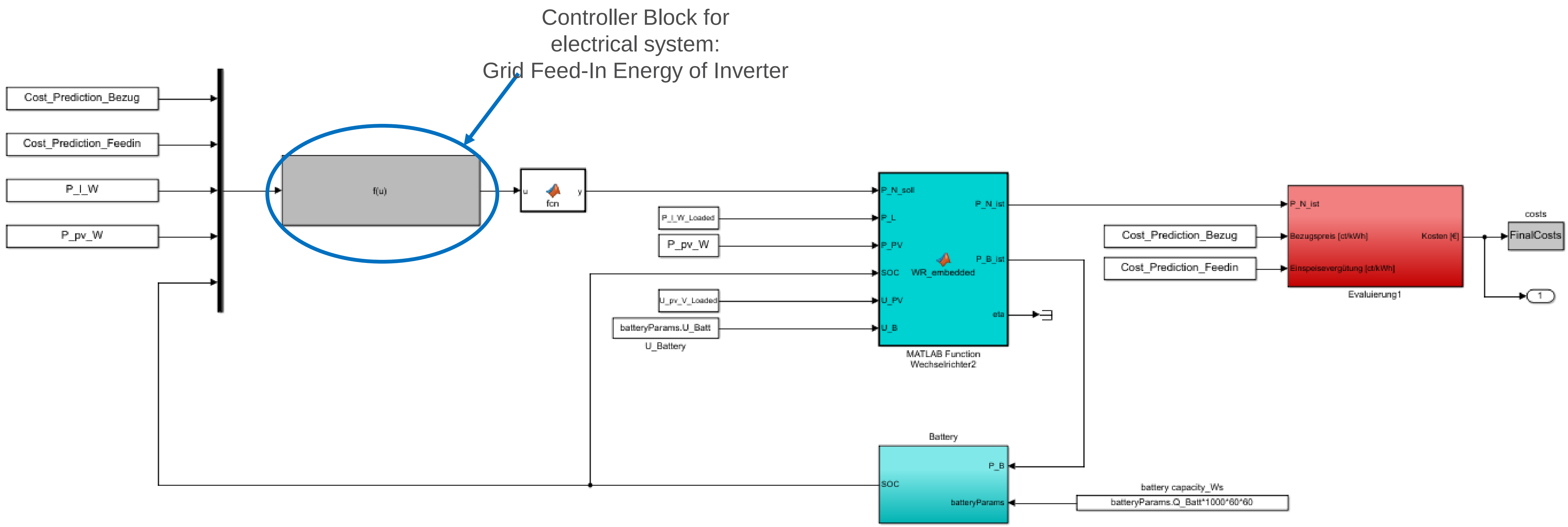
- HeuristicLab, MATLAB and MATLAB Simulink work together closely in a 2-step training process:
  1. Loading the training data using an extra MATLAB Simulink model



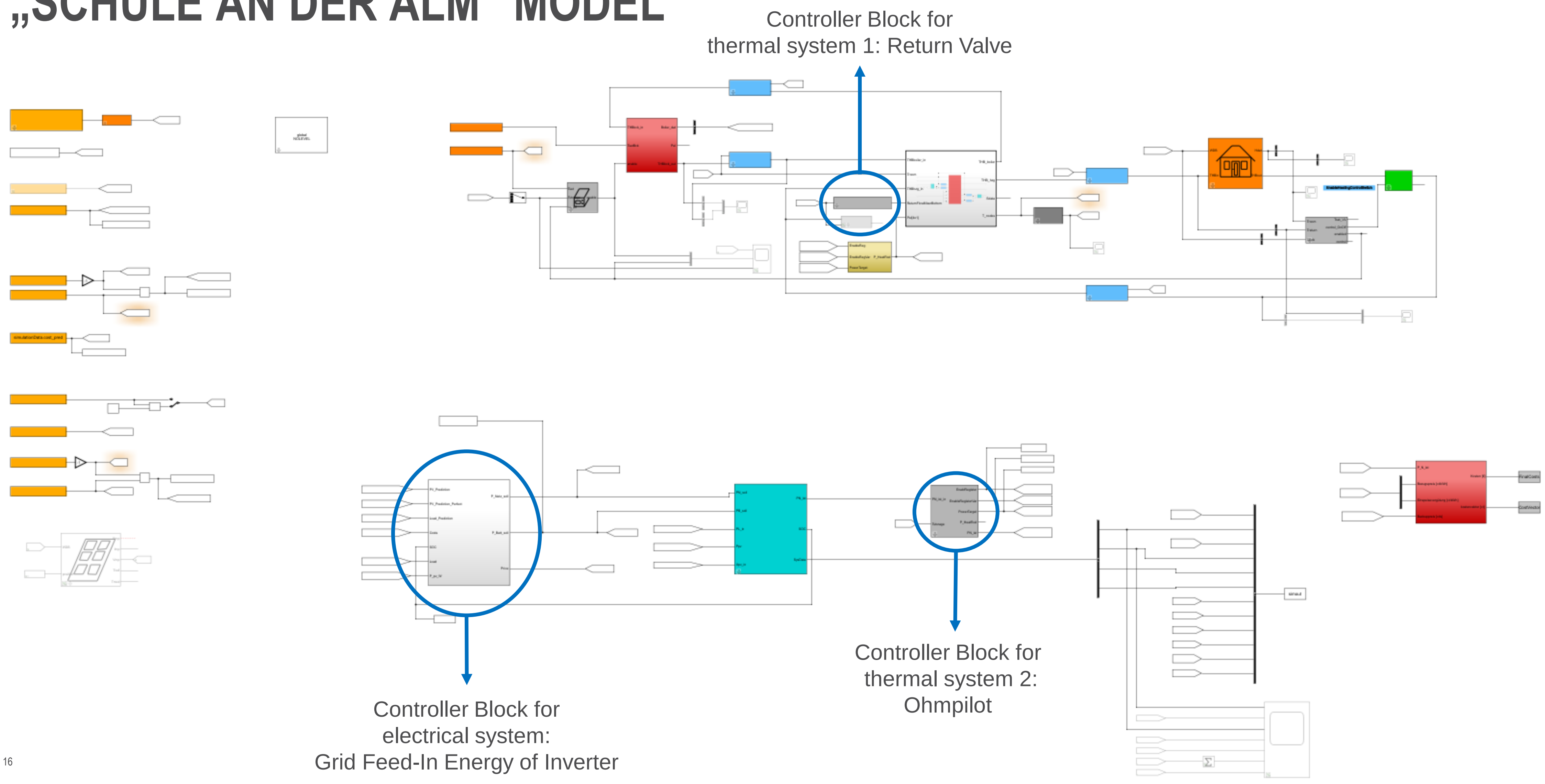
  2. Training the controller formulas



SIMPLIFIED MODEL



„SCHULE AN DER ALM“ MODEL

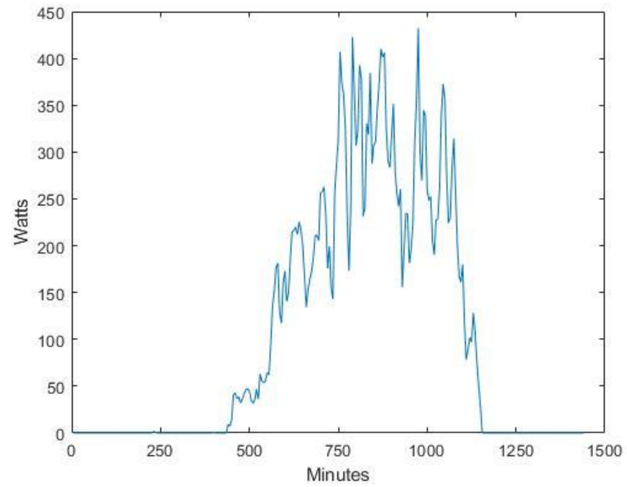


OPTIMIZATION EVALUATION

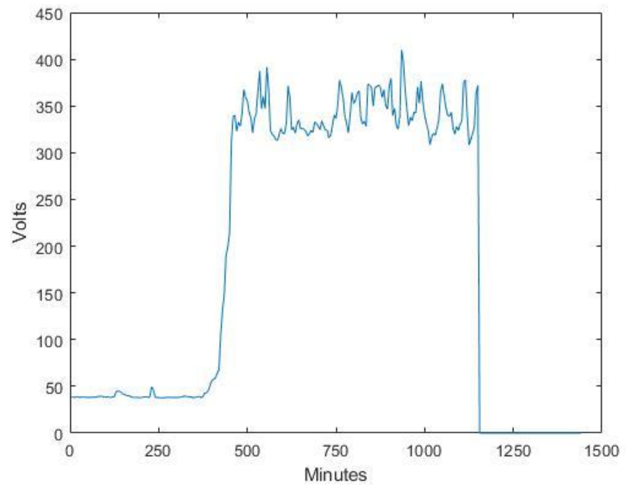
- Data Basis: measured data from a single-family household in Upper Austria
  - Photovoltaic Power and Voltage
  - Energy Tariff (Costs and Feed-In Tariff)
  - Household Load
- Training Data: 10th Feb 2017
- Test Data: 11th Feb 2017 – 31st Aug 2017
- Comparison to already existing Linear Optimizer developed by ASIC [5]

INPUT DATA EXAMPLE (TRAINING + TEST)

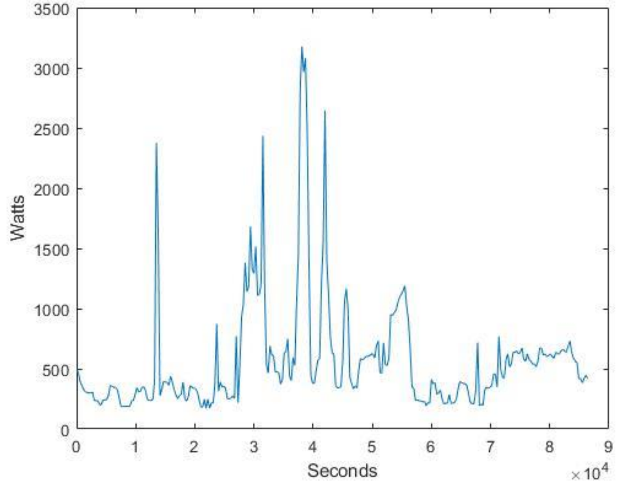
PV Power



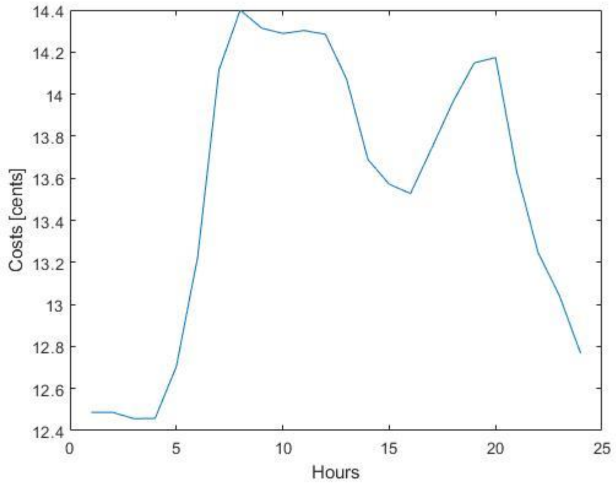
PV Voltage



Household Load



Energy Costs

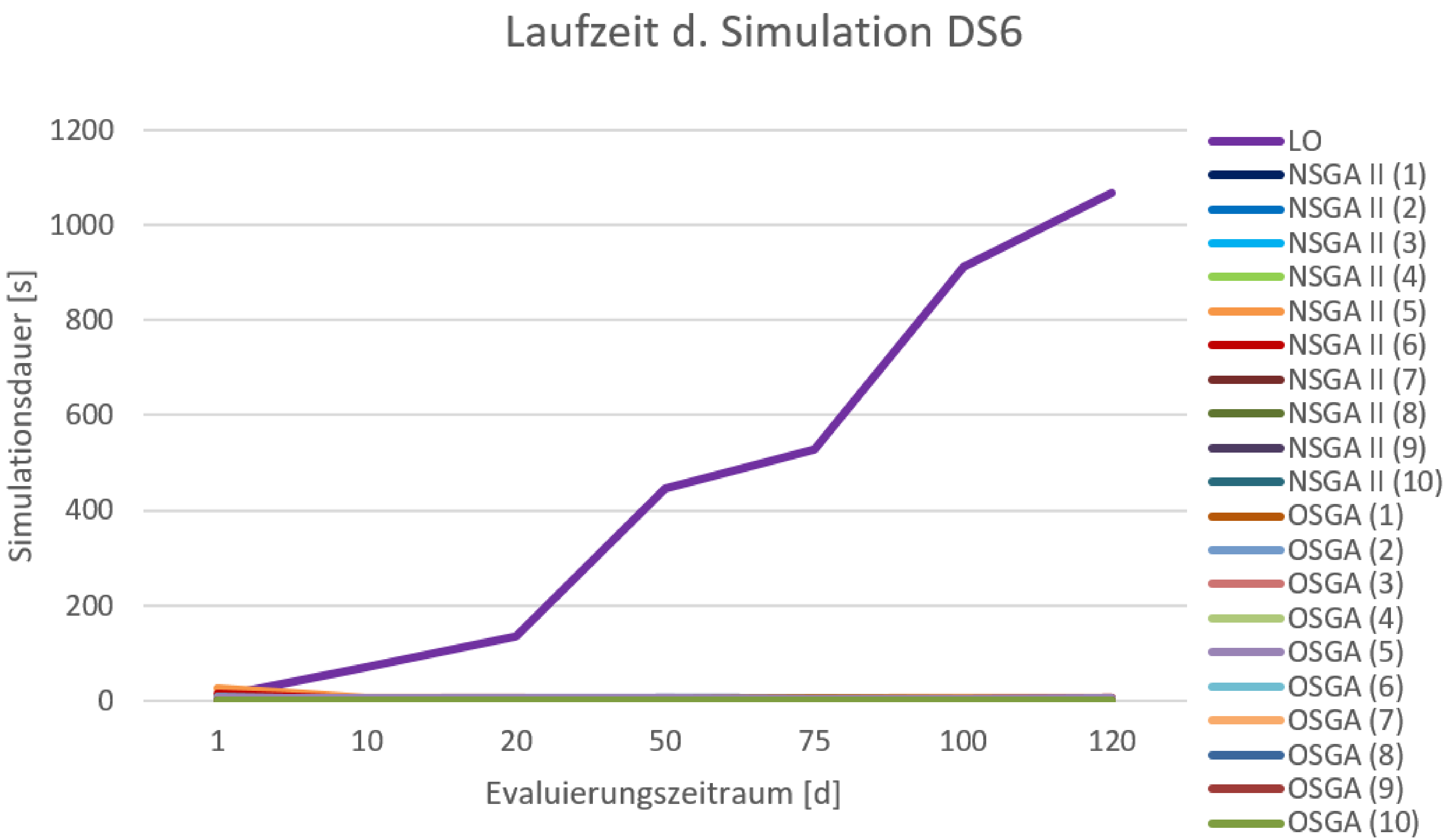


PRELIMINARY RESULTS SIMPLIFIED MODEL - SALDO

	LO	NSGA II (1)	NSGA II (2)	NSGA II (3)	NSGA II (4)	NSGA II (5)	NSGA II (6)	NSGA II (7)	NSGA II (8)	NSGA II (9)	NSGA II (10)
20	-22.58	-21.70	-22.03	-22.53	-22.50	-22.61	-22.64	-23.60	-22.09	-22.58	-21.86
50	-48.44	-46.63	-47.05	-48.17	-48.03	-48.02	-48.34	-49.92	-47.16	-48.03	-46.88
120	-85.45	-82.73	-81.52	-84.06	-83.74	-86.42	-90.25	-92.83	-82.32	-85.88	-83.46

	LO	OSGA (1)	OSGA (2)	OSGA (3)	OSGA (4)	OSGA (5)	OSGA (6)	OSGA (7)	OSGA (8)	OSGA (9)	OSGA (10)
20	-22.58	-22.47	-22.47	-22.99	-22.62	-21.97	-23.62	-23.63	-23.22	-22.53	-22.84
50	-48.44	-48.27	-47.30	-49.16	-48.45	-46.95	-50.03	-50.28	-49.35	-47.94	-48.11
120	-85.45	-89.59	-85.88	-91.99	-89.18	-81.19	-92.83	-93.08	-90.93	-89.28	-89.93

PRELIMINARY RESULTS SIMPLIFIED MODEL – SIMULATION DURATION



/ Perfect Welding / Solar Energy / Perfect Charging

REFERENZEN

[1] Mayuresh V. Kothare, Venkataramanan Balakrishnan und Manfred Morari. „Robust constrained model predictive control using linear matrix inequalities“. *Automatica* 32.10 (Okt. 1996), S. 1361–1379.

[2] João Figueiredo und José Sá da Costa. „A SCADA system for energy management in intelligent buildings“. *Energy and Buildings* 49.Supplement C (Juni 2012), S. 85–98.

[3] F. Kennel, D. Görges und S. Liu. „Energy Management for Smart Grids With Electric Vehicles Based on Hierarchical MPC“. *IEEE Transactions on Industrial Informatics* 9.3 (Aug. 2013), S. 1528–1537

[4] C. Chen u. a. „MPC-Based Appliance Scheduling for Residential Building Energy Management Controller“. *IEEE Transactions on Smart Grid* 4.3 (Sep. 2013), S. 1401–1410

[5] *Rechberger, P., Steinmaurer, G. & Reder, R. (2013). Control Algorithms for Photovoltaic Inverters with Battery Storage for Increased Self Consumption. Proceedings of the International Workshop on Simulation for Energy, Sustainable Development & Environment (SESDE) 2013, 25. - 27. September 2013. Athens*