ABILITY OPTIMAX POWERFIT, 05.02.2018

Parallel large-scale optimization and Internet of Things for cyber physical power systems

R. Franke, M. Schroschk, W. Braun, B. Bachmann, M. Johannes, C. Grindler

Agenda

Motivation of digital revolution

PARADOM project

Parallel Optimization

ABB OPTIMAX PowerFit

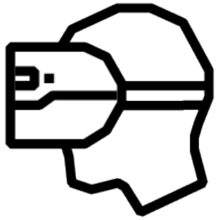
ABB Ability™ demo

Conclusions

Digital technologies are driving new innovation in industrial markets

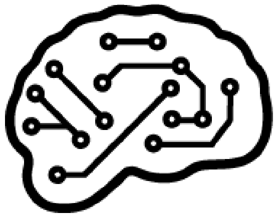
Media is focused on B2C but the “killer app” is in B2B

Virtual/ augmented reality

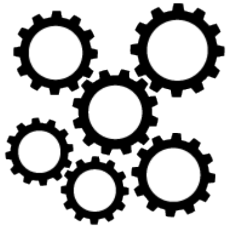


Software-defined machines

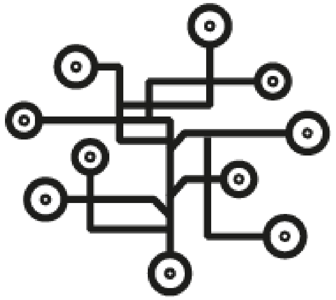
Machine learning



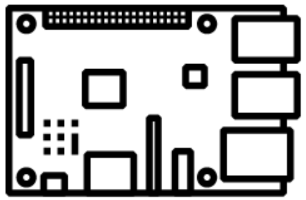
Time-sensitive networking



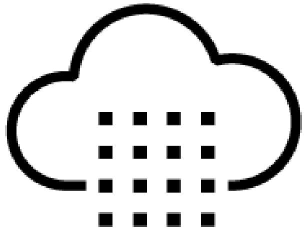
Big data



Inexpensive computing



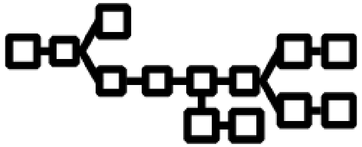
Cloud computing



Cybersecurity

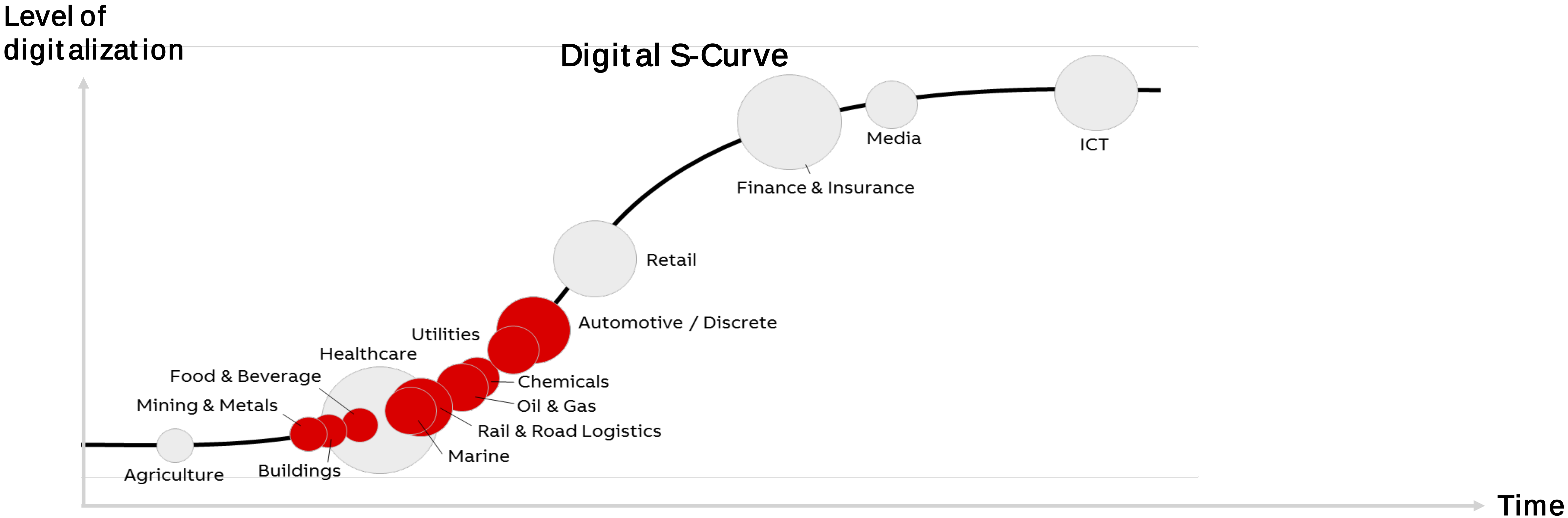
Connectivity

Blockchain



Industrial markets primed to adopt digital technologies

Computing + connectivity + cloud + analytics set to unlock value



Note: relative size of industry for advanced economies
Source: ABB analysis

Task:

Customer requirements

- Model complexity
- Optimization horizon
- Optimization step size
- Real-time
- ...

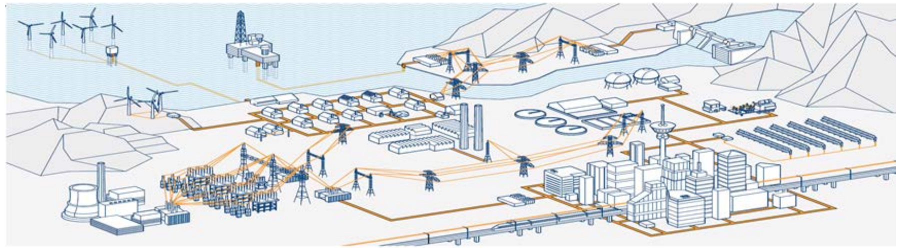
PARADOM approach:

1. Parallel Optimization (Multiple Shooting)
2. Parallel Algorithmic Differentiation
3. Parallel solution of equation systems

This presentation

Direct Multiple Shooting | Solution of equation systems

PARallel Algorithmic Differentiation in OpenModelica for real-time simulation and optimization
(Mai 2016 – April 2019)

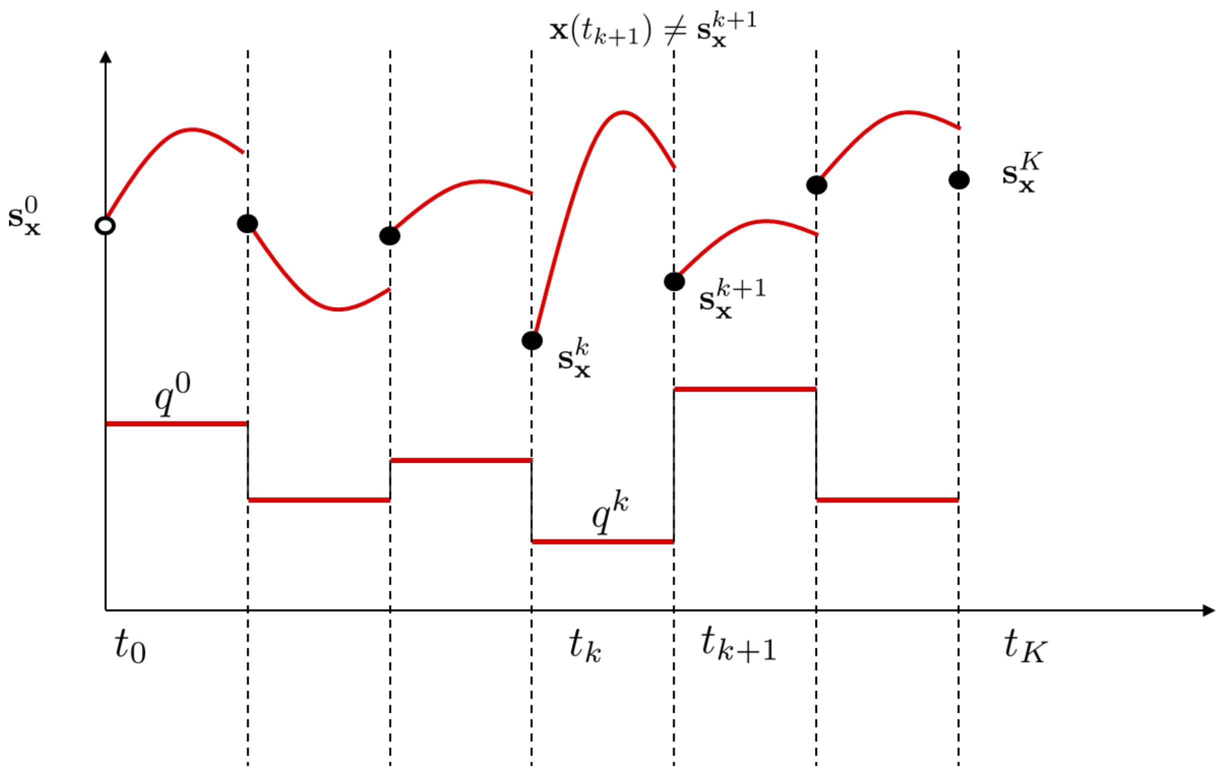


Application to digital power systems

Parallel Optimization with control vector parameterization (direct multiple shooting)

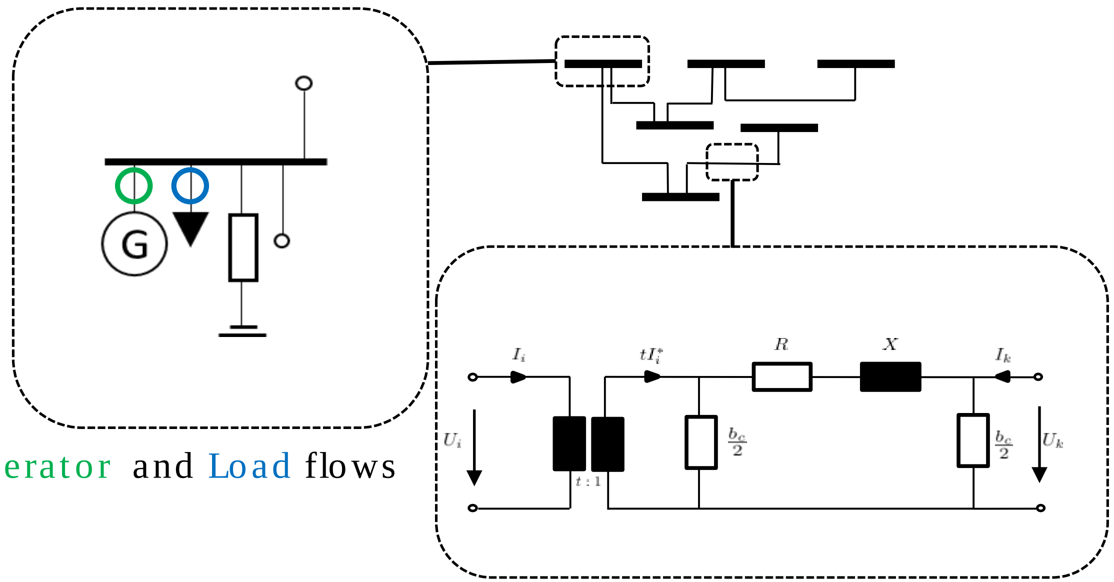
Idea:

- Describe control trajectory with control parameters q^k
- Introduce initial states of each interval as optimization variables s_x^k
- Parallel solution of initial value and sensitivity problems for each interval
- Treat junction conditions between intervals as optimization constraints



Application to planning of power production (dynamic optimal power flow problems)

- Treat power transmission system with nodes and admittances
- Equation based formulation in Modelica
- Translation to FMU with OpenModelica
- Investigation of different modi for model formulation, in particular:
  - **Modus II**
    Optimizer tunes generator nodes (eliminate load and internal nodes – cf. ODE mode)
  - **Modus IV**
    Tune generator and load nodes (eliminate internal nodes – cf. DAE mode)



Generator and Load flows

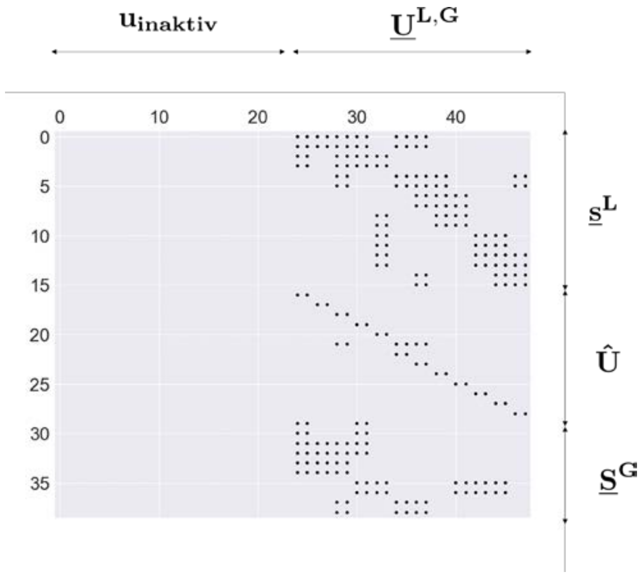
$$\mathbf{I} = \mathbf{G}\mathbf{U} \Leftrightarrow \begin{pmatrix} I_1 \\ \vdots \\ \vdots \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} G_{11} & G_{12} & \dots & \dots & G_{1N} \\ G_{21} & \ddots & & & \vdots \\ \vdots & & \ddots & & \\ \vdots & & & & \vdots \\ G_{N1} & \dots & & \dots & G_{NN} \end{pmatrix} \begin{pmatrix} U_1 \\ \vdots \\ \vdots \\ \vdots \\ U_N \end{pmatrix}$$

Clemens Grindler: Untersuchung paralleler Methoden der Optimalen Steuerung im Kontext der Leistungsflussoptimierung für Energieübertragungsnetze, Masterarbeit, KiT, 2017

Spy matrices of model Jacobians

Modus II

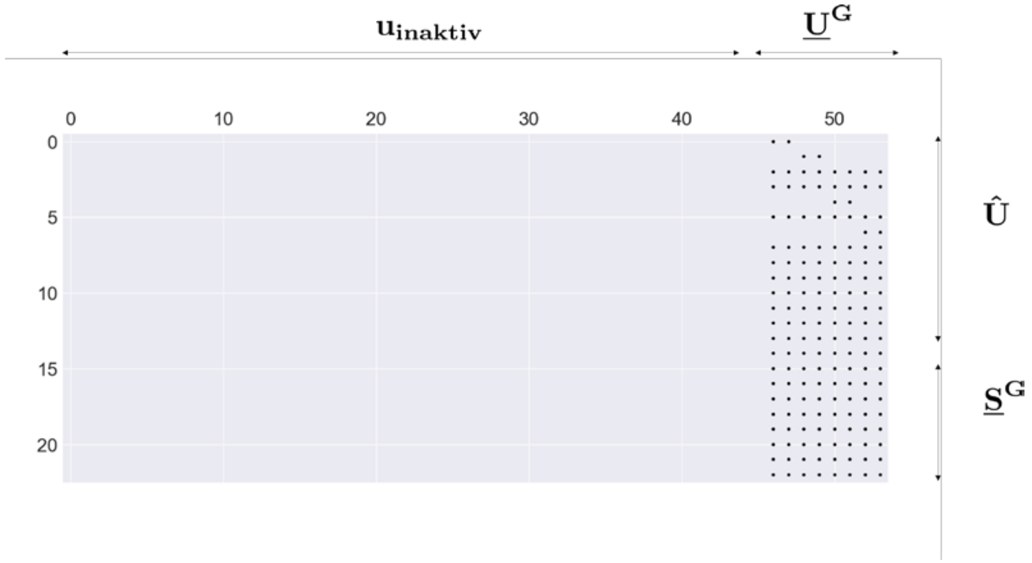
- Sparse structure
- Many small equation systems



Jacobian Model 14, Modus 2

Modus IV

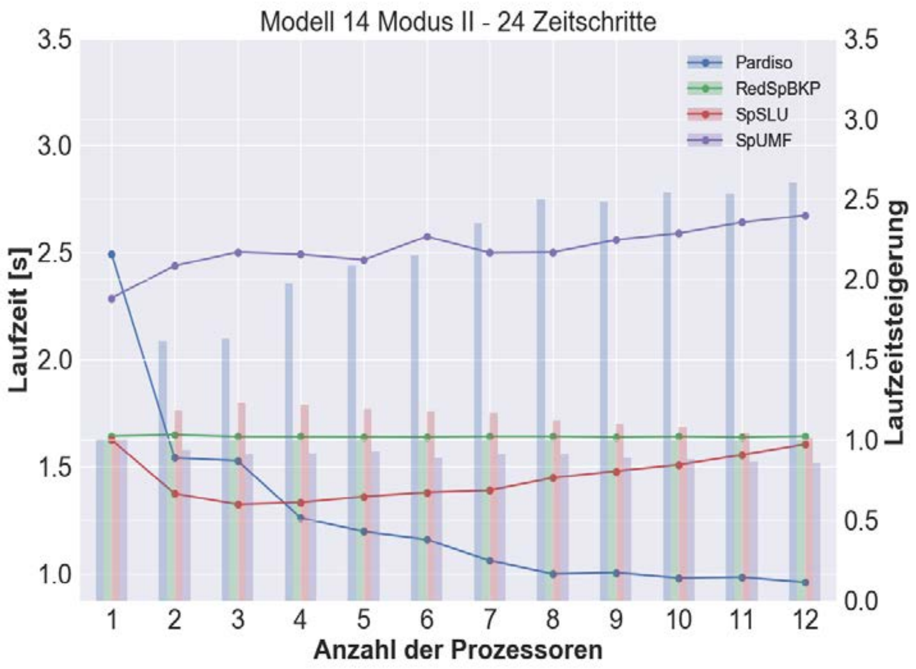
- Dense structure
- Few large equation system

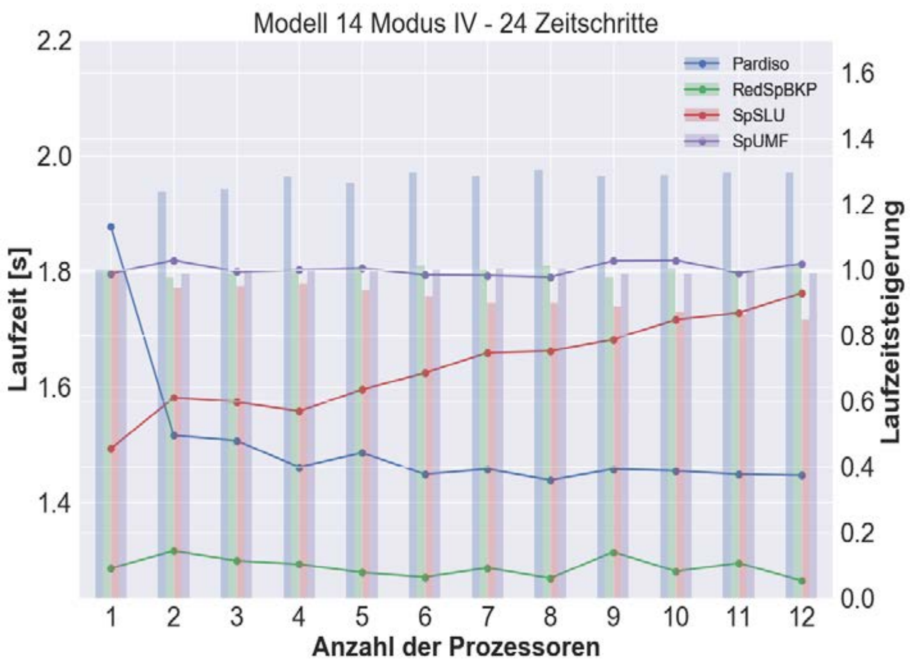


Jacobian Model 14, Modus 4

Results for different sparse solvers for equation systems

- Comparison of equation system solvers PARDISO, SuperLU, UMFPACK und BKP
- Model with 14 nodes: 24 resp. 8 tuned variables
- PARDISO shows best performance for Modus II, BKP for Modus IV

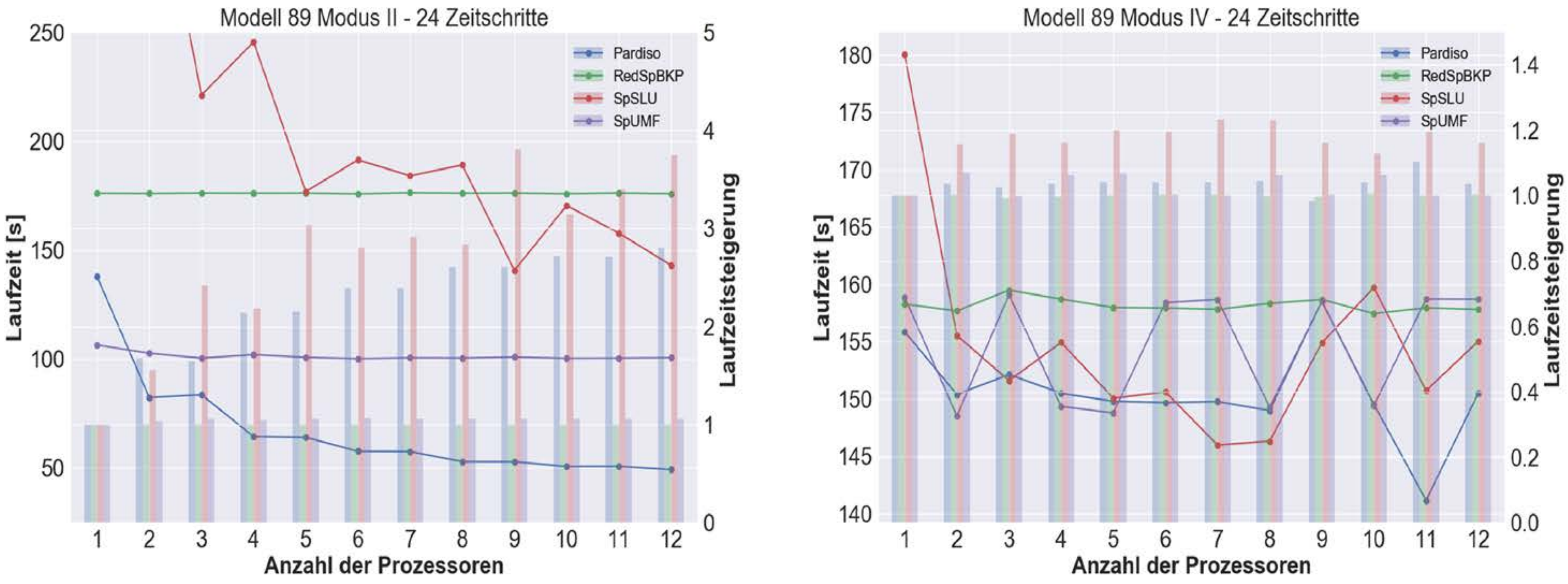




sequential MS, CPU times and speedup for up to 12 CPUs, Model 14

Results for different sparse solvers for equation systems

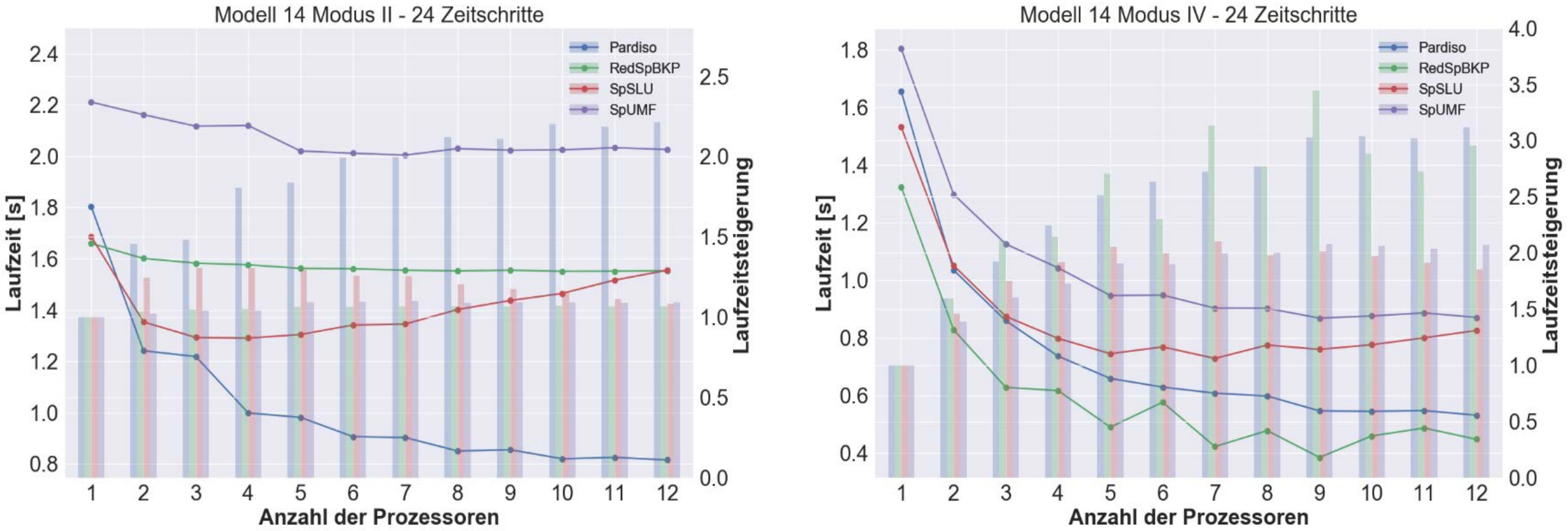
- Comparison of equation system solvers PARDISO, SuperLU, UMFPACK und BKP
- Model with 89 nodes: 92 resp. 22 tuned variables
- PARDISO shows best overall performance and good speedup for sparse Modus II



Sequential MS, CPU times and speedups with 12 CPUs, Model 89

Results parallel multiple shooting

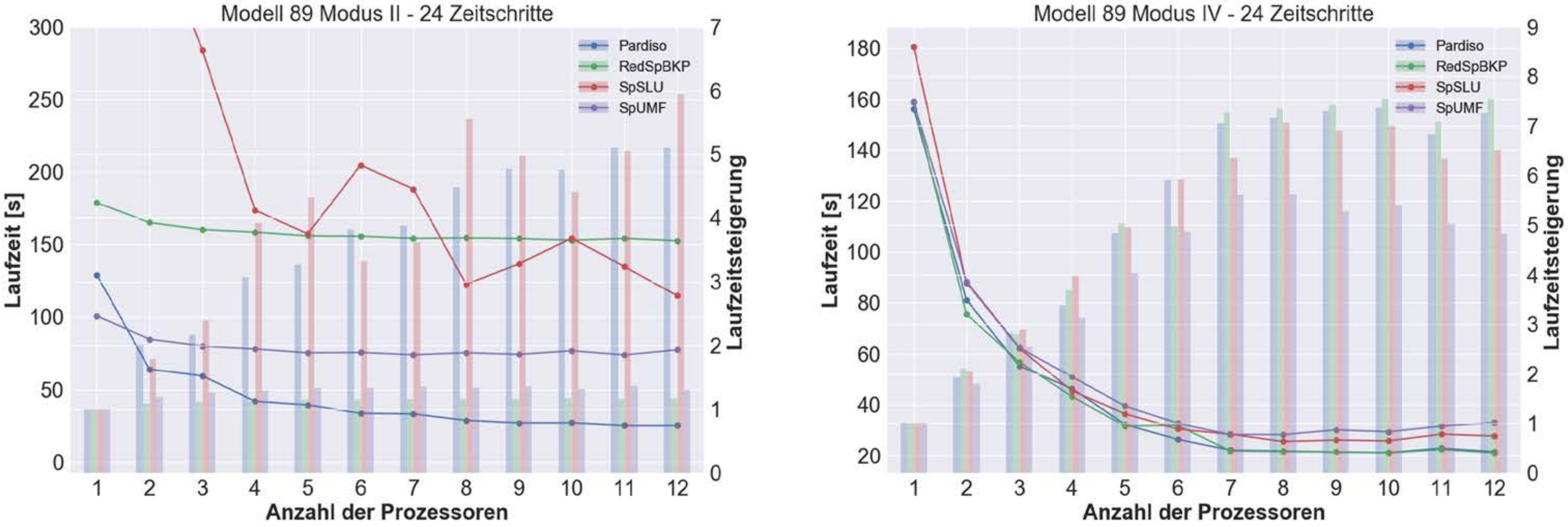
- Parallel multiple shooting increases speedup
- Speedup of up to 4 in Modus IV with 9 CPUs



parallel MS, CPU times and speedup for up to 12 CPUs, Model 14

Results parallel multiple shooting

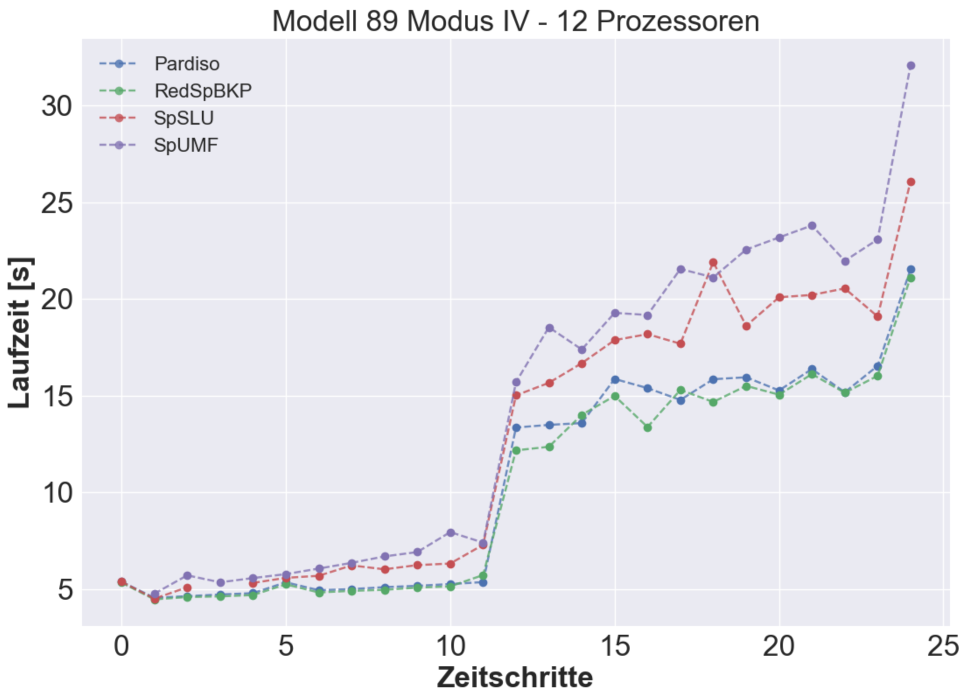
- Parallel multiple shooting increases speedup
- Speedup of up to 9 with 12 CPUs in Modus IV (because more work is done inside parallel FMUs)

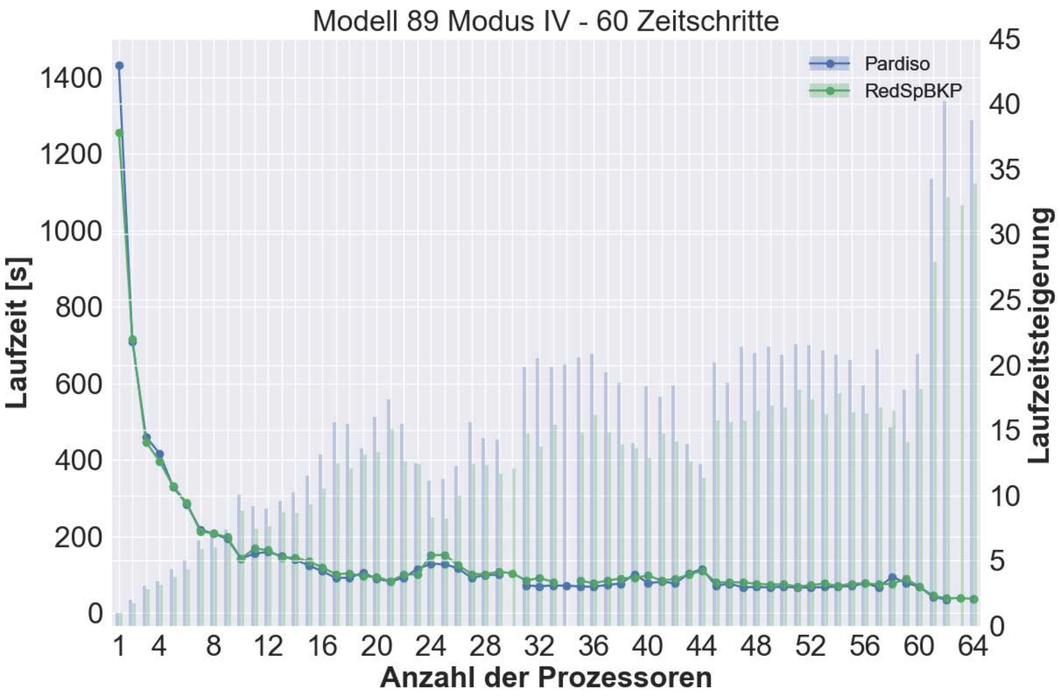


Parallel MS, CPU times and speedups with 12 CPUs, Model 89

Results for relation of #CPUs and #Intervals

- Left plot: CPU time increases if #Intervals exceeds #CPUs
- Right plot: substantial speedup starting from 61 CPUs when having 60 intervals

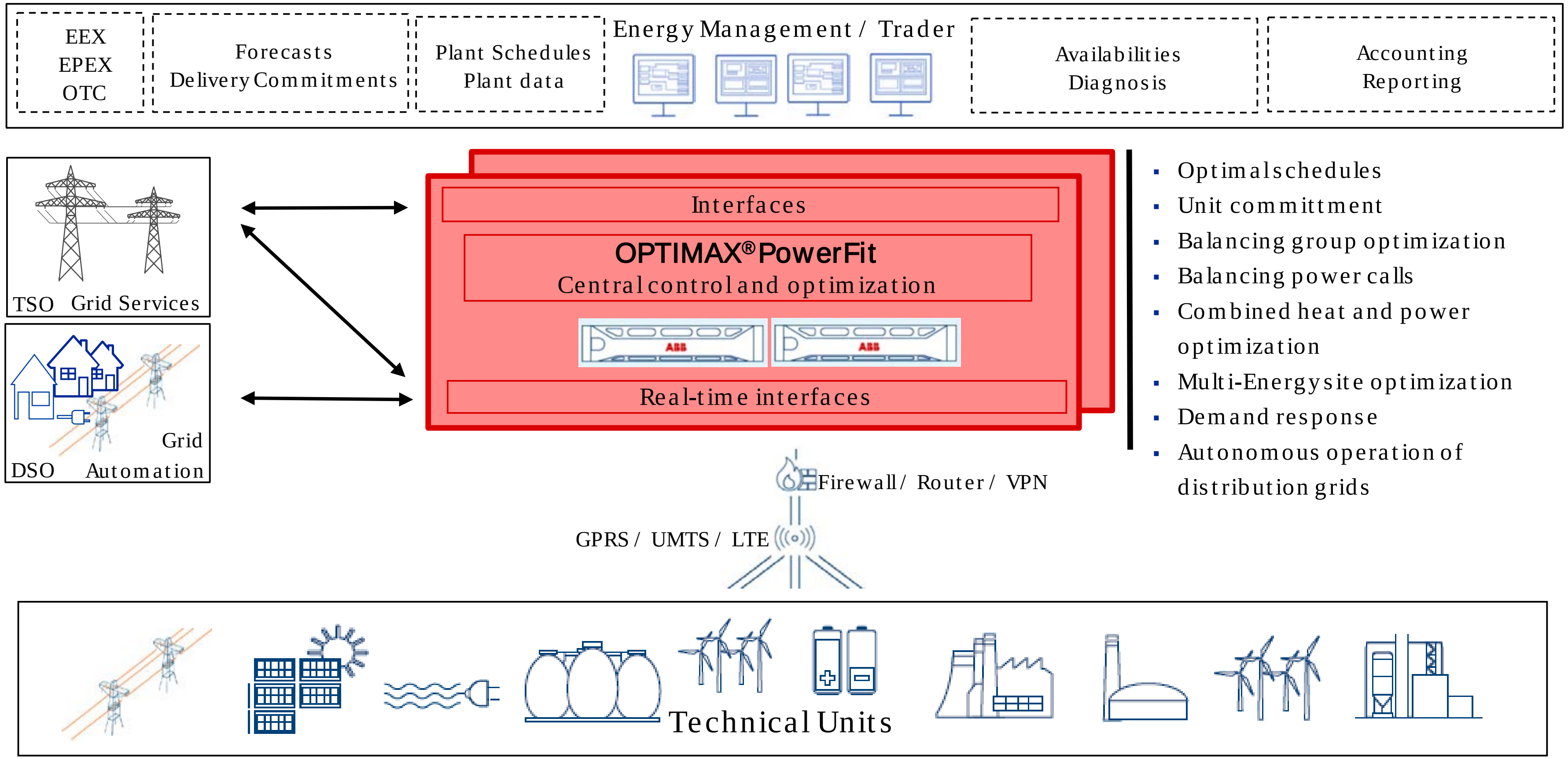




Relation shooting intervals – CPUs

ABB OPTIMAX PowerFit

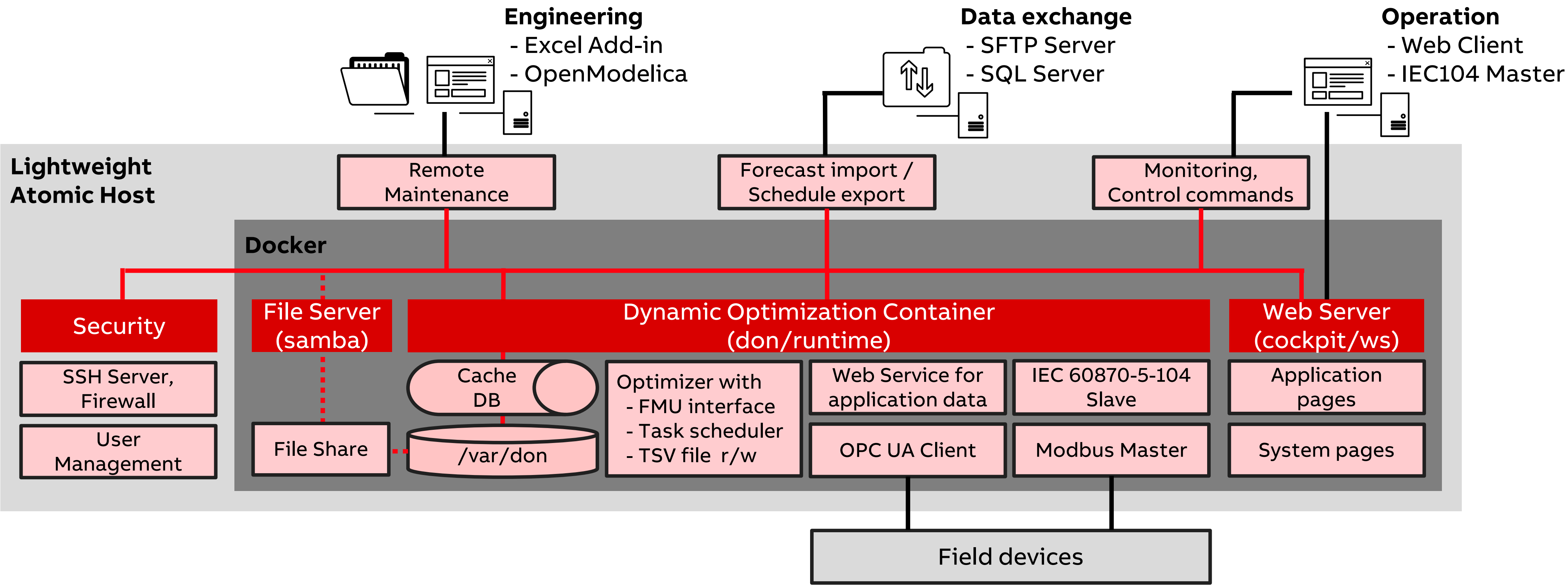
General System Architecture



- Optimal schedules
- Unit committment
- Balancing group optimization
- Balancing power calls
- Combined heat and power optimization
- Multi-Energy site optimization
- Demand response
- Autonomous operation of distribution grids

ABB OPTIMAX PowerFit

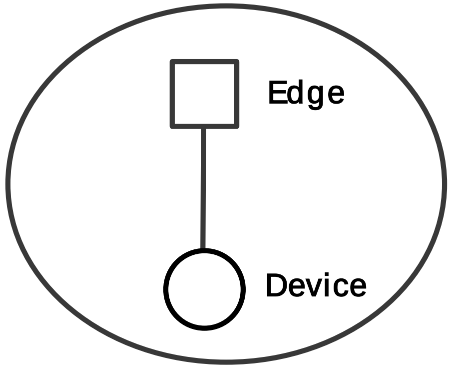
Internal Architecture



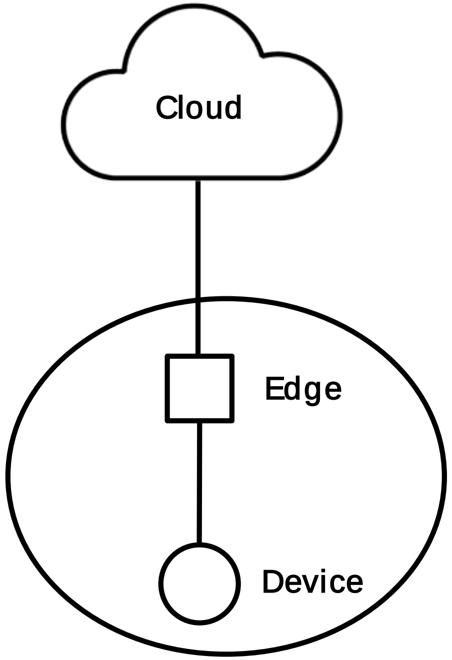
Leveraging the ABB Ability™ platform

Secure digital solutions on-premise, in the cloud, and in an ecosystem

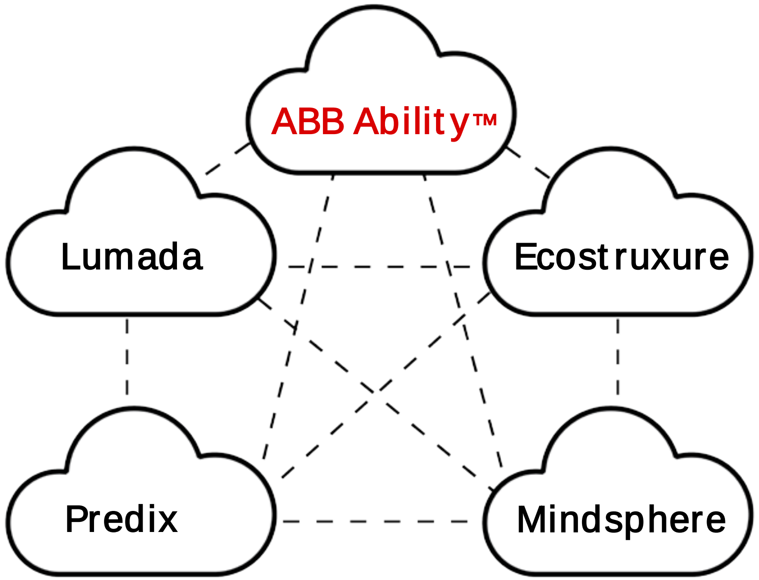
Fog



Cloud

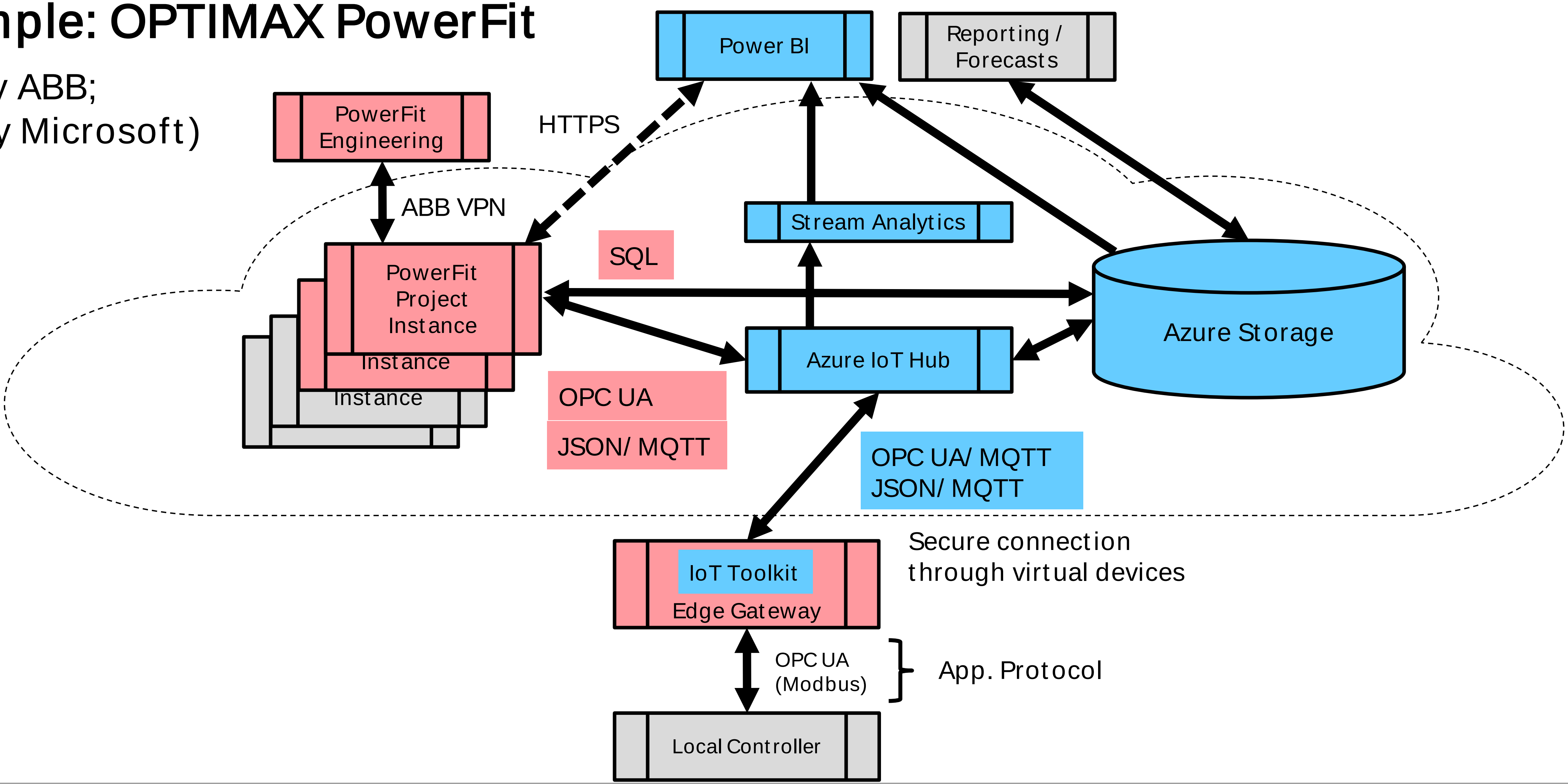


Intercloud

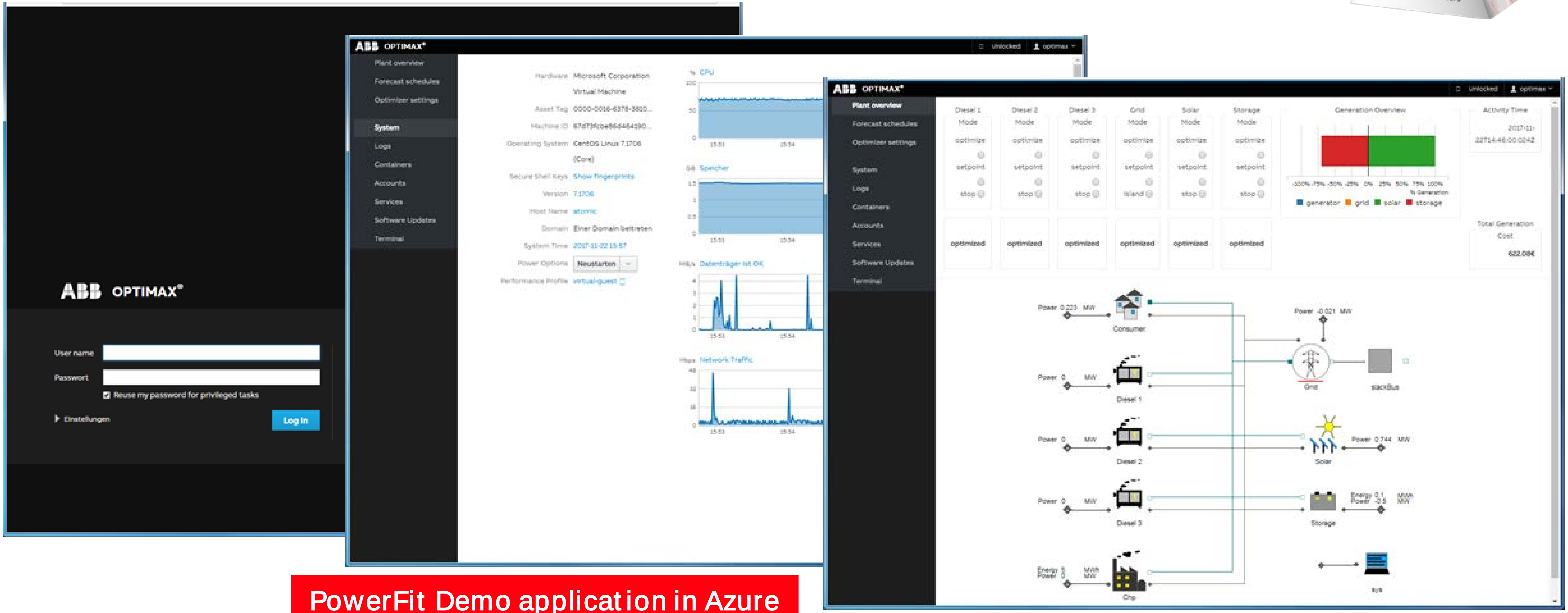


Example: OPTIMAX PowerFit

(red by ABB;
blue by Microsoft)



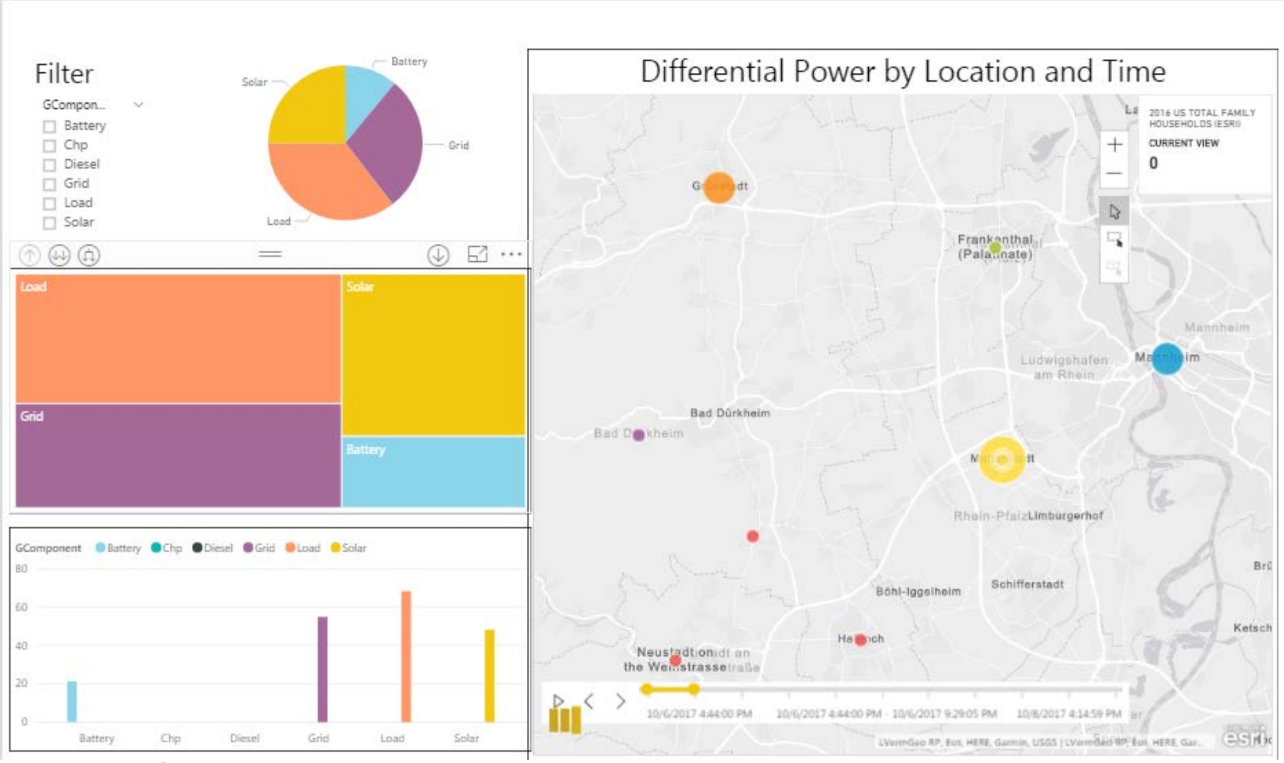
OPTIMAX PowerFit in Azure (with new Cockpit) – Cloud

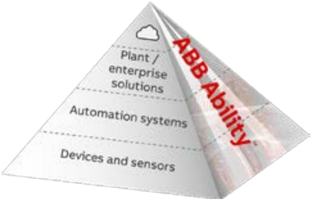


PowerFit Demo application in Azure

PowerBI for PowerFit – Intercloud

New Microsoft dashboard software





Accessing Azure storage written by PowerFit Demo application

ABB

Conclusions

Cloud computing, connectivity and inexpensive computing resources are three drivers of digital revolution

Exploitation in ABB Ability OPTIMAX PowerFit for management of renewable power considering grid limits

Parallel optimization with control vector parameterization (multiple shooting)

- Solve model and sensitivity equations in parallel for each time interval
- Need to find best compromise for treatment of equation systems in model vs by solver (cf. ODE vs reduced DAE vs full DAE)

OpenModelica provides modeling and translation technology

- Generate FMUs for different modi (degree of elimination of nodes in grid model)
- Well suited for research projects; still limited for commercial use, despite of huge progress during last years (efficiency of modeling workflow for complex models, lacking encryption of model libraries)

PARADOM using OpenModelica and HQP

- Successful implementation of parallel optimization with multiple FMU instances
- New OpenModelica feature: algorithmic differentiation of FMUs (fmi2GetDirectionalDerivative)

ABB