Energy management and standardized field bus communication for optimized hybrid PV battery systems

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Agenda

- Motivation
- Hybrid PV battery systems
- Standardized field bus communication
- Energy and battery management
- Hybrid battery systems
- Conclusions

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Application areas of hybrid PV systems

Present / Past

Main application area: Up to 15 kW

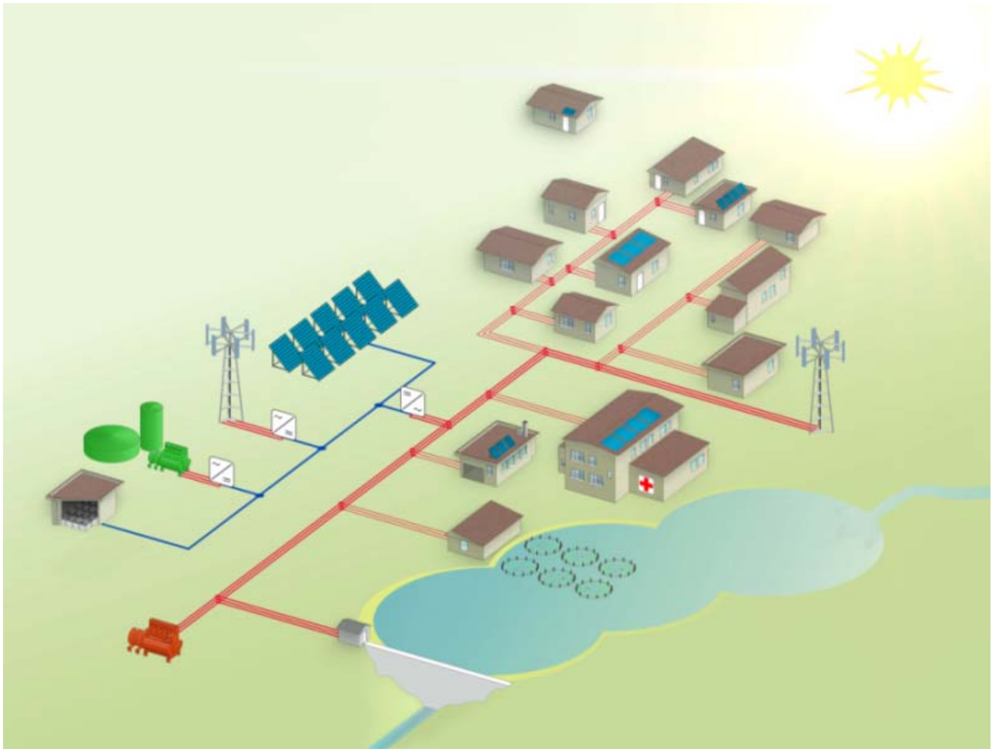
Future

Main application area: Several 100 kW to MW

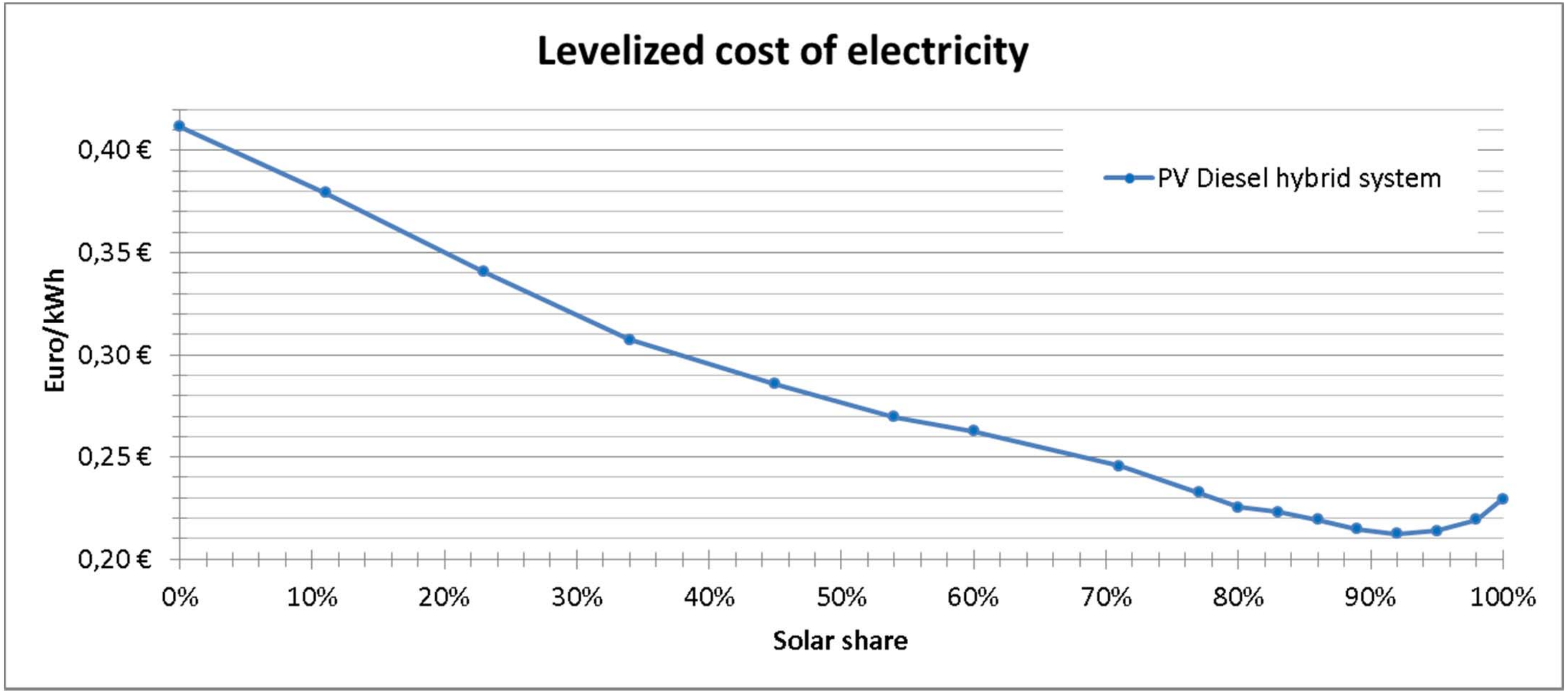
- Increasing demand for high power PV off-grid systems due to
  - drop of component prices (PV-generator, battery system)
  - lower lifetime cost compared to diesel systems (increasing diesel prices)
  - lower CO_2-emissions compared to diesel systems
- How can existing system technology cope with the new requirements?

Hybrid PV systems – Levelized cost of electricity
Example Uganda

- Load:
  - Peak load: 200 kW
  - Annual consumption: 574 MWh
- PV Diesel hybrid system:
  - PV system (incl. PE): 1,5 Euro/Wp
  - Battery system: 220 Euro/kWh
  - Diesel invest: 273 $/kW
  - Diesel fuel cost: 1$/l
  - Diesel maintenance cost: 0.7 $/h

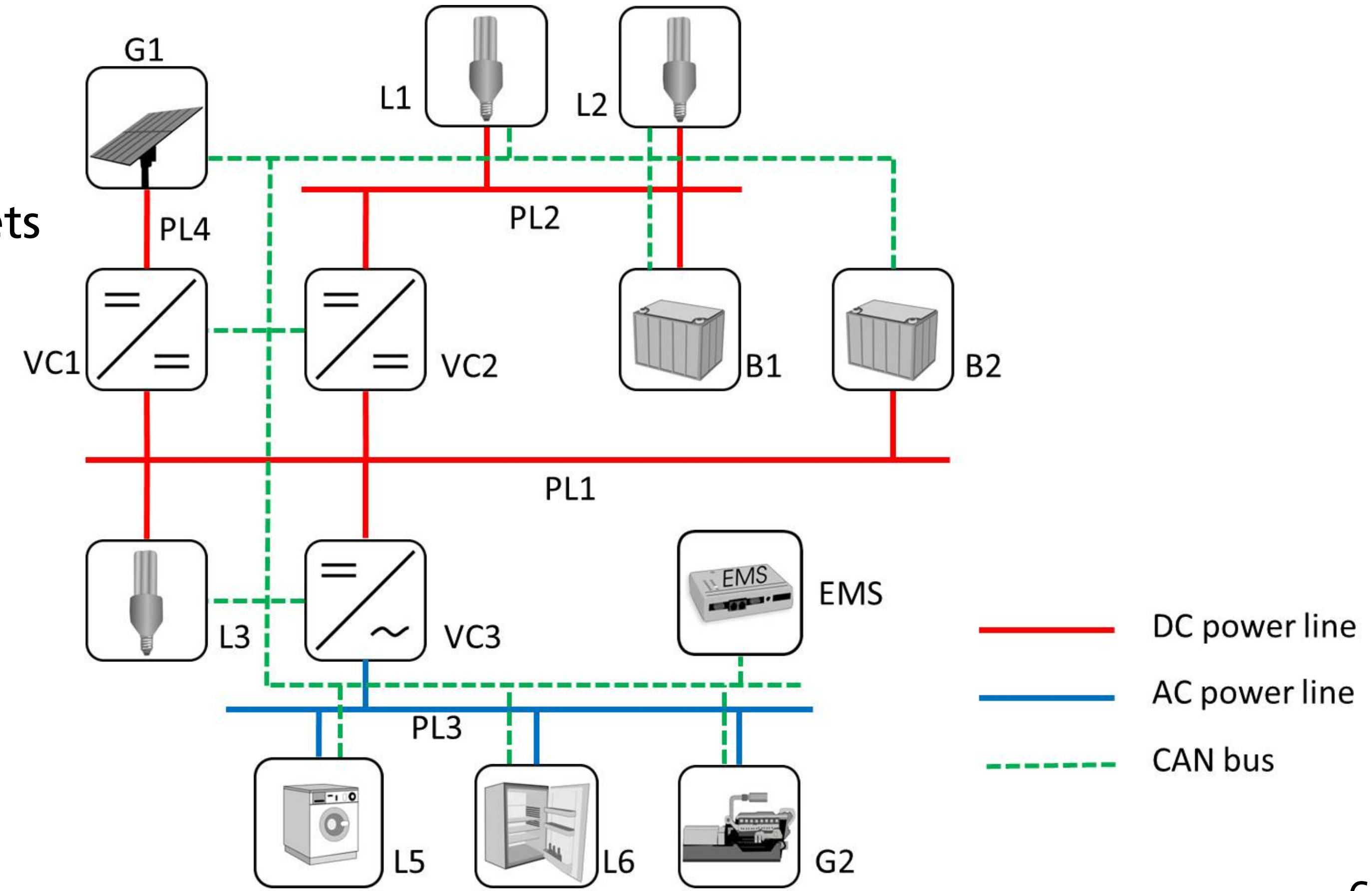


Hybrid PV systems – Levelized cost of electricity
Example Uganda



Hybrid PV systems – Components

- Generators:
  - Fluctuating: PV, wind
  - Switchable: E.g. Diesel gensets
- Loads:
  - Shiftable
  - Non-shiftable
- Battery storages
- Energy management system
- Communication



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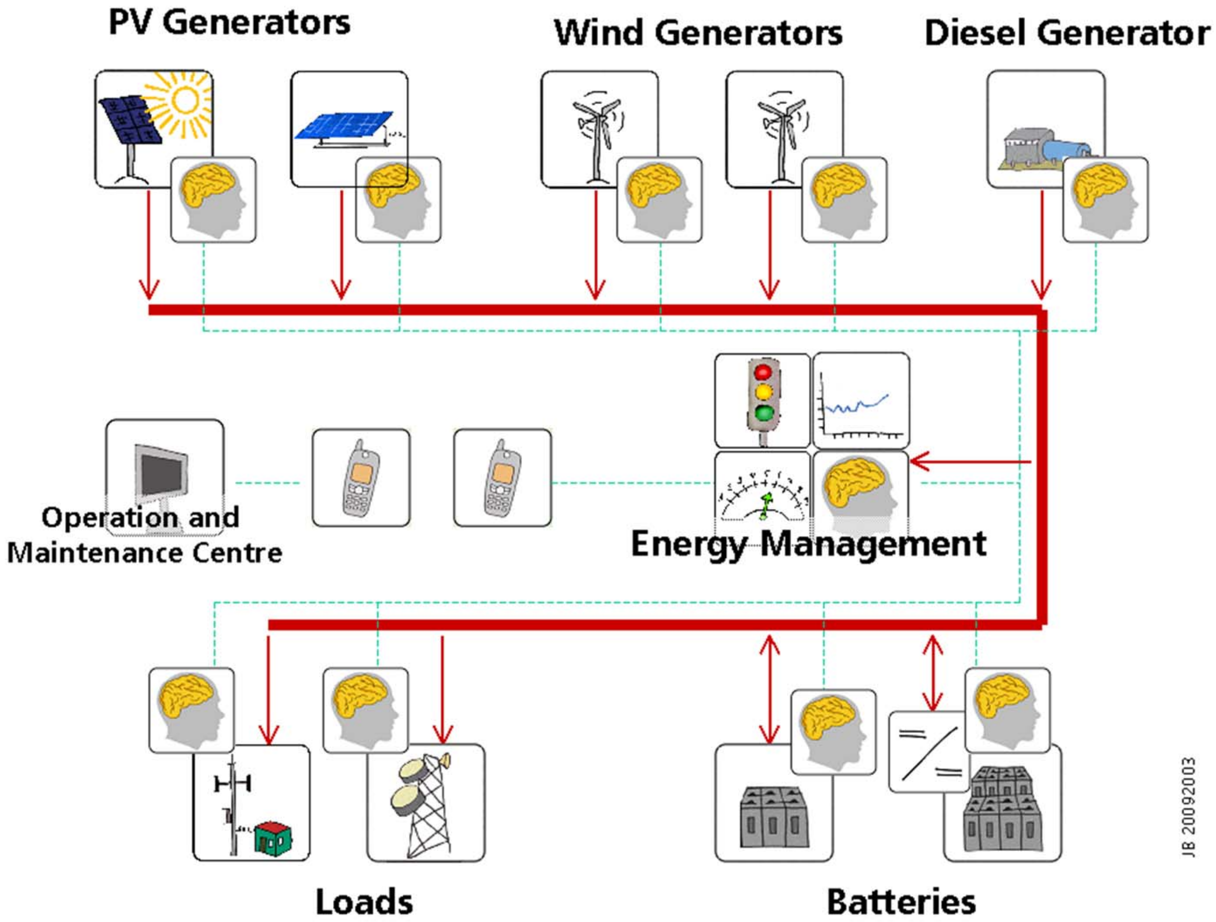
Development of a communication standard

- Superordinate energy management system
- Intelligent components
  - Generators
  - Battery management
  - Loads
- Communication bus
- Standardized “Universal Energy Supply Protocol”

→ Modular, flexible und expandable



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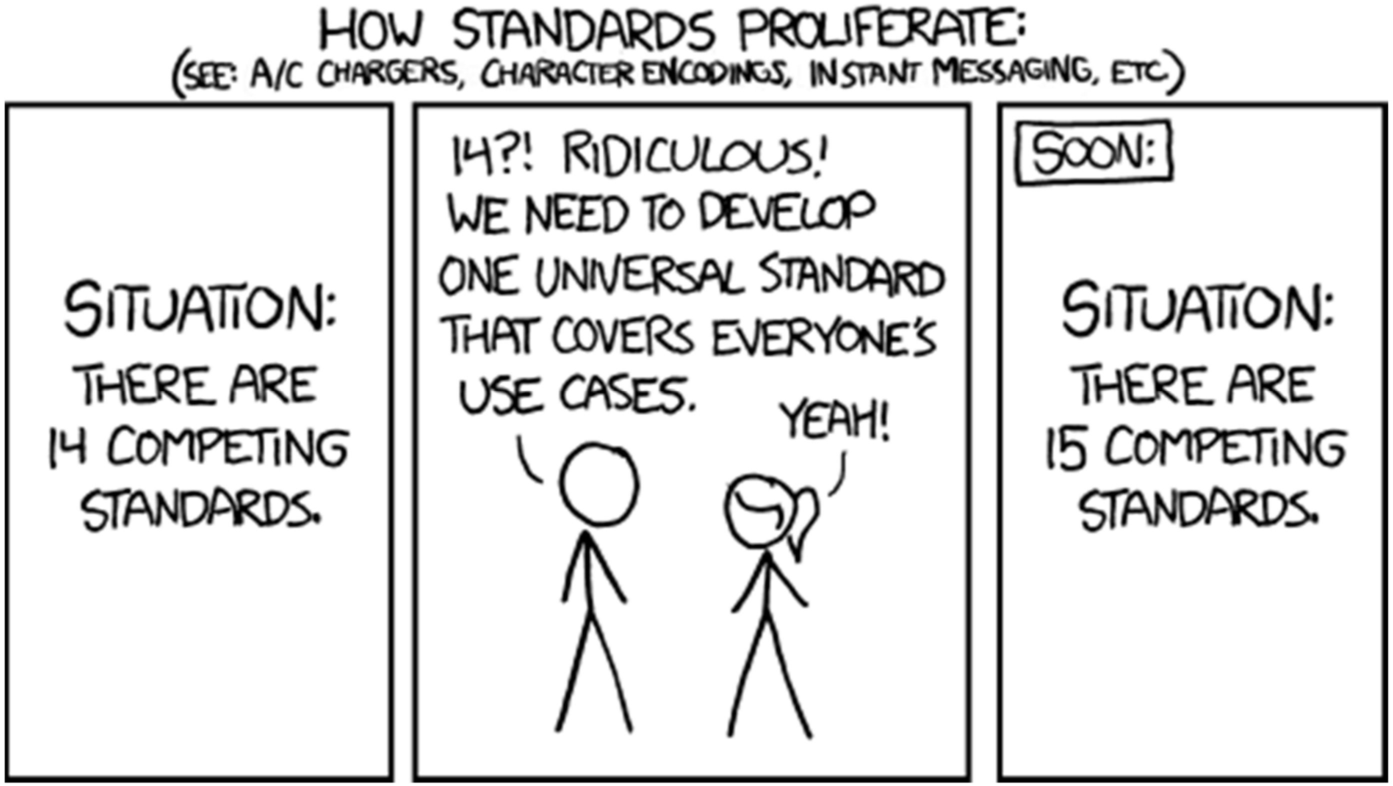
Development of a communication standard



Source: imgs.xkcd.com/comics/standards.png

- Better: Use a solid base and trim to your application
- The contents of UESP were brought into the CANopen application profile CiA 454 “Energy Management Systems”

Development of a communication standard

Transition in Can in Automation (CiA) specification → WG 454

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  - Generators
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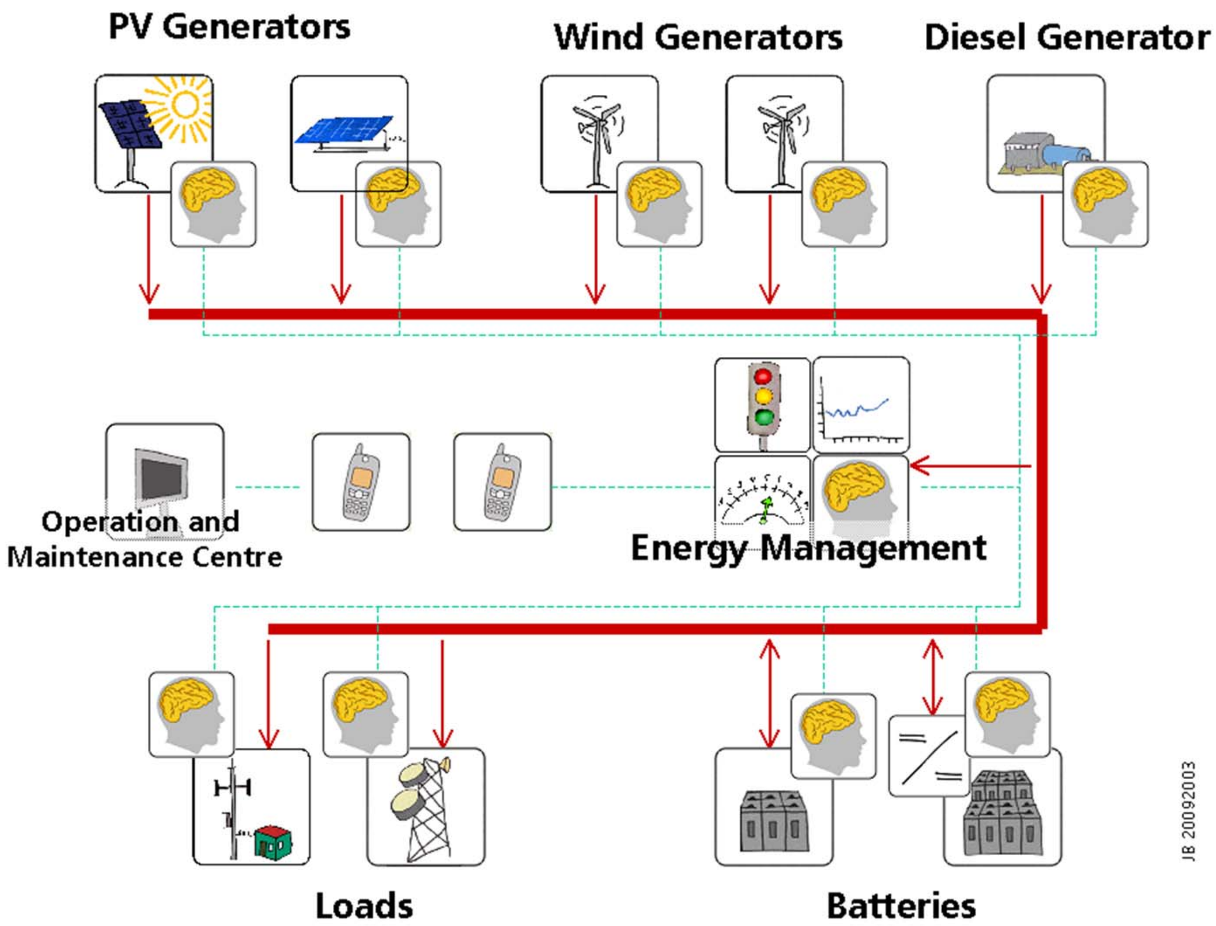

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EnergyBus e.V.

with CANopen specification → CiA 454

- Starting point of EnergyBus e.V.:
  - ➢ Interoperability of components of light electric vehicles LEV: Plugs, communication interface, etc.
  - ➢ Communication: CANopen specification CiA 454 LEV
  - ➢ Significant similarities with stationary PV off-grid and also on-grid (!) applications: batteries, power electronics, loads, user displays, etc.
- Now extended for energy management applications in general

  → New name of CiA 454: "Energy management systems"

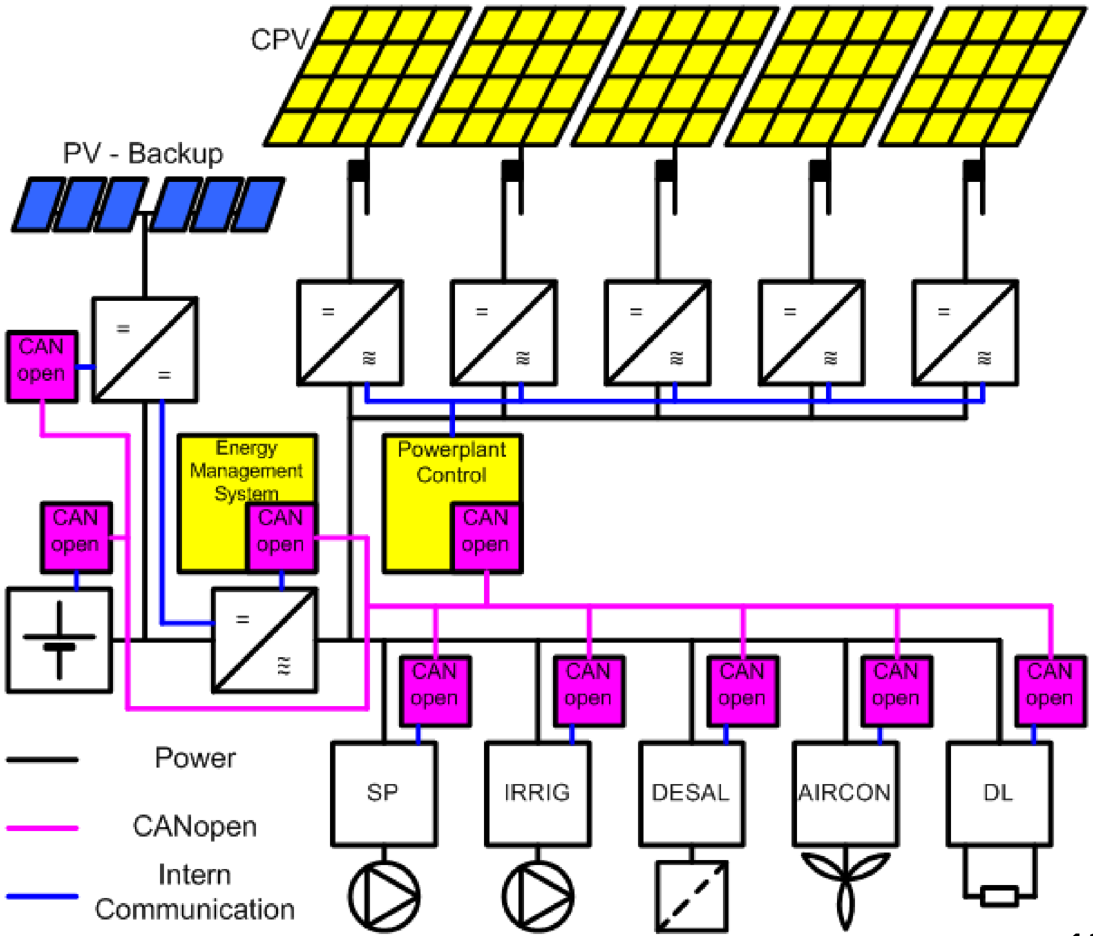
A first reference implementation
Water treatment system in Egypt

First off-grid concentrating
photovoltaic power plant

A first reference implementation
Water treatment system in Egypt

First off-grid concentrating photovoltaic power plant

- Small battery bank to reduce investment cost
- Large share of controllable loads → water can be stored in tanks
- EMS accumulates available power and dispatches the generators and loads



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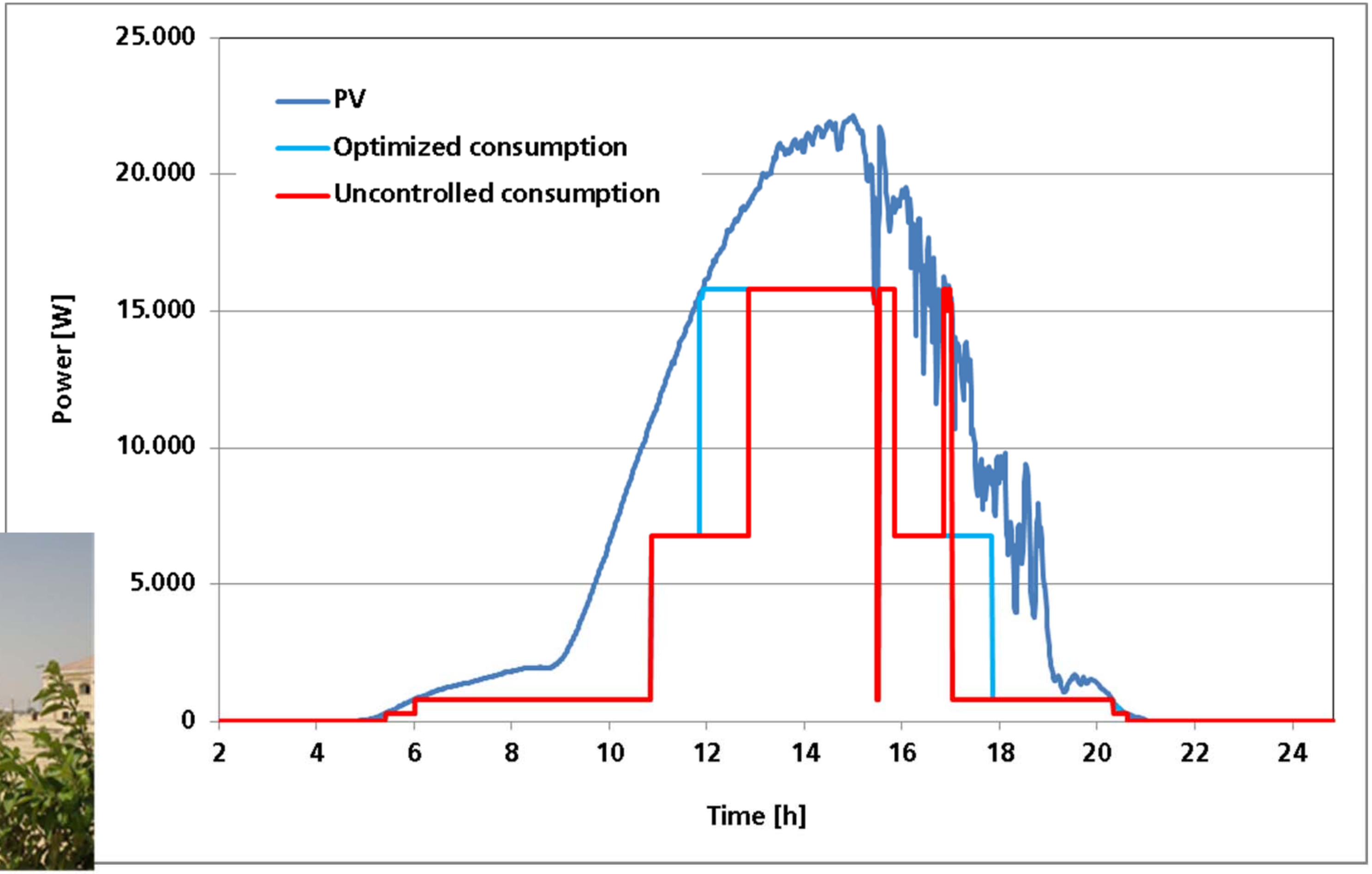
A first reference implementation
Water treatment system in Egypt

Demand-side management



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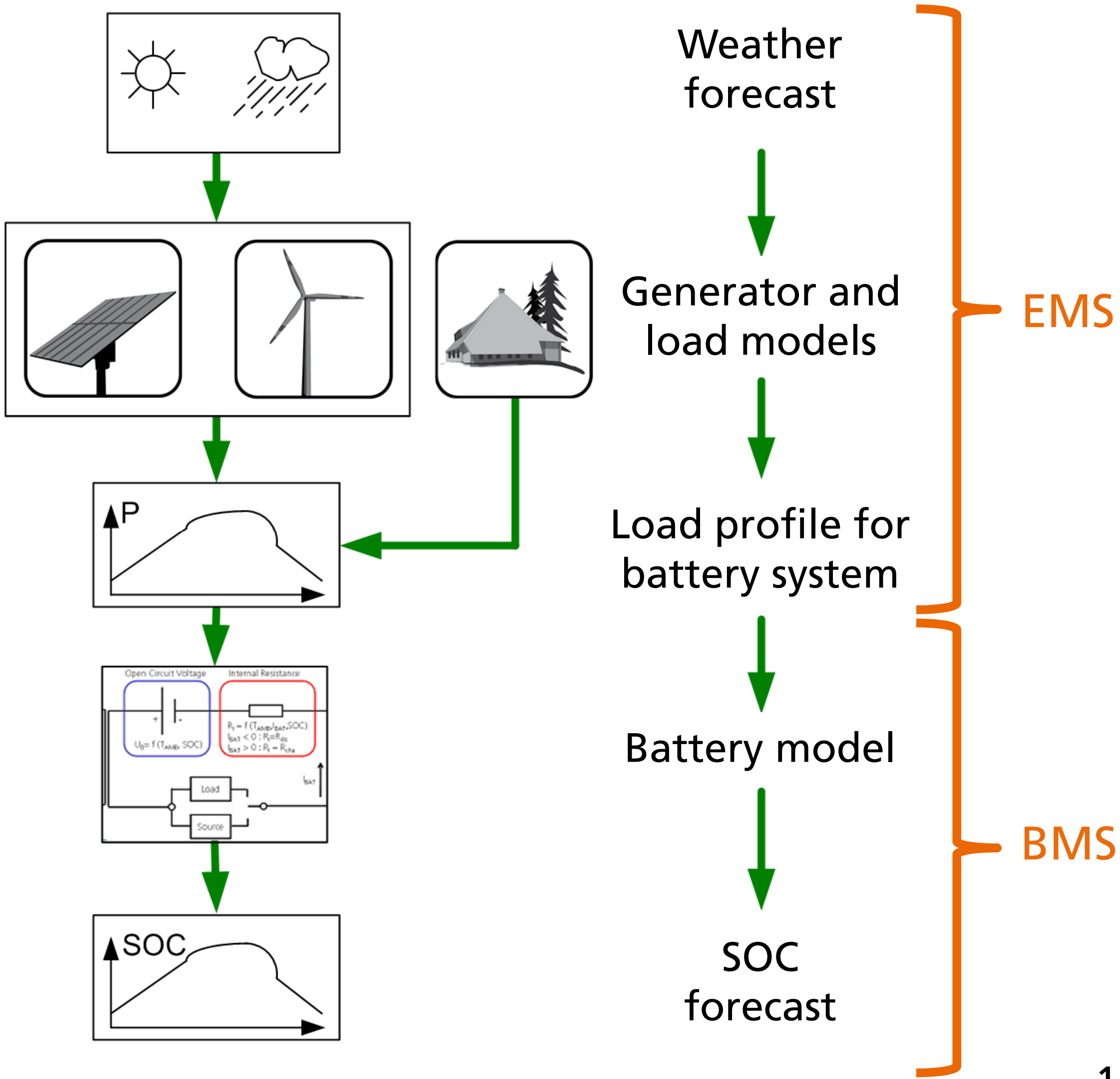
Smart battery management as part of an optimized energy management

- Communication interface between EMS and BMS
- Model based energy management
  - ➢ Load and generation management
  - ➢ Optimized operation of battery system
  - → Control of energy fluxes
- Model based battery management
  - ➢ SOC prediction in dependence on load profile forecast
  - ➢ Efficiencies in dependence on load profile forecast
  - ➢ Information on aging



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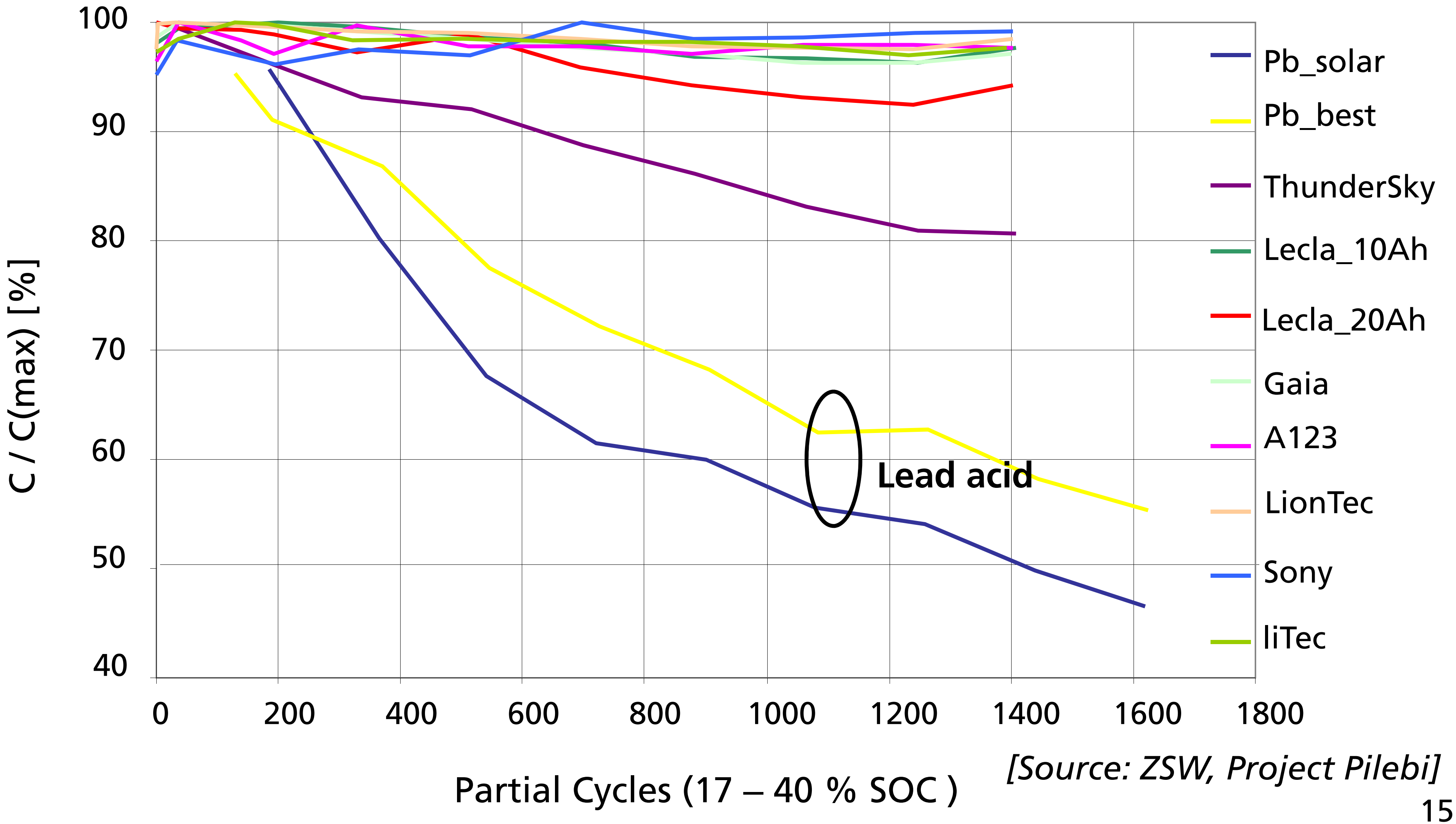
Batteries in PV applications
Partial cycling at low states of charge



[Source: ZSW, Project Pilebi]

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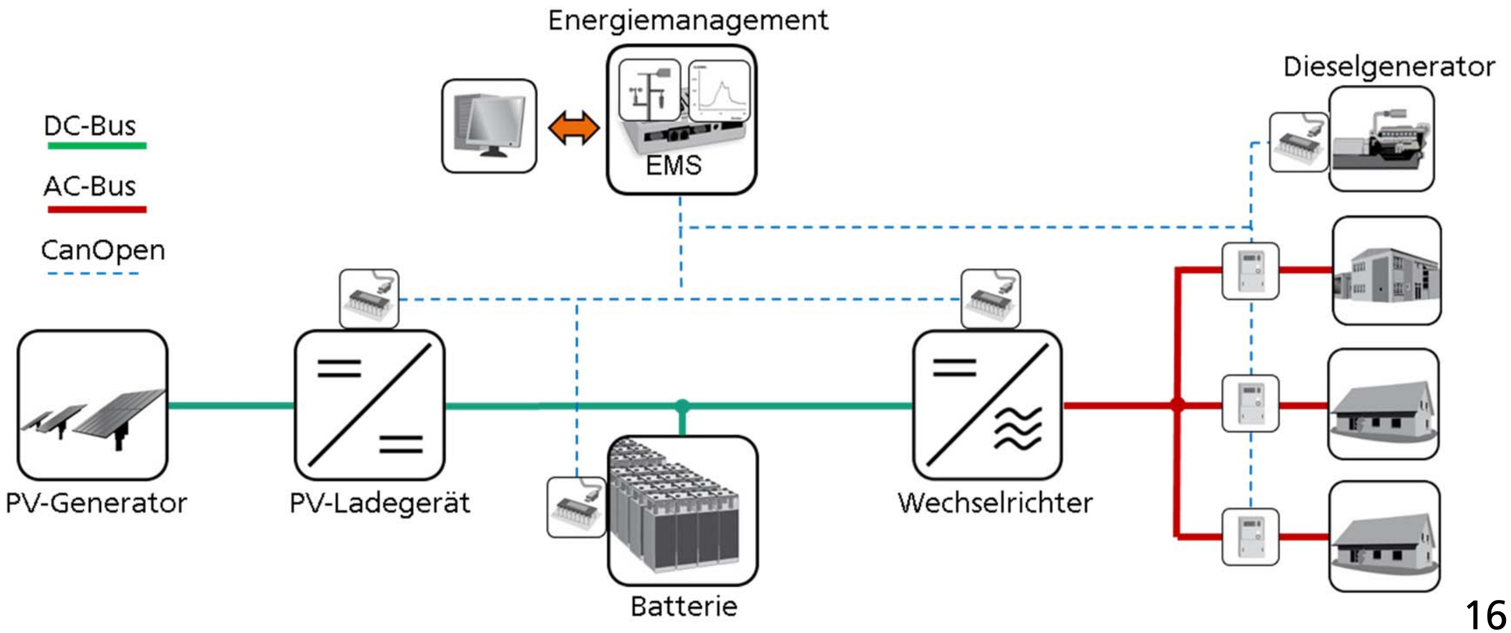
System simulation – Hybrid PV mini-grid application

PV generator	110 kWp
DC-DC converter (nominal power)	2 x 51 kW
Inverter (nominal power)	120 kW
Diesel generator	60 kW
Lithium battery system ($LiFePO_4$)	289 kWh
Lead-acid battery system	1.152 kWh
Annual consumption	100.132 kWh



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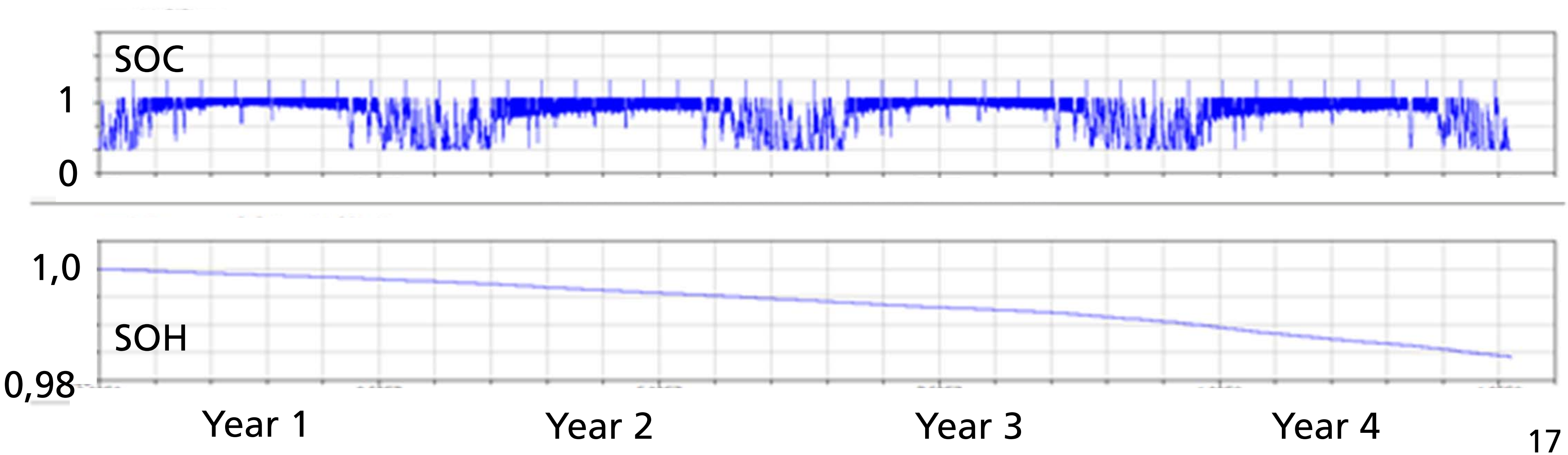
System simulation – Example for a period of four years

- Starting point: Measurement data of a lead-acid battery operated with advantageous boundary conditions (integrated BMS and frequent full charges)
- Loss of capacity of lead-acid battery with simulation period of 4 years: 1.5 % (!)

Lead-acid battery



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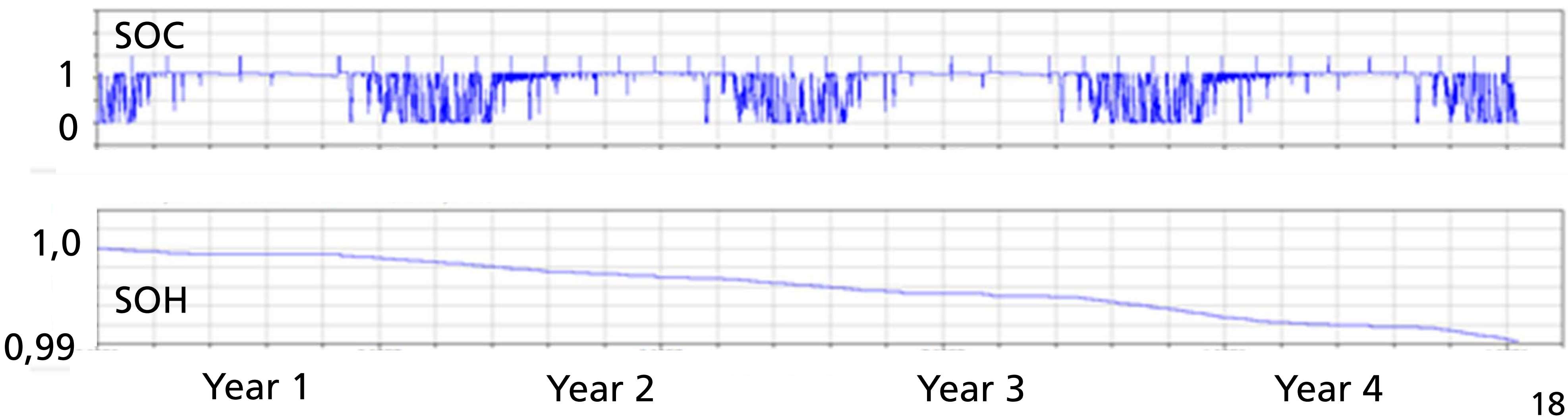
System simulation – Example for a period of four years

- Starting point: Measurement data of a lead-acid battery operated with advantageous boundary conditions (integrated BMS and frequent full charges)
- Loss of capacity of lead-acid battery with simulation period of 4 years: 1.5 % (!)
- Hybridization: Loss of capacity: 0.9 %
  → Reduction of aging: 40 % (within simulation period of 4 years !!!)

Hybrid battery system – Consideration of lead-acid sub-system



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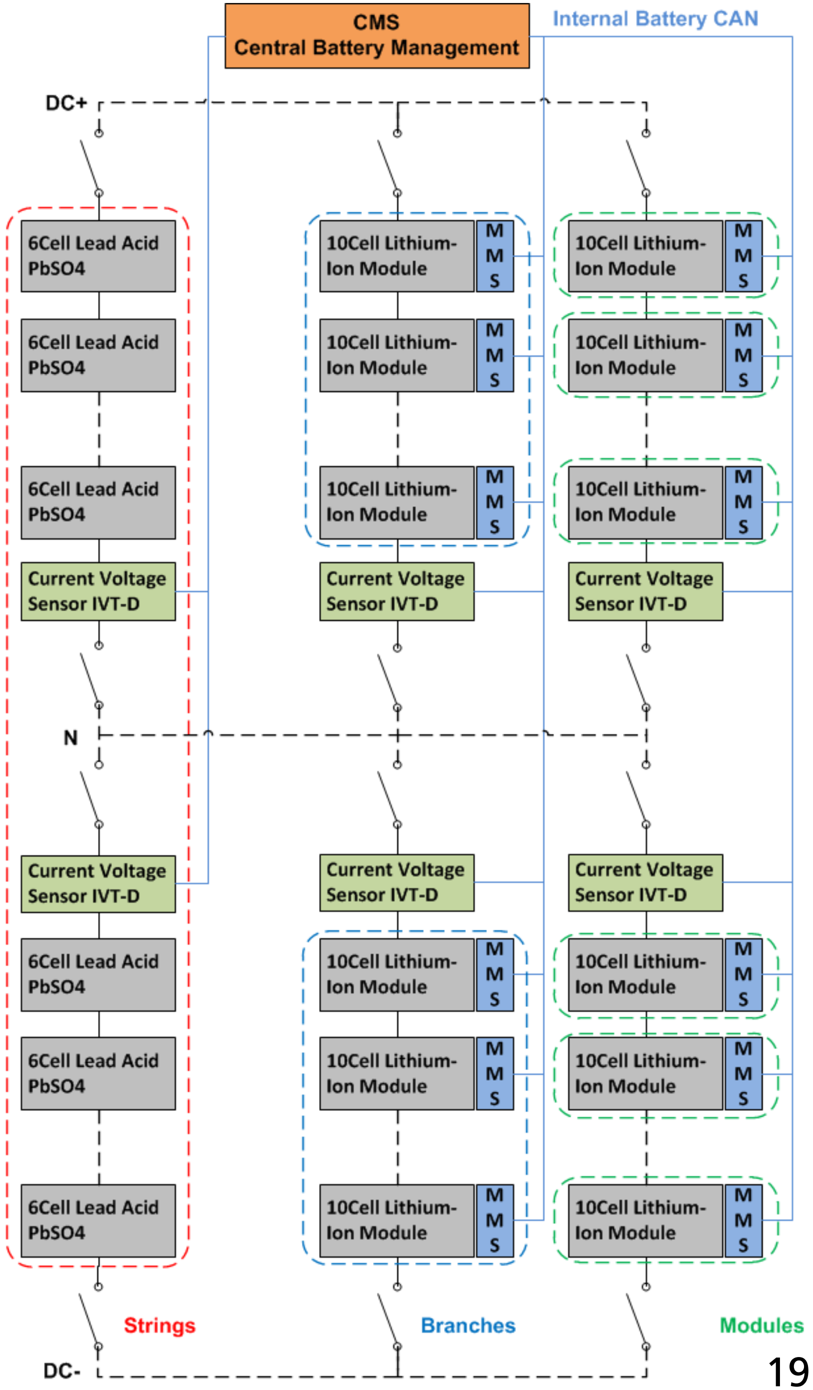
Hybrid lithium-ion lead-acid battery system for PV mini-grids

→No additional DC-DC converter

Scaled laboratory version



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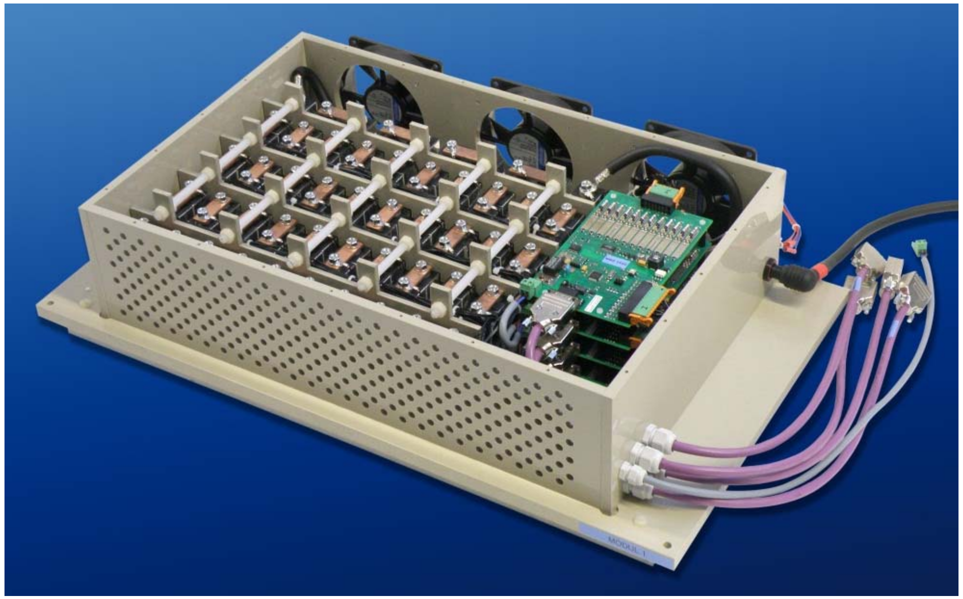
Hybrid battery system – Lithium-ion sub-system

- Battery cabinet (11.55 kWh):
  - One lithium-ion battery string for up to 46.2 kW @ up to 1 kV
  - Consisting of 7 modules
  - Can be switched in parallel
  - Ventilation system for cooling



- Lithium-ion battery module:
  - Contains 40 battery cells
  - Air cooling
  - High discharge rates (4C continuous, 6C @ 30 s)
  - Easy and safe to exchange

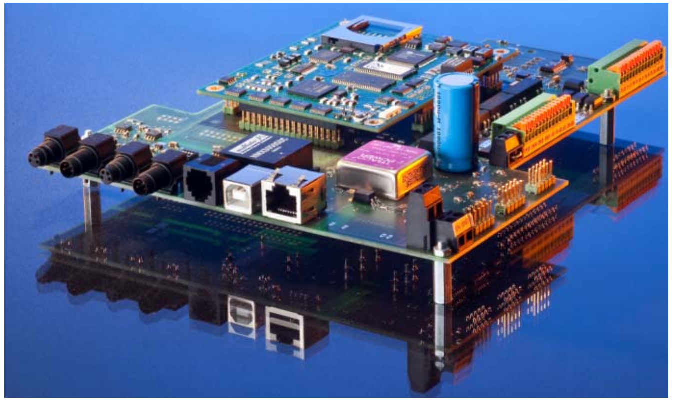
Battery management systems
Motivation and objective

Objective:

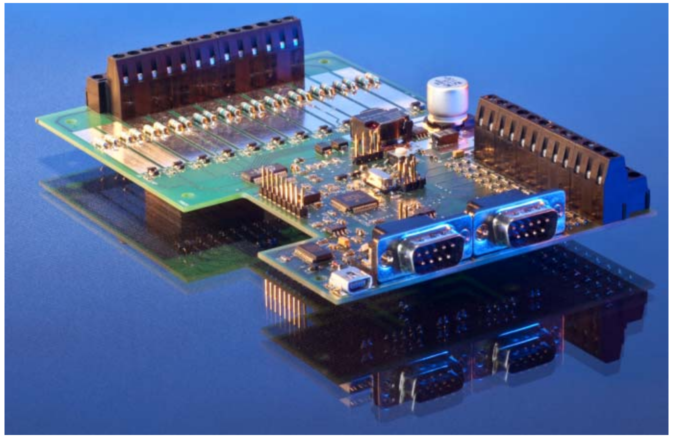
Lithium-ion cells have to be monitored and controlled, important issues are:

- Safety (e.g. overvoltage / undervoltage detection)
- Cycle and calendar life time
- State estimation
- Temperature / voltage monitoring
- High efficiency (well suited cell balancing, low energy consumption of the BMS)

Objective reachable
with high end battery management systems



Central management unit



Module management unit

Structure of a battery management system
Overview and function blocks

State estimation
- SOC
- SOH
- Other states (optional)

Control system
- Actuators and switches
- Battery models
- Load management
- Energy management (optional)

control layer

Error management
- Safety for cells

Battery **M**anagement **S**ystem

Thermal management
- Thermal battery models
- Thermal control

safety layer

Measurement and monitoring
- Cell voltages
- Temperature
- Current

Communication
- Internal
- To external components

functional layer

Conclusions

- Hybridization of Diesel mini-grids with PV economic viable
- Advanced solutions for hybrid PV systems on the market of close to market entry
- Standardization of communication enables easy combination of components of different manufacturers:
  - Power electronics (inverters, charge controllers)
  - Battery systems with integrated battery management
  - Energy management systems
  - Additional power generators
  - Loads
- Energy management: Increase of direct used PV power by integrating an intelligent demand-side management
- Variety of new battery technologies on the market or close to market entry
- But: The lead acid battery will not disappear…e.g. in hybrid PV mini-grids
  - Hybrid approaches to enlarge the life time of lead-acid batteries by integrating a comparably small lithium-ion sub-system

Thanks for your attention !!!

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