Sol-ion PV Storage System: Field Trial Results and Implications on Battery Lifetime Expectancy

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Overview

- Operating Modes and Parameters
- Results of Field Trial
- Spread of Operating Conditions
- Battery Operation and Implications on Lifetime
- Summary / Conclusion

The Sol-ion Project
Partners and Field Trials

Sol-ION PROJECT

VOLTWERK

Fraunhofer IWES

ISEA

ZSW

e·on

Field Trial – French Case: „Island Mode“

saft

ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

TENESOL A SUNPOWER COMPANY

Field Trial – German Case „Self-Consumption“

Support and funding by

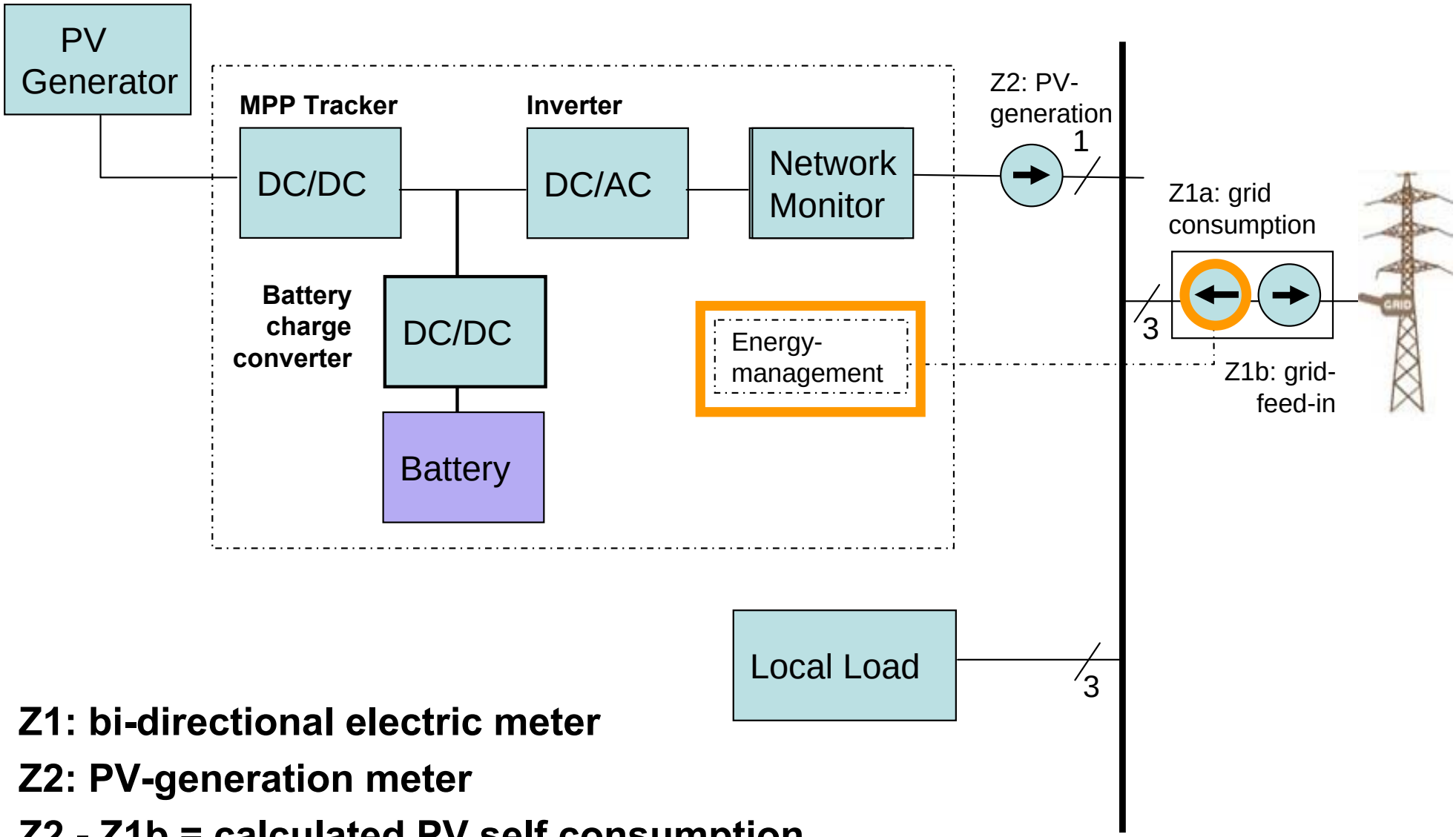
eurogia

MINISTÈRE DE L'ÉCONOMIE DES FINANCES ET DE L'EMPLOI

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

ZSW

Sol-ion: Self Consumption Mode

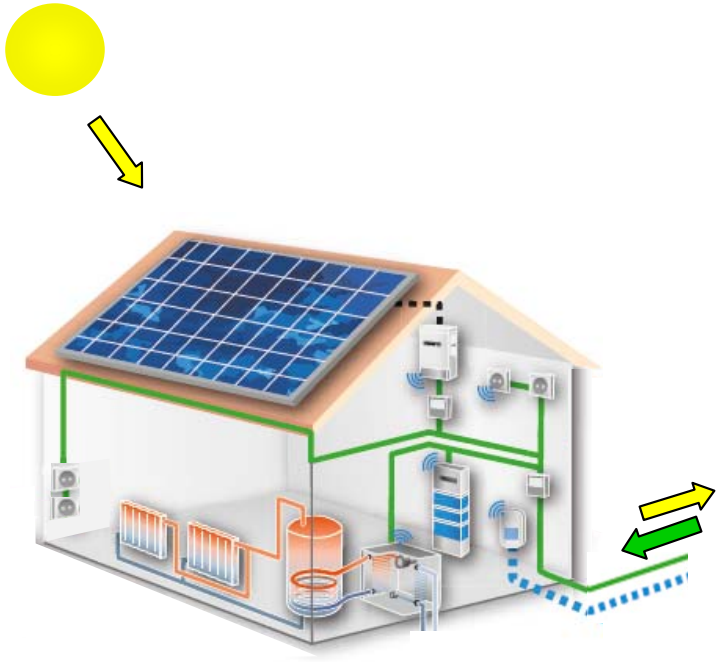


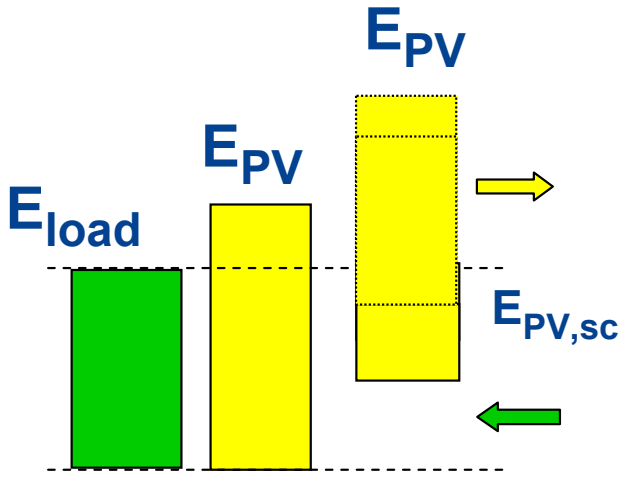
Z1: bi-directional electric meter

Z2: PV-generation meter

Z2 - Z1b = calculated PV self consumption

Relative Size of PV, Self Consumption and Autarky





Solar self consumption

- Which portion of the PV generation is consumed locally.

$$\frac{E_{PV,sc}}{E_{PV}}$$

Autarky

- Which portion of the total energy demand is produced locally

$$\frac{E_{PV,sc}}{E_{load}}$$

Important factor

- Size of PV in relation to yearly local load
- Size of battery in relation to daily load

$$\frac{E_{PV}}{E_{load}}$$

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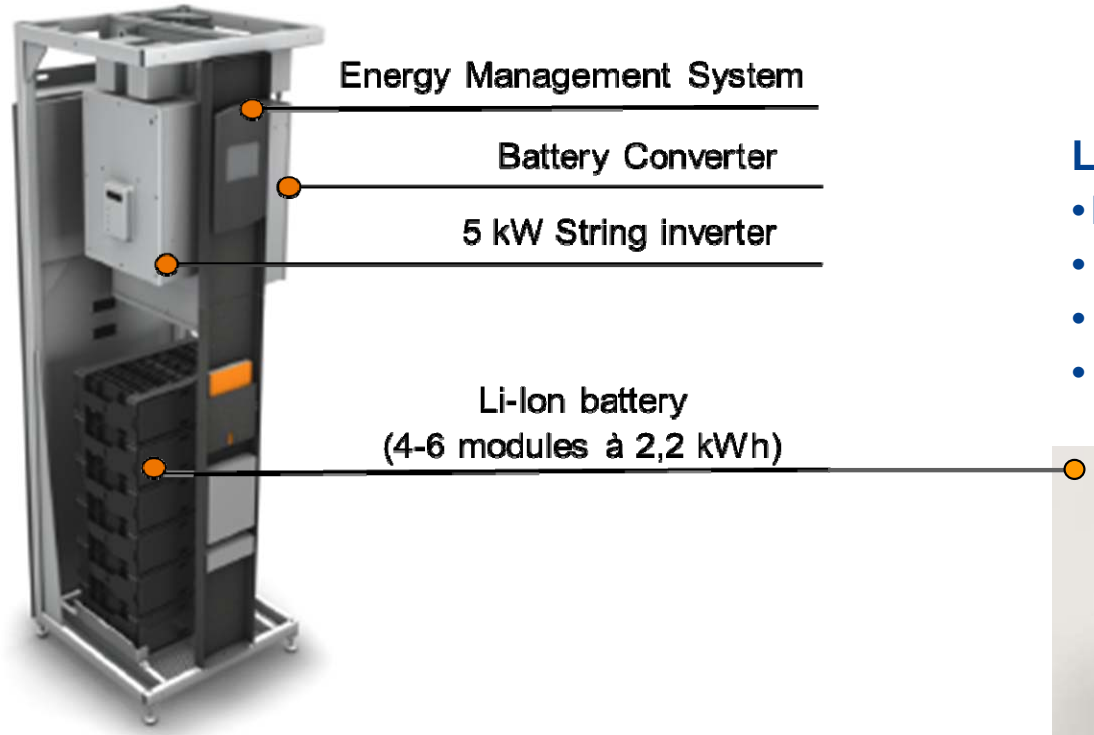
Sol-ion – PV Storage System
Installation and Commissioning



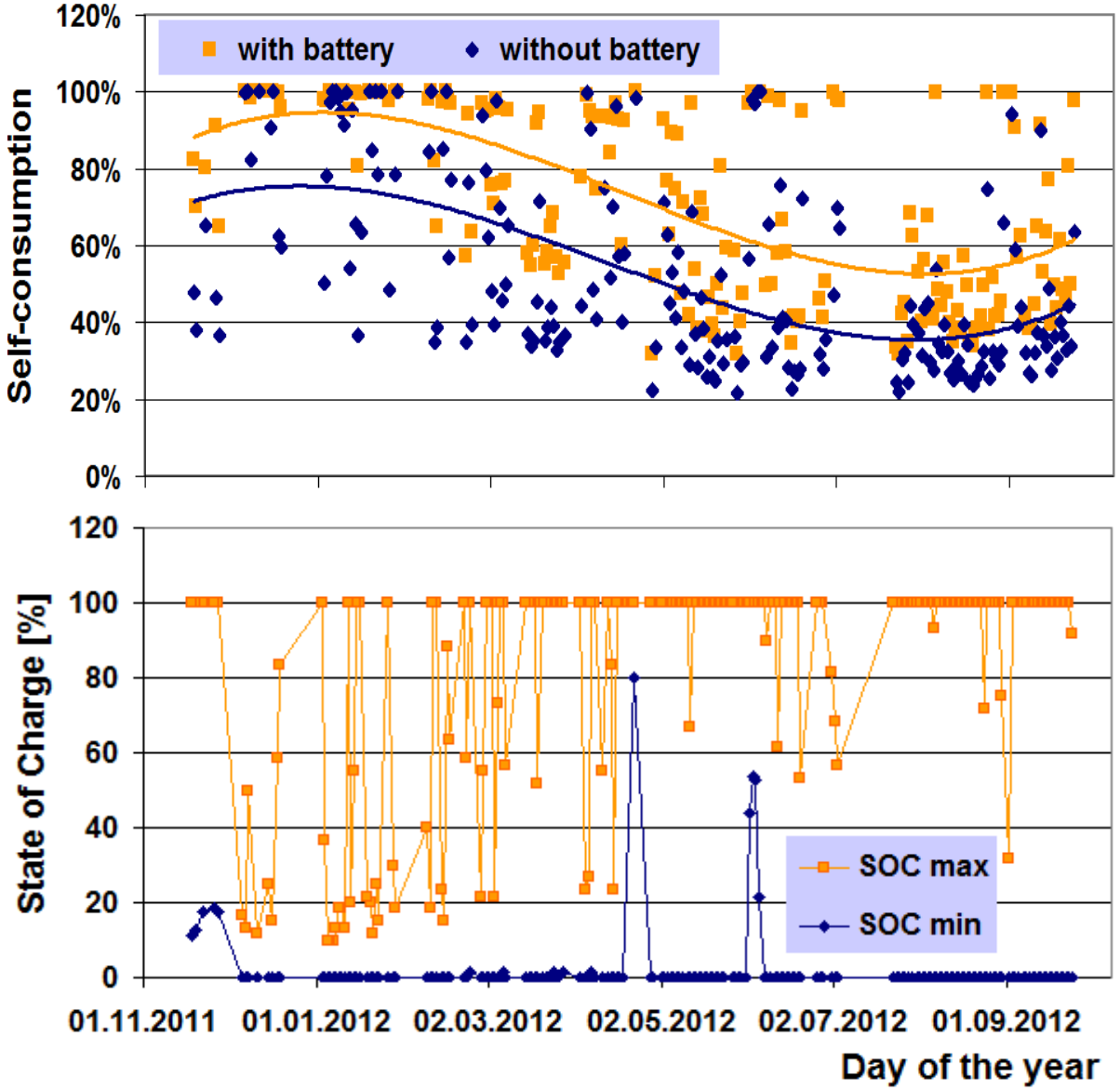
Li-Ion Battery

- Module is comprised of 14 cells type VL45E
- Nominal capacity (C/3): 45 Ah
- Voltage: 42 – 56 V
- Energy (C/3): 2200 Wh

- Functional test at the factory
  - Weight 250 kg, Size: 50x50x170 cm
- Delivered to customer site in pretested sub-units
- Mechanical Set-up in 1-2 hours, assuming PV Generation and DC cabling is installed
- Commissioning and test within 1 hour

Self-Consumption and Cycling of Battery

Seasonal Dependance at Field Trial Location „ZSW“



Effect of battery

- Self-consumption is raised through the battery by 20 - 30% per day.
- Average over 10 months: increase from 38 to 57%

State of Charge (SOCdyn)

- During summer the battery is fully cycled on most days

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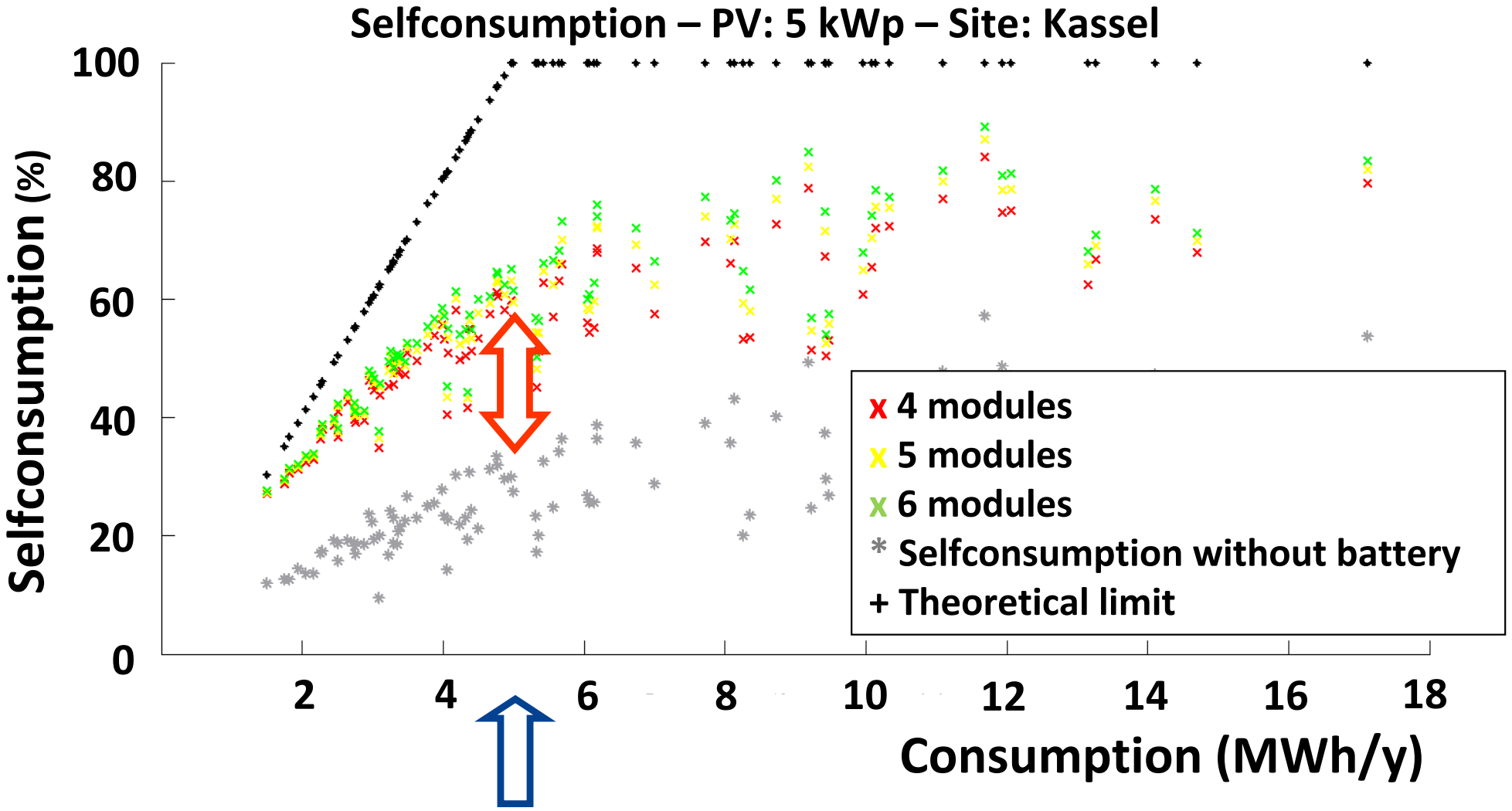
Simulation of Self-Consumption
based on 89 Consumer Load Profiles

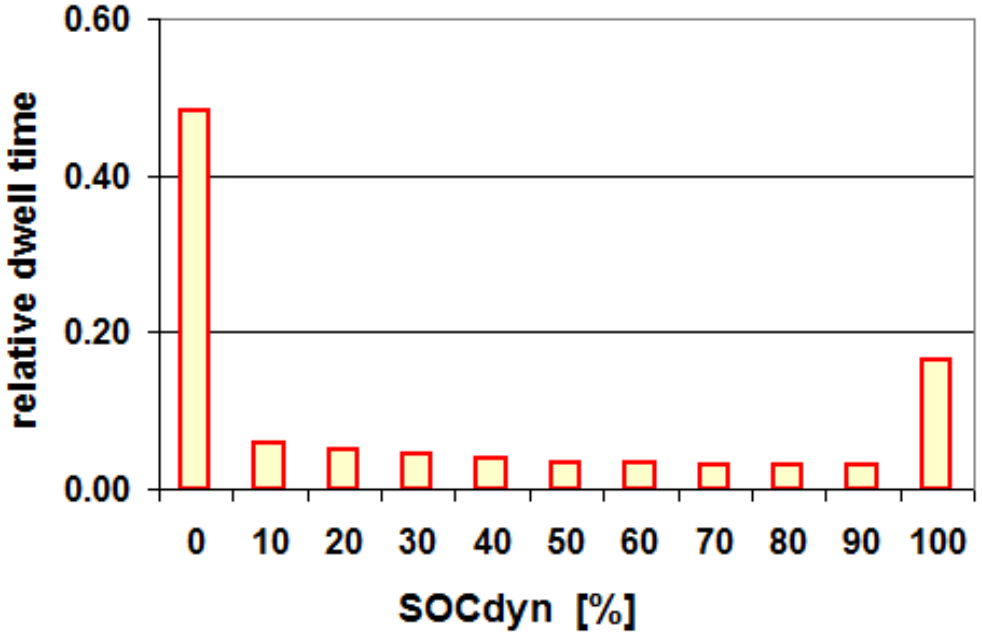


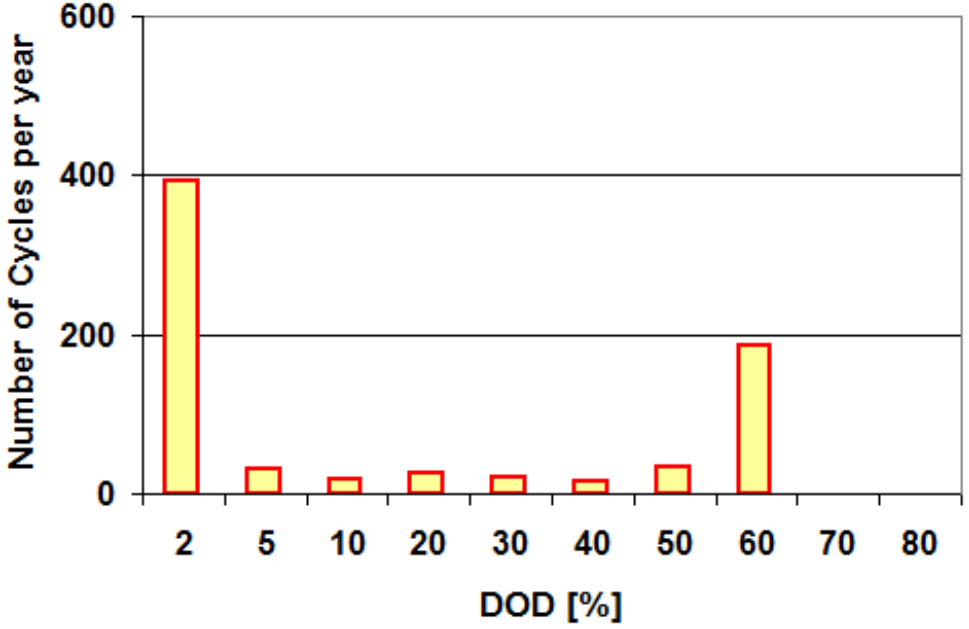
Statistics of Battery Cycling

- From time series of SOC levels through one year
  - sum up dwell times at different SOC levels
  - calculate the number of cycles and categorize by Depth of Discharge (DOD) using the rainflow-counting algorithm

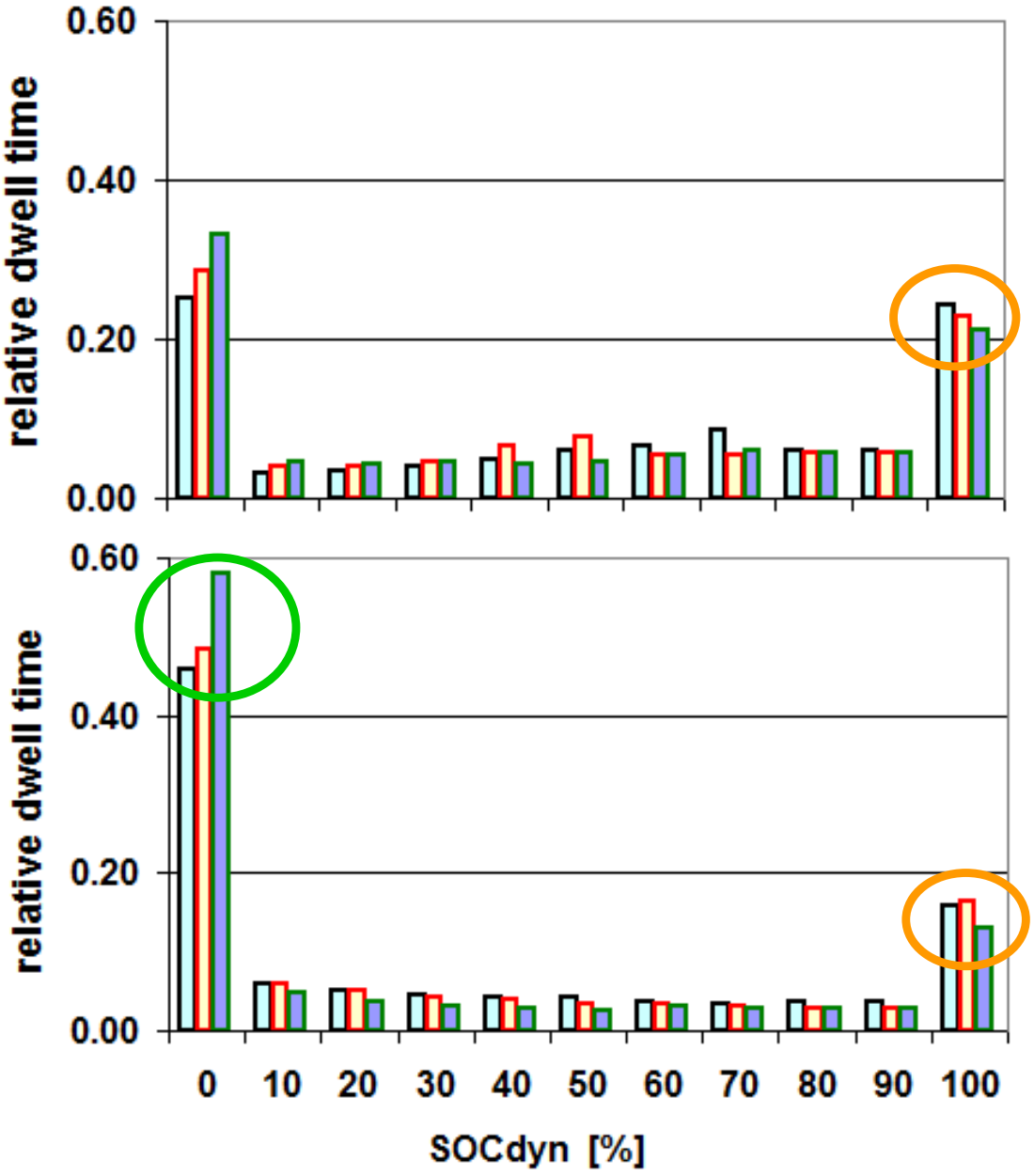
NOTE

- the transition from SOC_{dyn} = 100% to SOC_{dyn} = 0 % delivers 60% of the nominal battery capacity at all times (i.e. aging reserve in place)





Statistics of Battery Cycling – State of Charge (SOC)

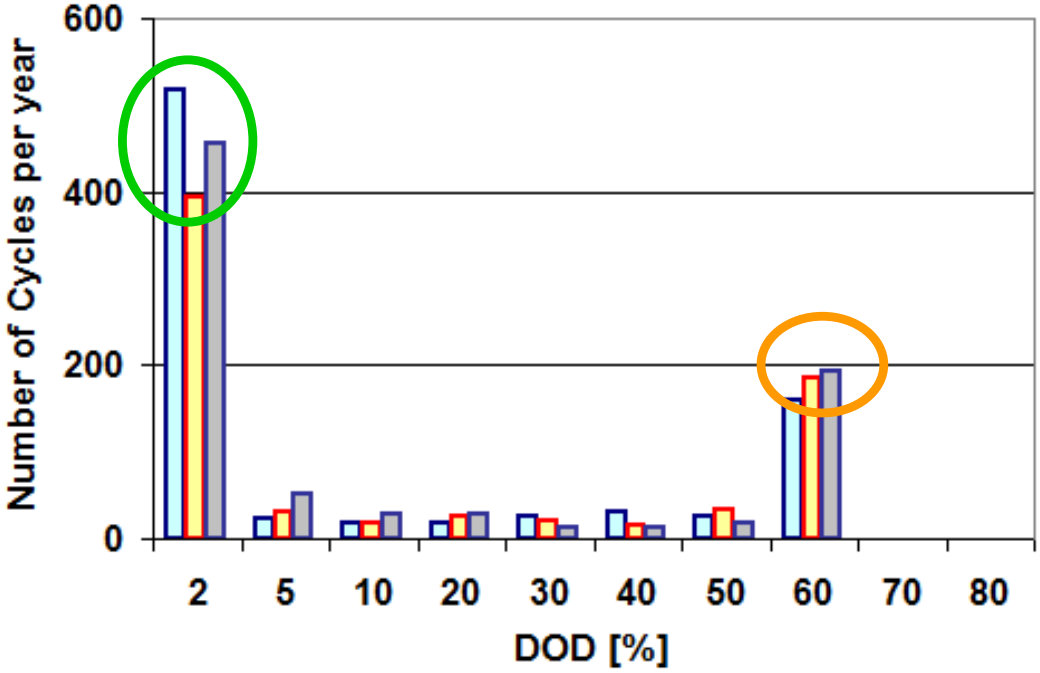


Dwell times at charged state
15- 25% of time

Increasing load
- increases dwell time at discharged state
- decreases dwell time at partially charged state

5000 kWh/a
PV Generation

Statistics of Battery Cycling – Depth of Discharge (DOD)



Load

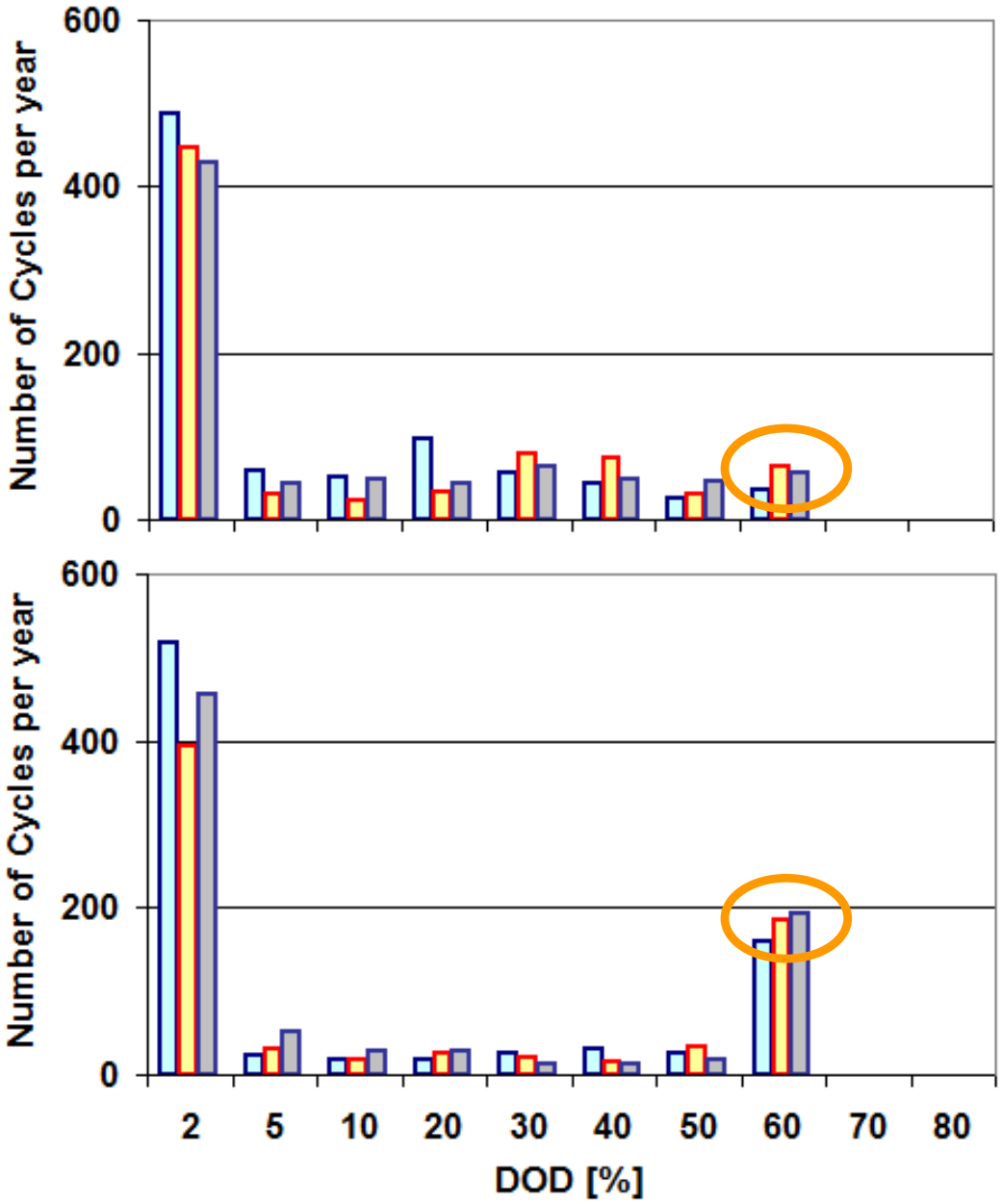
- 4593.4 kWh/a
- 4958.9 kWh/a
- 5861.3 kWh/a

190 full cycles (60% DOD) per year

400-500 cycles at ~ 2% DOD
(cycles < 1.5% DOD not counted)

⇦ 5000 kWh/a
PV Generation

Statistics of Battery Cycling – Depth of Discharge (DOD)

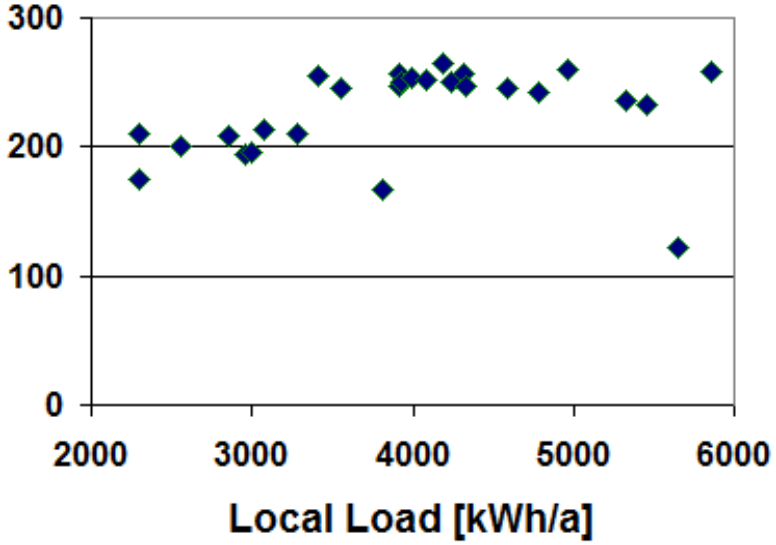


Load

- 2293.4 kWh/a
- 2300.9 kWh/a
- 2560.4 kWh/a

Equivalent full cycles per year

(dynamic range, not counting cycles < 1,5 %)



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⇦ **5000 kWh/a**
PV Generation

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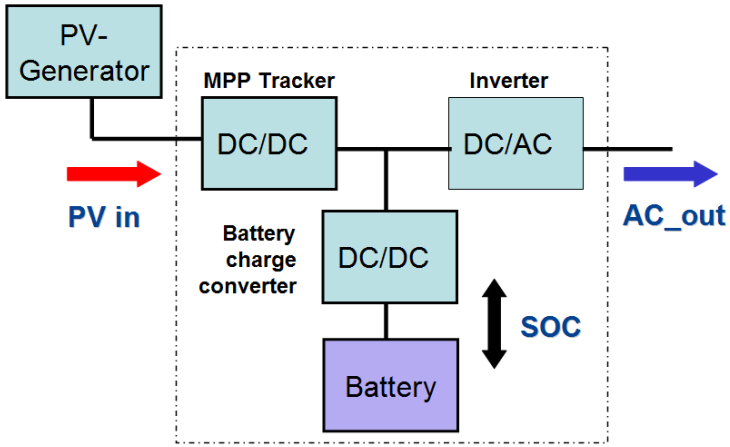
Battery Operation and Aging



Modelling of Aging distinguishes:

- Calendaric Aging
- Cyclic Aging

Battery aging depends strongly on battery type and chemistry

- Modelling is based on
  - Manufacturers (SAFT) aging tests for Li-ion batteries and
  - Aging test within the Sol-ion project on a single cell level
    - over a period of 2 years for lifetime
    - and with accelerated cycling compared to domestic use
    - at different temperature levels and depths of discharge

Measured capacity fade in accelerated aging tests comprises of both aging impacts

Empirical Aging Model for Lithium-Ion Batteries

Calendar Aging:

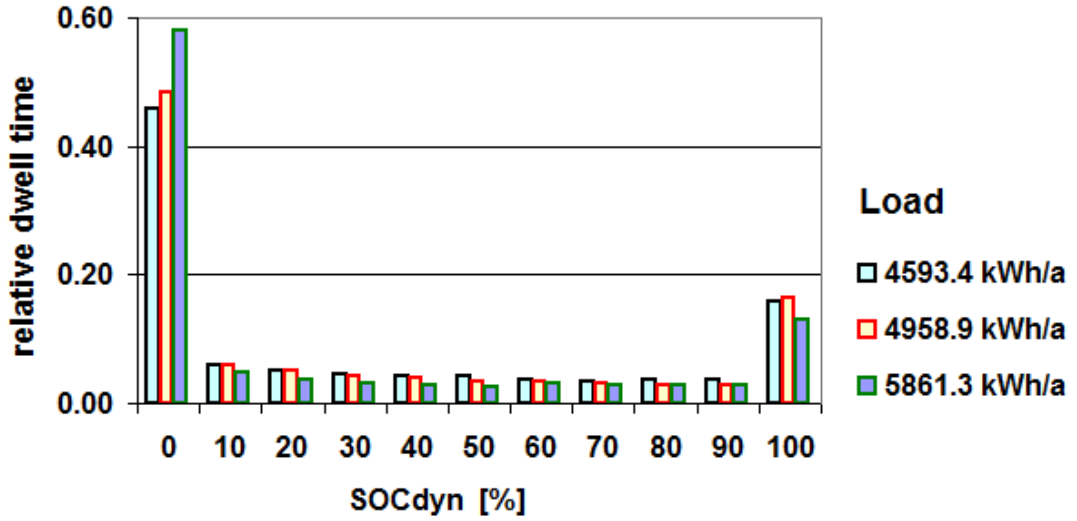
- Main Aging Process:
  - Generic thermodynamic instability of materials
- Main Impact Factors: Voltage (SOC) and Temperature
  - Increased electrode potentials lead to accelerated material decomposition
  - Increased temperature leads to increased reactivity (Arrhenius‘ Law)

Cyclic Aging:

- Main Aging Process:
  - Loss of active material due to mechanical stress (volume change)
- Main Impact Factor: Depth of Discharge (DOD = ΔSOC)
  - Higher cycle depth increases mechanical stress
    ➔ accelerated aging

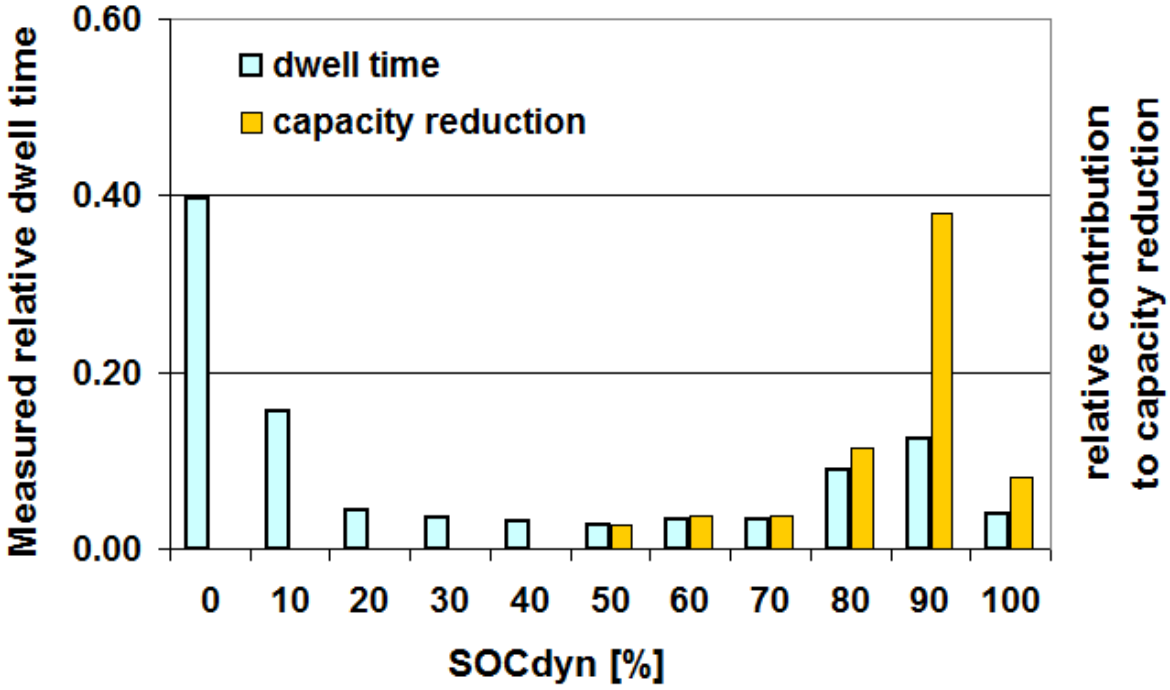
➔ Model Assumption: direct linear superposition of cyclic and calendaric aging

Calendaric Aging as a Function of SOC



Simulated dwell times

- simulation for PV = 5 kWp
- sample time: 15 min



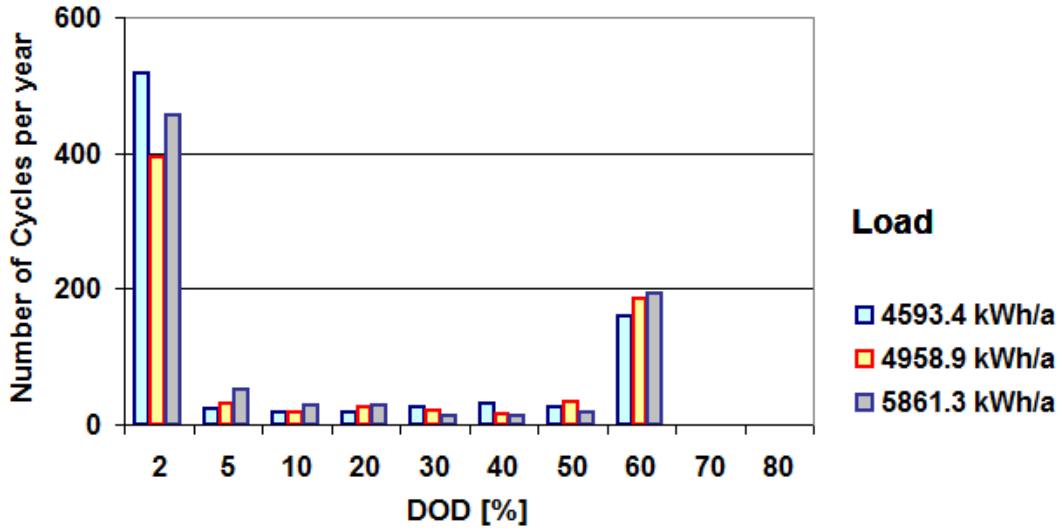
Dwell times

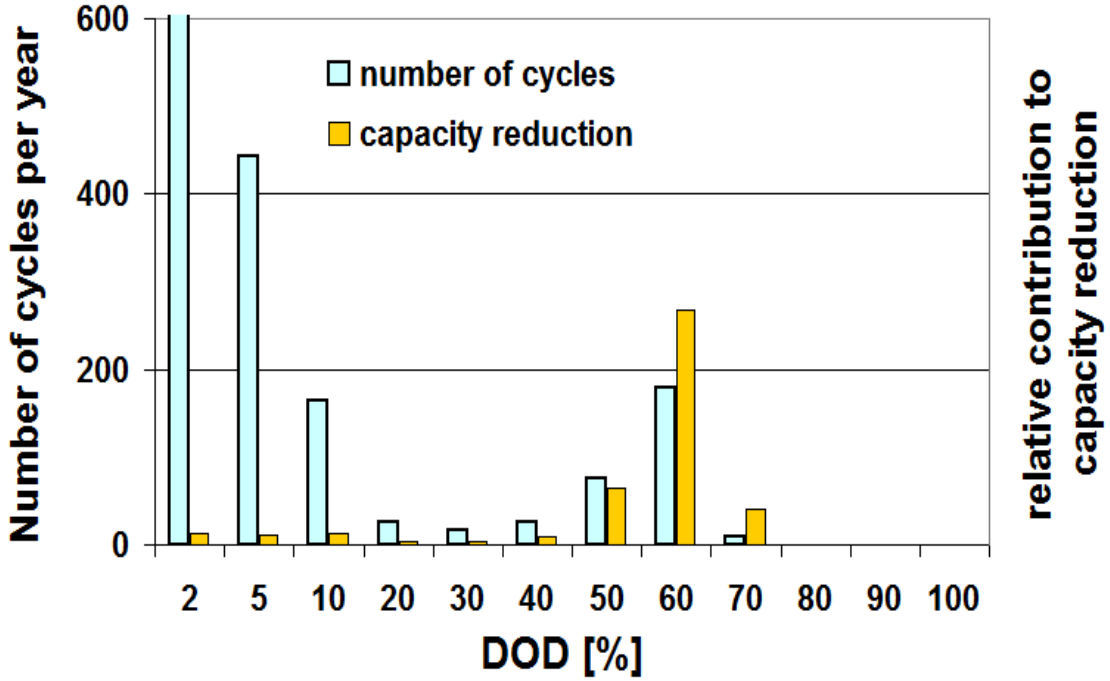
- measured for 180 days
- system operated at room temp.

Calendar aging

- capacity reduction based on measured SOC statistics
- calendaric aging is dominated by dwell times at large SOC levels
- calendaric aging at low SOC levels is very low in comparison and not shown

Cyclic Aging as a Function of DOD





Number of cycles per year

- simulation for PV = 5 kWp
- sample time: 15 min

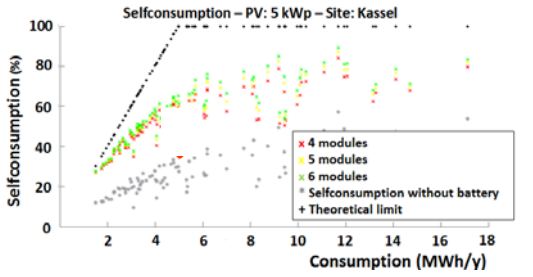
Number of cycles

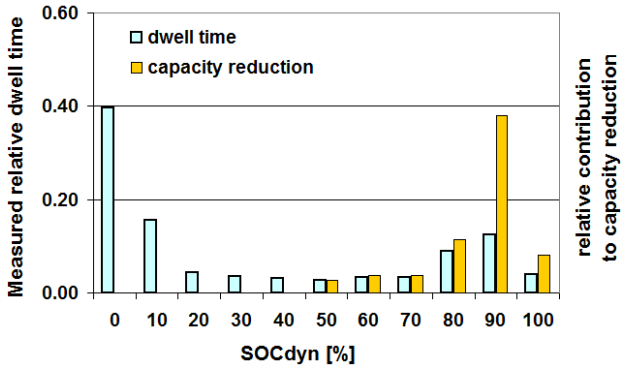
- Calculated from measured SOC; duration 180 days, sampling 30 sec
- system operated at room temp.

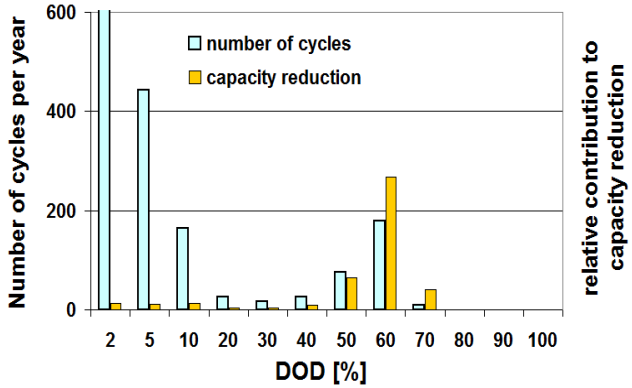
Cyclic aging

- capacity reduction depends strongly on the cycle (DOD) statistics
- cycles at low DOD are tolerated without sigificant aging
- the count of cycles at large DOD dominates capacity reduction

Summary







- Sol-Ion PV storage systems have been deployed in field test location, delivering data for periods of 5-12 months
- self consumption rates depend strongly on load profile and ratio between PV generation and load
- however, observed self consumption increase and battery cycling are less dependant on local conditions
  - equivalent full cycles per year: 200 - 250
  - number of large cycles decrease with local load
- Aging increases
  - with dwell time at charged state
  - with number of large cycles
- calculated remaining capacity after 20 years for Sol-ion battery based on presented cycling:
  - remaining capacity ~ 80 %
  - cycling accounts to approx. 2/3 of capacity reduction
  - calendaric aging account to approx. 1/3

Thank you for your attention !

ZSW Solar Test Field Widderstall