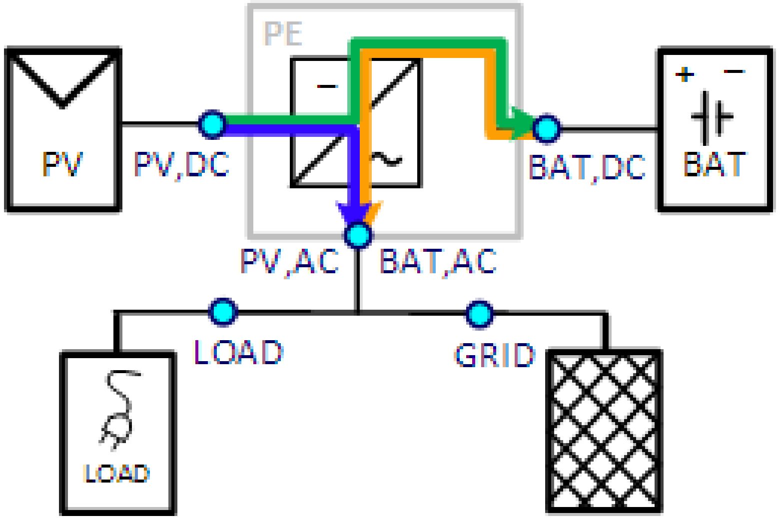
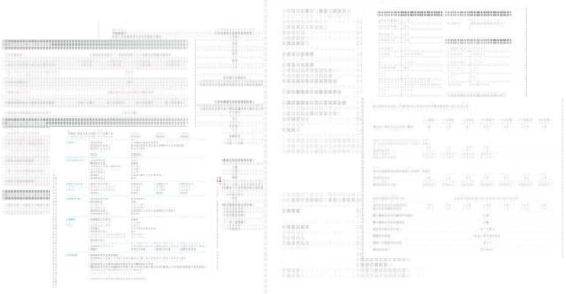


Using a Dynamic System Model to Characterize a Complex PV Systems

M. Köntges and M. Littwin, Institute for Solar Energy Research Hamelin

Intersolar Conference, 06 October 2021

Motivation for a Dynamic Battery System Model




Efficiency guideline for PV storage systems

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BSW SOLAR

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- Data sheet figures provide insufficient performance information
  - Max. battery capacity, max. inverter efficiency
  - Min. stand-by consumption
- Validated and comparable measured figures as input
  - According to efficiency guideline from BVES/BSW
  - Settling time, battery round trip efficiency, stand-by consumption, inverter efficiency characteristics

→ Performance indicators like $\varepsilon_{Autarky}$, $\varepsilon_{self\text{-}consumption}$, η_{Sys} can easily be generated

M. Knoop *et al.*, "MATLAB-basiertes Simulationsmodell zur Berechnung der elektrischen Leistungsflüsse im PV-Speichersystem," in *32. Symposium Photovoltaische Solarenergie*, 2017.

Current Standards

Component level:

- EN 50530 and IEC 61683 specify the weighted EURO efficiency and the weighted California Energy Commission (CEC) efficiency of PV inverters

System level *Performance ratio* (*PR*):

- $PR = \frac{Output}{Input}$

- $PR_{\text{PV system,AC}} = \frac{Energy_{\text{PV system,AC}}}{Energy_{\text{PV modules},DC}}$

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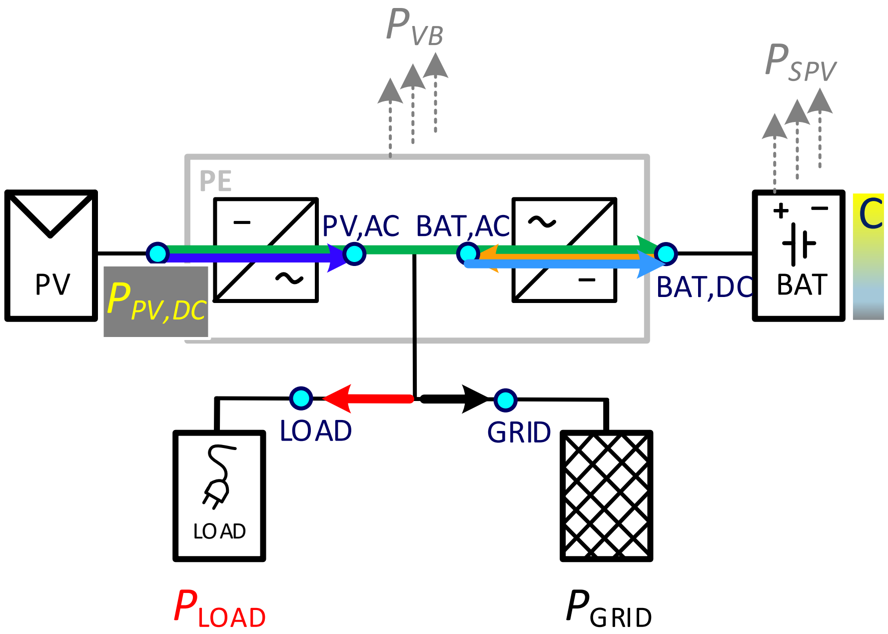
Dynamic System Model Power Flow Paths



- Characterizing the battery system completely:
  - knowledge of each power flow path
  - respective efficiency curves
  - at any time
- Power and power flow paths in PV storage systems: PV2AC, PV2BAT, AC2BAT, BAT2AC, PV,DC, GRID, LOAD, VB, SPV
- Battery state of charge *C*

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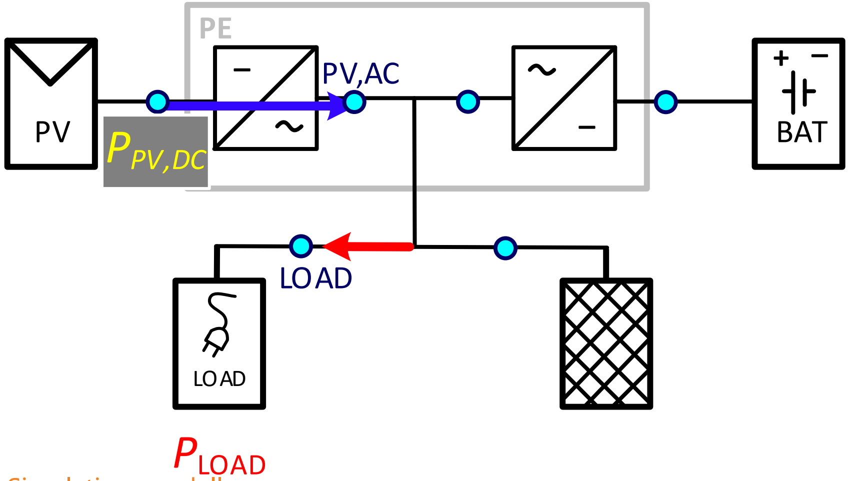
Power Flow Calculation

$P_{PV2LOAD}$ P_{PV2Bat} resp. P_{BAT2AC} P_{GRID} Battery state of charge C

$$P_{PV2LOAD}(t) = \min\left(P_{PV,AC'}(t), P_{LOAD}(t)\right)$$

$$P_{PV,AC'}(t) = P_{PV,DC}(t) * \eta_{PV2AC}\left(P_{PV,DC}(t)\right)$$



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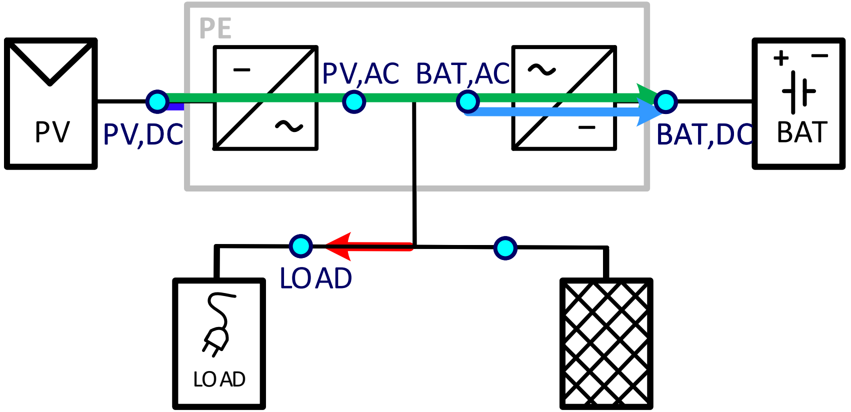
Power Flow Calculation

$P_{PV2LOAD}$ P_{PV2Bat} resp. P_{BAT2AC} P_{GRID} Battery state of charge C

Battery charging for $P_{PV,AC'} > P_{LOAD}$

$$P_{PV2Bat,AC}(t) = P_{Bat,AC'} * \eta_{AC2BAT}(P_{Bat,AC'}(t))$$



P_{LOAD}

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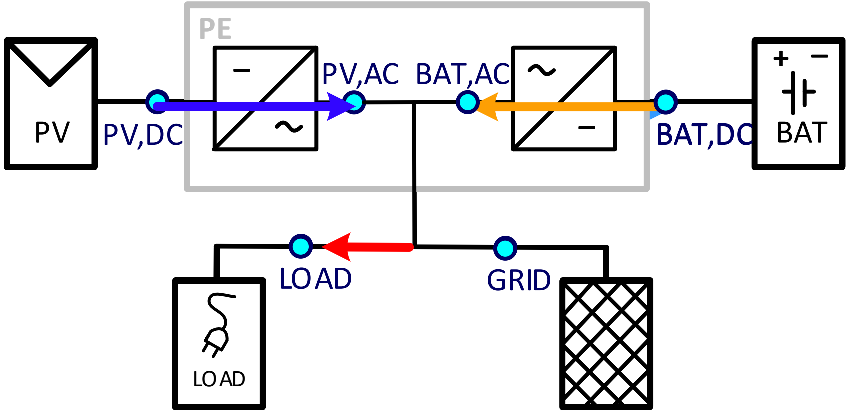
Power Flow Calculation

P_{PV2LOAD} P_{PV2Bat} resp. P_{BAT2AC} P_{GRID} Battery state of charge C

b) Battery discharging for $P_{\mathrm{PV,AC'}} < P_{\mathrm{LOAD}}$



P_{LOAD}

$$P_{\mathrm{BAT2AC}}(t) = \frac{P_{\mathrm{BAT,AC}}(t)}{\eta_{\mathrm{BAT2AC}}\left(\frac{P_{\mathrm{BAT,AC}}(t)}{\eta_{\mathrm{AC2BAT}}\left(P_{\mathrm{BAT,AC}}(t)\right)}\right)}$$

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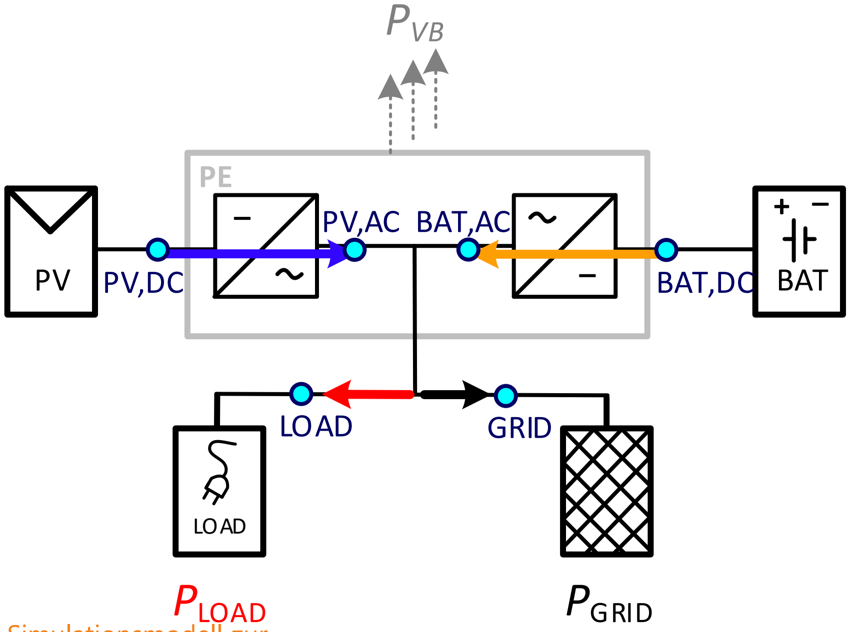
Power Flow Calculation

P_{PV2LOAD} P_{PV2Bat} resp. P_{BAT2AC} P_{GRID} Battery state of charge C

$$P_{\mathrm{Grid}}(t) = P_{\mathrm{PV,AC'}}(t) - P_{\mathrm{BAT,AC}}(t) - P_{\mathrm{LOAD}}(t) - P_{\mathrm{VB}}(t)$$



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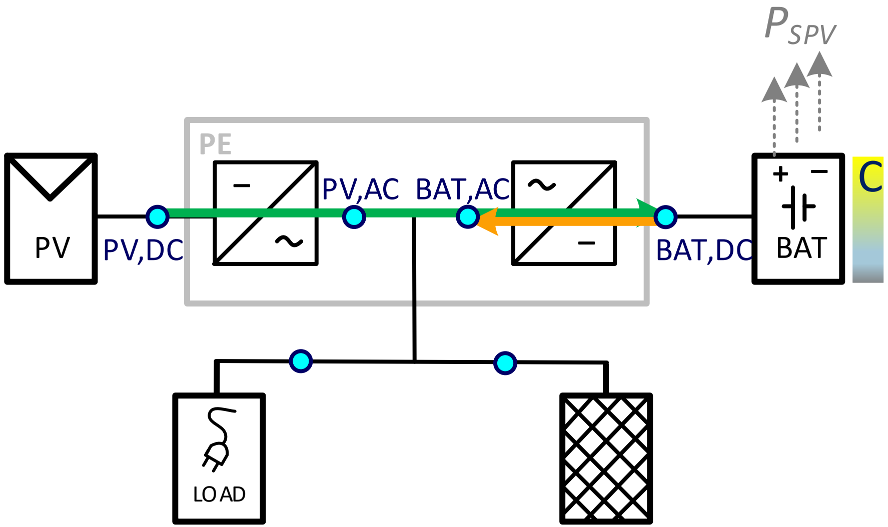
State of Charge Calculation

P_{PV2LOAD} P_{PV2Bat} resp. P_{BAT2AC} P_{GRID} Battery state of charge C

$$C(t+\Delta t) = C(t) + (P_{\text{PV2BAT}}(t) - P_{\text{BAT2AC}}(t) - P_{\text{SPV}}(t)) * \Delta t$$



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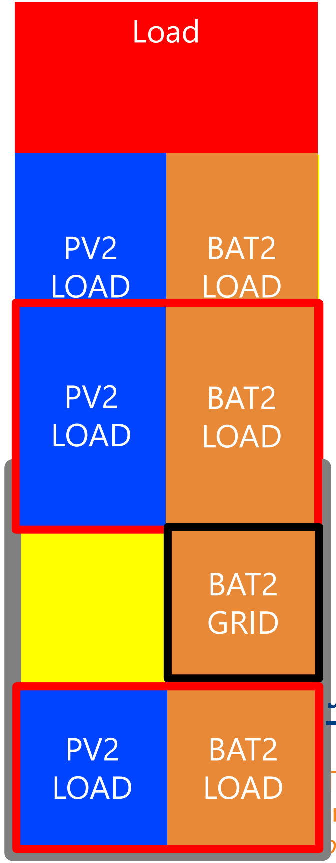
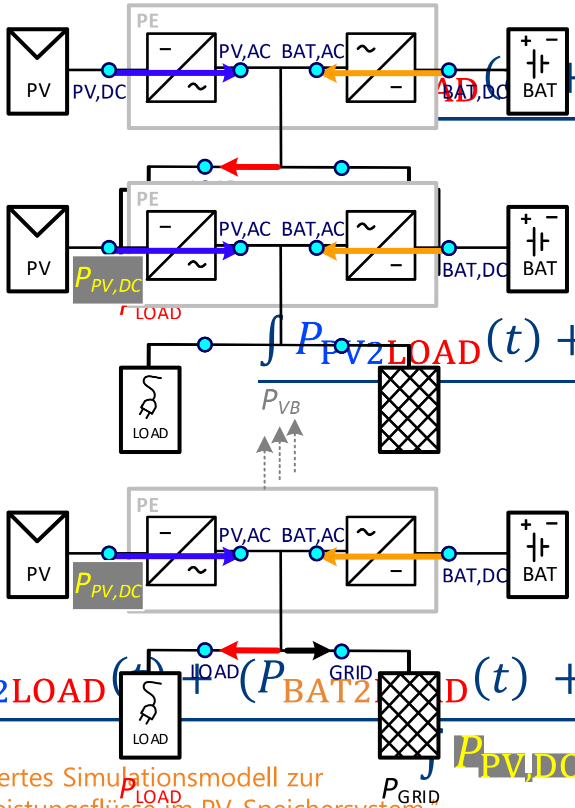
Three Performance Indicators





$$\varepsilon_{\text{self-sufficiency}} = \frac{\ldots(t) + P_{\text{BAT2LOAD}}(t) * \eta_{\text{BAT2AC}}(P_{\text{BAT2AC}})\,\mathrm{d}t}{\int P_{\text{LOAD}}(t)\,\mathrm{d}t}$$

$$\varepsilon_{\text{self-consumption}} = \frac{\int P_{\text{PV2LOAD}}(t) + P_{\text{BAT2LOAD}}(t) * \eta_{\text{BAT2AC}}(P_{\text{BAT2AC}})\,\mathrm{d}t}{\int P_{\text{PV,DC}}(t)\,\mathrm{d}t}$$

$$\eta_{\text{Sys}} = \frac{E_{\text{used}}}{E_{\text{supplied}}} = \frac{\int P_{\text{PV2LOAD}}(t) + (P_{\text{BAT2LOAD}}(t) + (P_{\text{BAT2GRID}}(t)) * \eta_{\text{BAT2AC}}(P_{\text{BAT2AC}})\,\mathrm{d}t}{\int P_{\text{PV,DC}}(t) + P_{\text{VB}}\,\mathrm{d}t}$$

…TLAB-basiertes Simulationsmodell zur …rischen Leistungsflüsse im PV-Speichersystem," …tovoltaische Solarenergie*, 2017.

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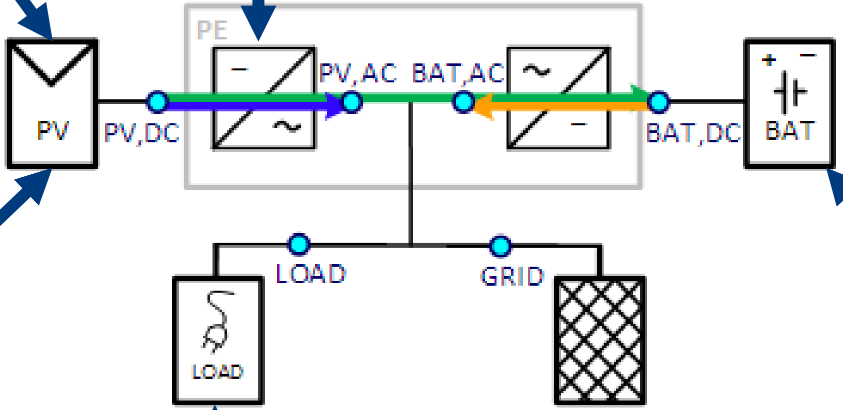
System Evaluation, AC-coupled Storage

10 kW
PV inverter

Weather data



11 kWp PV generator 30° inclined, south oriented

2.5 kW charging and discharging power, 5.9 kWh usable

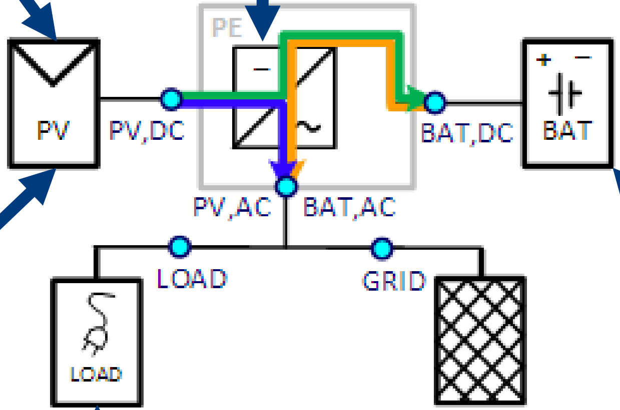
Household load profiles, 3.5 MWh/a to 8.6 MWh/a

M. Knoop *et al.*, "MATLAB-basiertes Simulationsmodell zur Berechnung der elektrischen Leistungsflüsse im PV-Speichersystem," in *32. Symposium Photovoltaische Solarenergie*, 2017.

System Evaluation, DC-coupled Storage

10 kW
PV inverter

Weather data



11 kWp PV generator 30° inclined, south oriented

3 kW charging and 2.7 kW discharging power, 6.1 kWh usable

Household load profiles, 3.5 MWh/a to 8.6 MWh/a

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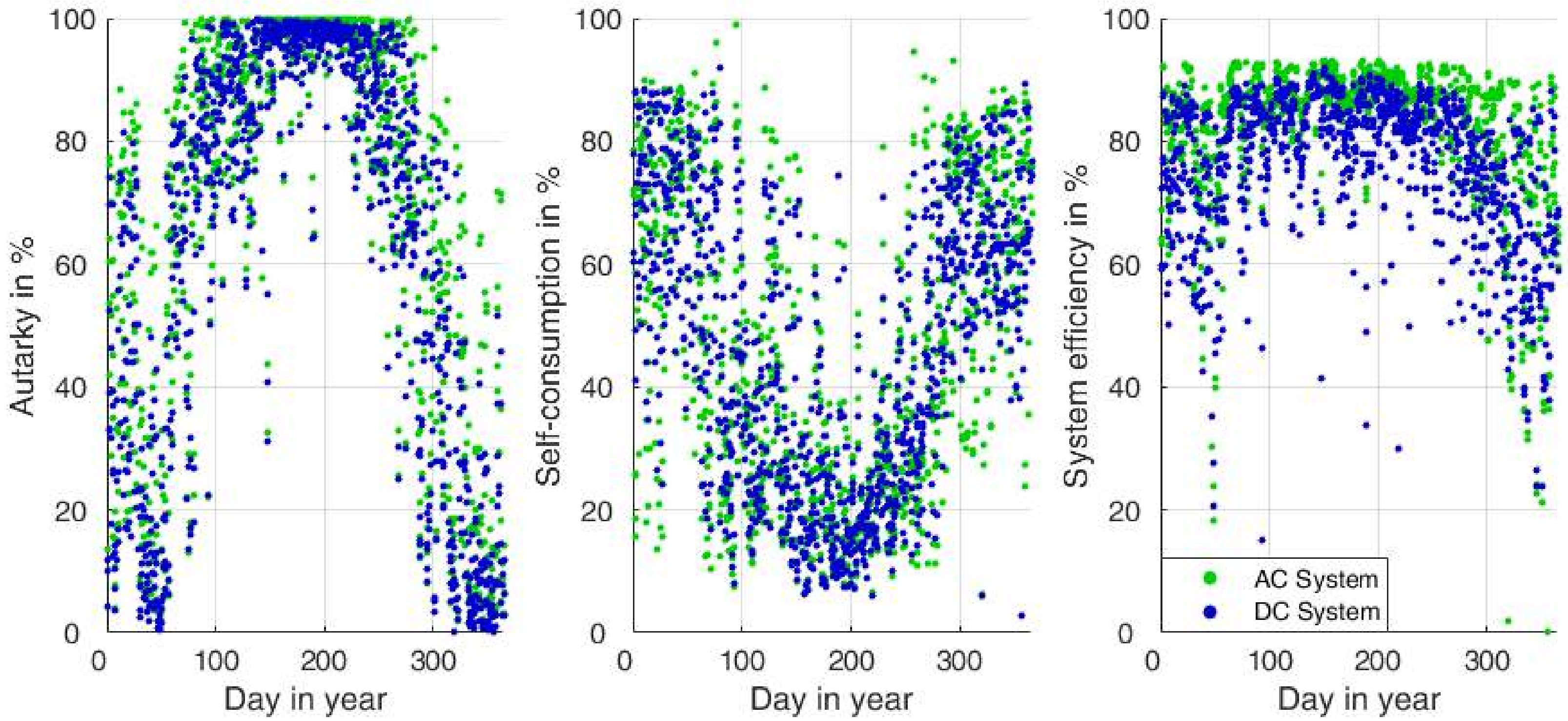
System Evaluation



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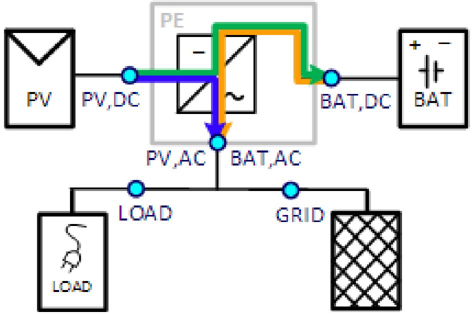
A dynamic system model of complex PV systems



	DC-System (Lead-Acid)	
	Model	Measure-ment
$\varepsilon_{Self-sufficiency}$	71.1%	69.5%
$\varepsilon_{Self-consumption}$	65.6%	65.3%
η_{Sys}	76.6%	76.9%

- Uses output data from efficiency guideline for PV storage systems
  - They serve as reliable input for the model for individual case evaluation
- Model calculates all power flow paths in a PV battery storage system at any time (time dependent properties)
- Simulated use cases results enable to calculate any KPIs, e.g. $\varepsilon_{\text{self-sufficiency}}$, $\varepsilon_{\text{self-consumption}}$, η_{Sys}

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Performance Indicator Comparison

Comparison based on one day as example

	DC-System (Lead-Acid)		AC-System (Lithium-Ion)	
	Model	Measurement	Model	Measurement
$\varepsilon_{Autarky}$	71.1%	69.5%	81.8%	78.8%
$\varepsilon_{Self\text{-}consumption}$	65.6%	65.3%	74.6%	71.7%
η_{Sys}	76.6%	76.9%	81.2%	80.8%

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Conclusion

- Yearly simulations with the dynamic battery system model enables
  - Calculation of meaningful key performance indicators
  - Comparison of different battery storage systems
- Model accuracy has been proved
- The model can work with figures based on an upcoming standard based on the BVES/BSW efficiency guideline
- Model described in Task 13 ST 1.3 report
- The IEA PVPS Task 13 ST 1.3 report is ready for download from the IEA PVPS website https://iea-pvps.org/

Acknowledements

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Thank you for your attention!

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