Reliability of PV + BESS

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Elmia Solar, Jönköping, February 5th 2025

Agenda

1. Introduction
2. Battery Energy Storage Systems (BESS)
3. How and when do we ensure reliability?
4. Performance, degradation and lifetime
5. Case studies
6. Concluding remarks

1. Introduction

- A rapidly increasing volume of PV + BESS in operation
- Large variety across multiple dimensions
  - Scales
  - Applications (= use cases and duty cycles)
  - Deployment environments
  - Technology (= components, design, software)
  - Criticality

= large variety in performance, reliability and O&M requirements!

1. Introduction

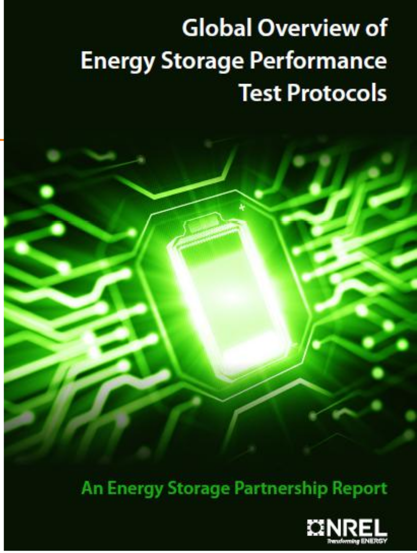
- A Report on the status of Reliability of PV + Storage is being prepared
  - IEA-PVPS Task 13 collaborative
  - International collaboration

- Table of contents:

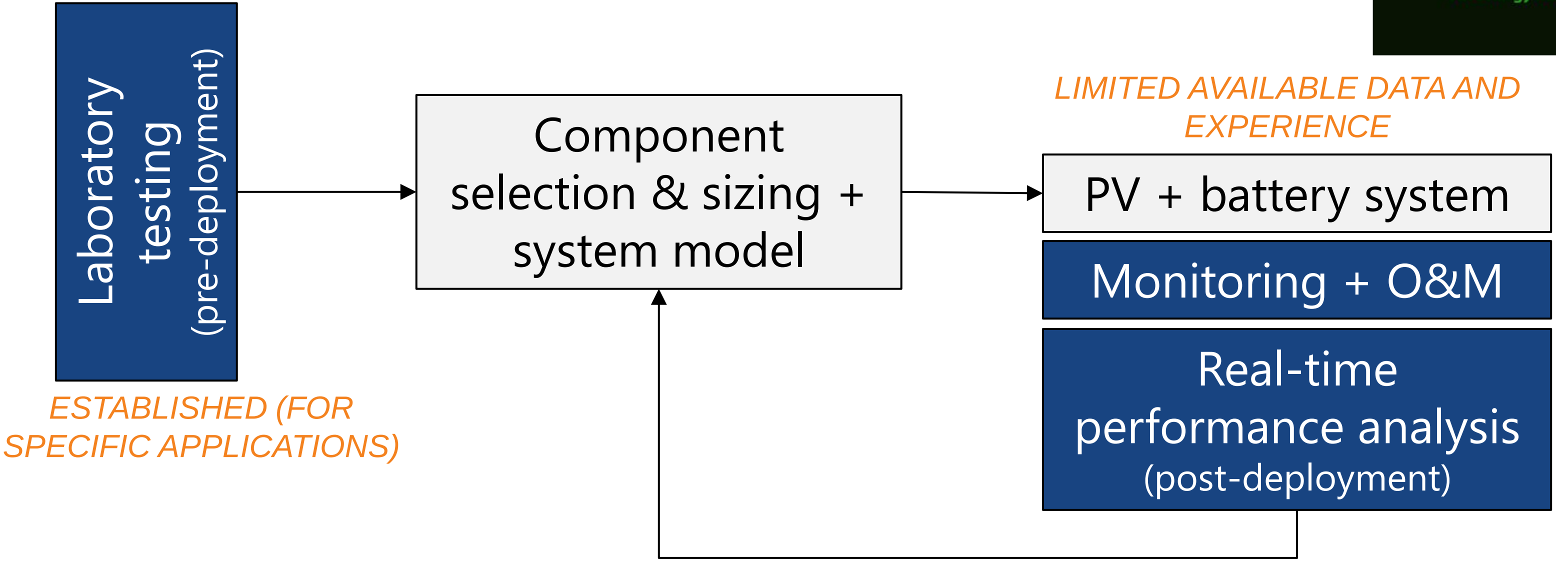
1. Introduction
2. Review of battery technologies and use cases
3. PV + BESS performance metrics
4. Performance, degradation and lifetime
5. Case studies
6. Conclusions

- In the following, key learnings from this work will be discussed

1. Introduction



- Main focus of this work: performance analysis of fielded PV + BESS
  - Important basis already established for PV modules and inverters
  - Real-time analysis of available data time series from the PV + BESS
  - Added complexity: BESS performance and reliability depends on use case



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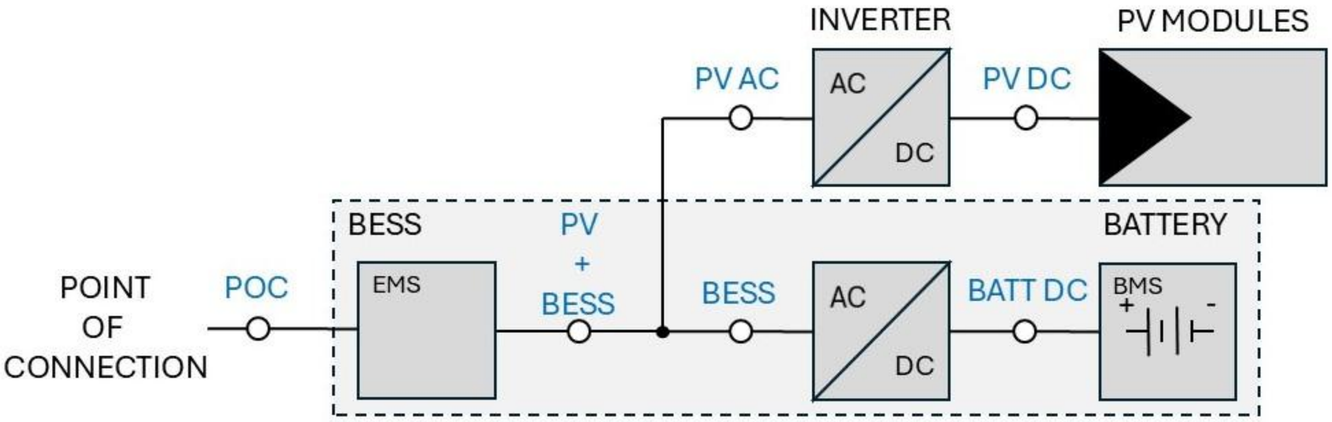
2. Battery Energy Storage Systems (BESS)



Data can be available for performance analysis throughout the BESS hierarchy. An example of an AC-coupled PV + BESS.

Parameter	Description	Unit
Time stamp	Time	S
Measured voltage	The voltage between battery terminals under operation	V
Measured current	The current between battery terminals under operation	A
SOC	The battery state of charge, given as percentage of maximum	%
Temperature	Measured ambient and/or battery temperature	ºC

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2. Battery Energy Storage Systems (BESS)

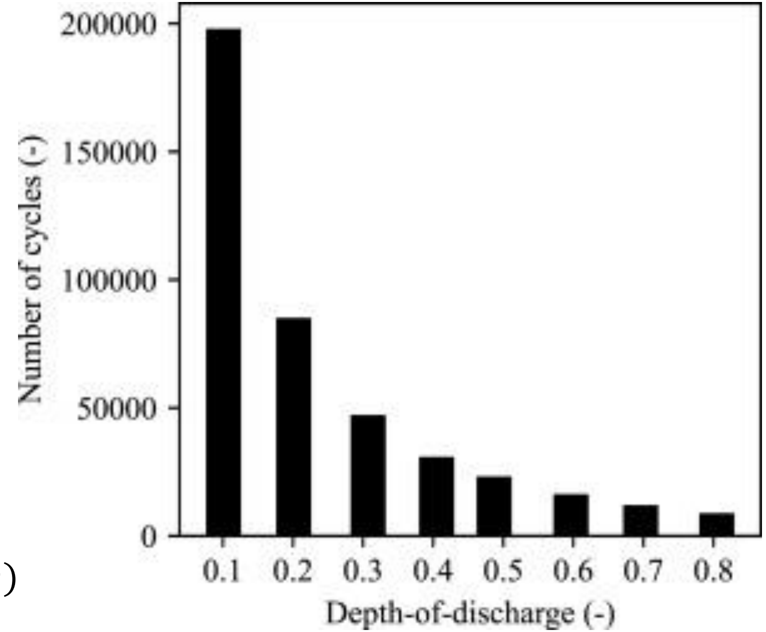
- Battery ageing strongly affected by the use case it is set up to perform!

- Ageing modeled as sum of two components:

  - Calendar ageing (L_{cal})
    - Assumed to depend on average SoC and T_c

  - Cyclic ageing (L_{cyc})
    - Calculated as the sum of all events
    - Models exist, more validation needed!

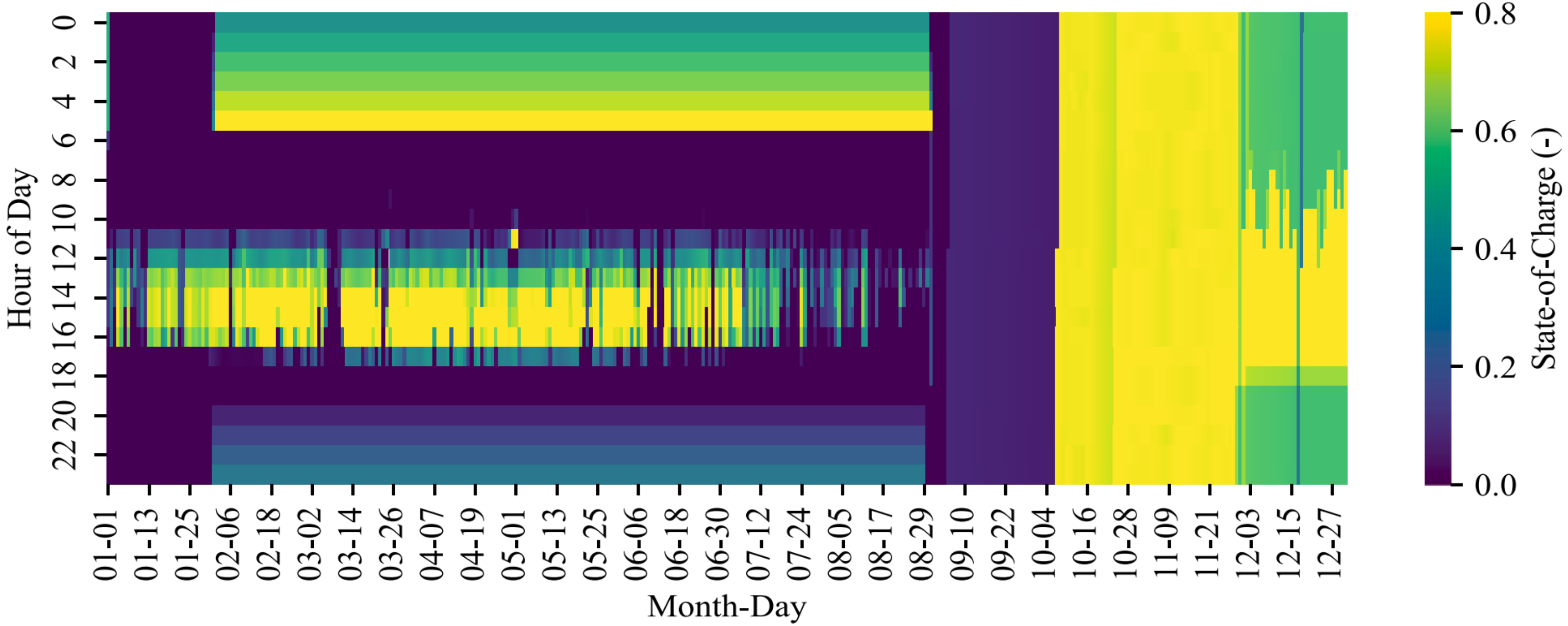
$$Q_{loss}^{total} = Q_{loss}^{cal}(t, SOC, T) + Q_{loss}^{cyc}(cycles, C - rate, T, SOC, DOD)$$



Fagerström et al, J. Energy Storage (2023)

2. Battery Energy Storage Systems (BESS)

- Example duty cycle: peak shifting in hybrid PV+hydropower plant



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Fagerström et al, J. Energy Storage (2023)

2. Battery Energy Storage Systems (BESS)

- Large variety in applications, use cases and duty cycles!
- Better validation of predictive ageing models needed!

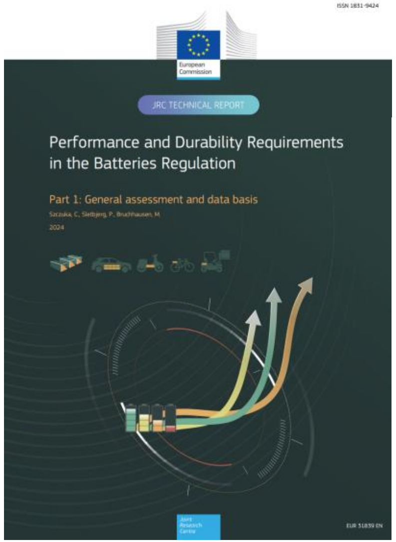
Use cases for PV + battery systems			
Time shifting	Peak shaving and time shifting	Avoid/reduce clipping losses Avoid/reduce curtailment losses Increase utilization of infrastructure Reduce energy costs of operation	Daily/few deep cycles
	Self-consumption and self-suffi-ciency	Maximize share of self-consumed PV power	Daily/few deep cycles
Market operations	Spot market	Energy arbitrage	Frequent cycles of vary-ing depth
	Capacity market	Profitability based on ability to supply firm power (W_p) in accordance with con-tract (PPA)	Daily/few deep cycles with frequent smaller cor-rections
	Day ahead and in-tra-day bidding	Reduction of production forecast uncer-tainty Reduction/avoidance of imbalance fee	Variable
Resilience	End user energy resilience	Energy resilience for end users Power back-up Black start capabilities	Few deep cycles
System services	Capacity firming and smoothing	Capacity firming Smoothing Ramp rate control	Frequent shallow cycles (firming, smoothing), few deeper cycles (ramp rate control)
	Ancillary services	Provision of frequency reserves Provision of voltage support	Frequent fast and poten-tially deep cycles
Off-grid	Off-grid PV and appliances	Off-grid PV systems PV appliances	Large variation

2. Battery Energy Storage Systems (BESS)

- Which parameters are important to monitor?

- Battery-specific PIs
  1. Capacity
  2. Power tolerance
  3. Internal resistance
  4. Energy round-trip efficiency
  5. Response time
  6. Self-discharge

- Use case-specific Pis
  1. Self-consumption
  2. Self-sufficiency
  3. Net profitability / Income
  4. Firmness (e.g. fraction of time at required capacity)



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3. How do we ensure reliability of PV + BESS?

RESIDENTIAL	
MEDIUM SIZE	
UTILITY	

PROJ. DEV. EPC OPERATIONAL PHASE

3. How do we ensure reliability of PV + BESS?

RESIDENTIAL

MEDIUM SIZE

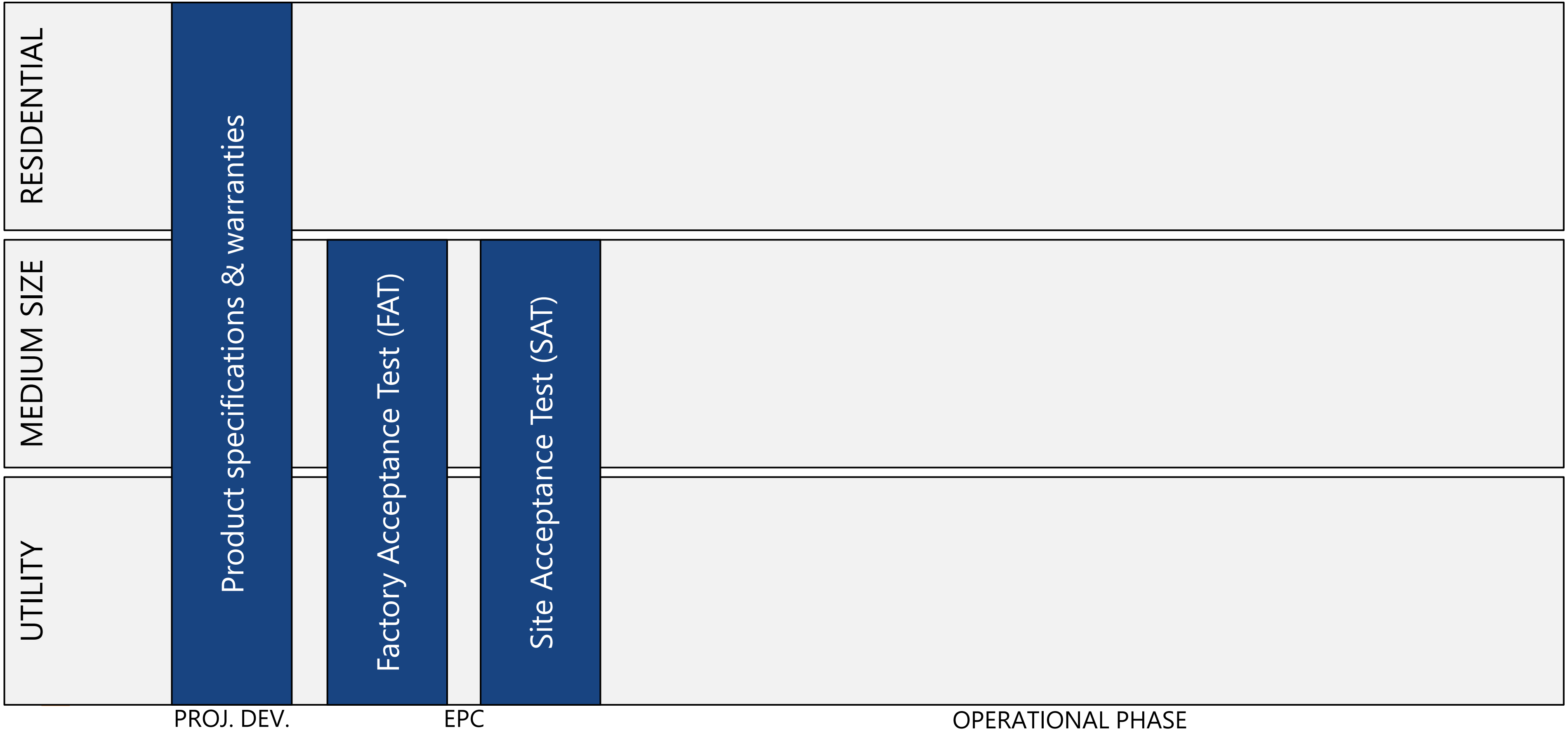
UTILITY

Product specifications & warranties

Parameter	Description	Unit
Standard discharge capacity	Available capacity from 100% SOC down to the cut-off voltage	Ah
C-rate (charging/discharging)	The rate of which a battery can be charged/discharged	-
Cut-off voltage	The minimum voltage allowed by the battery	V
Max charge voltage	The voltage the battery is charged to at full capacity	V
Max continuous and/or pulse charge current	Recommended and maximum charge currents	A
Max continuous and/or pulse discharge current	Recommended and maximum discharge currents	A
Weight	Weight of battery	kg
Dimensions	Physical dimensions of battery	m^3
Operating temperature	Recommended temperature range for battery operation	ºC
Storage temperature	Temperature ranges linked to calendar life	ºC
Cycle life	The number of discharge-charge cycles before which the battery fails a specific performance criterium	#cycles
Calendar life	The time before which the battery fails a specific performance criterium, often given for different storage temperatures	h

PROJ. DEV. EPC OPERATIONAL PHASE

3. How do we ensure reliability of PV + BESS?



3. How do we ensure reliability of PV + BESS?

RESIDENTIAL
MEDIUM SIZE
UTILITY

Product specifications & warranties
Factory Acceptance Test (FAT)
Site Acceptance Test (SAT)

Factory Acceptance Test should include:

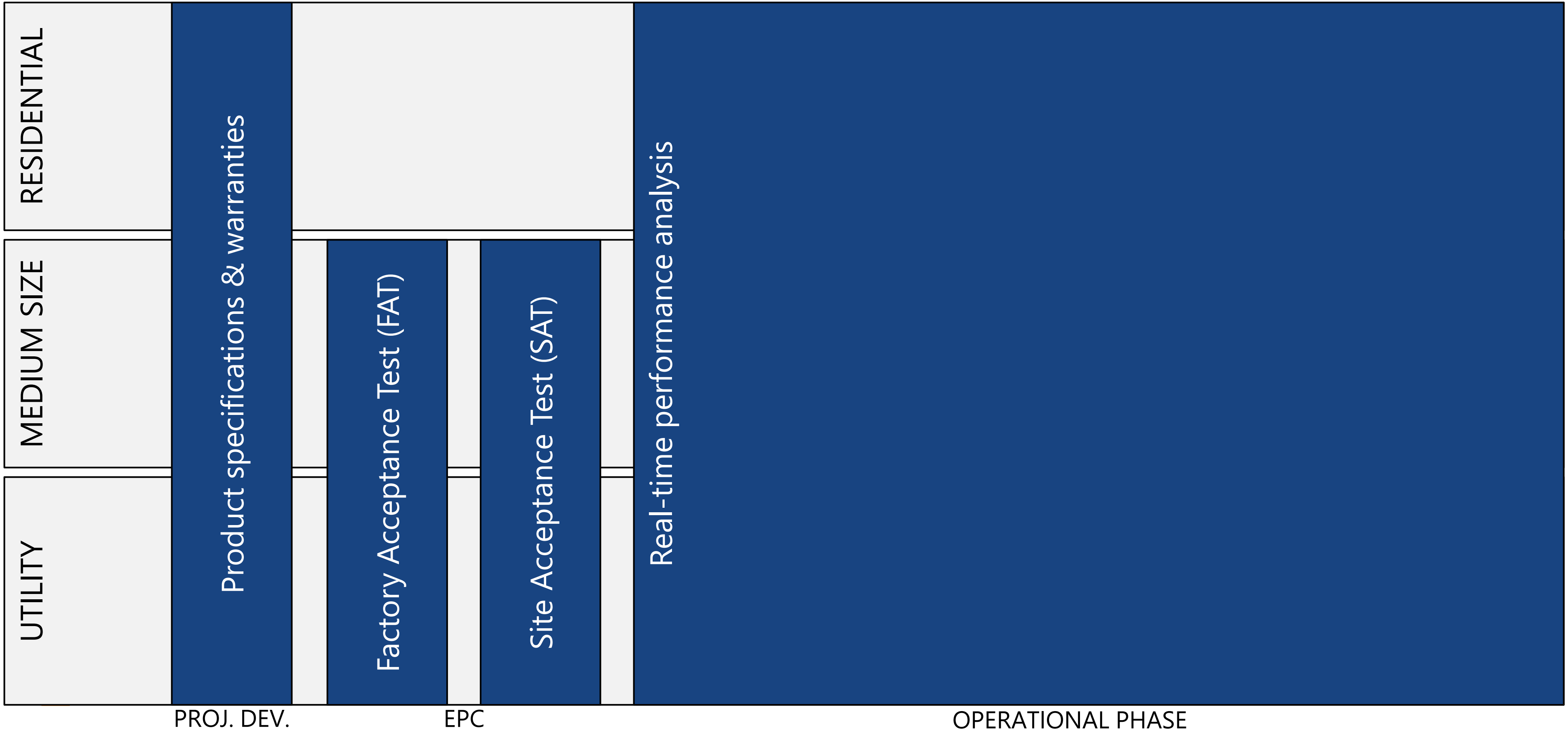
1. Visual Inspection
2. Functionality Testing
3. Performance Testing
4. Environmental Tests
5. Documentation

Site Acceptance Test should include:

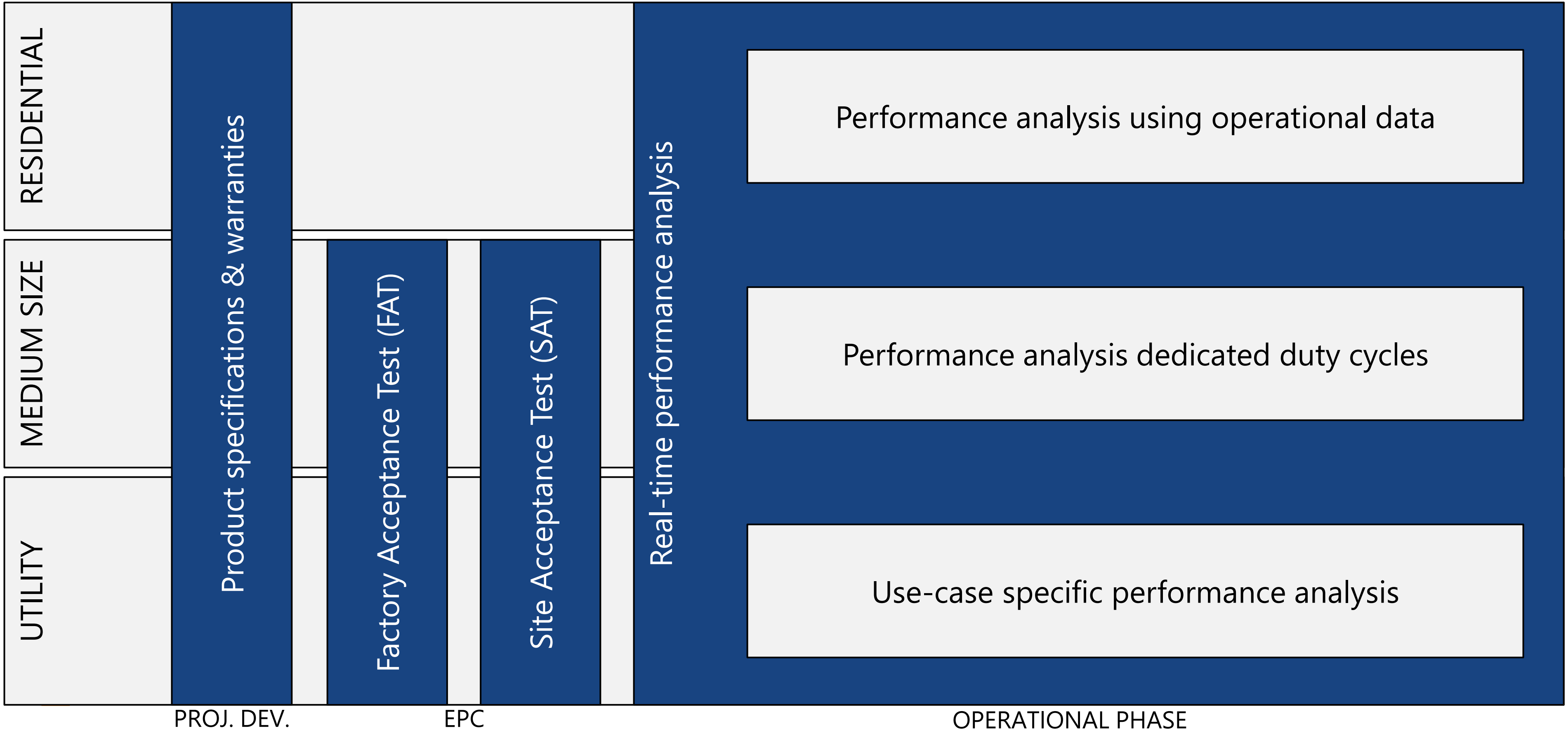
1. Physical Installation Inspection
2. Integration Tests
3. Functional Testing
4. Safety Testing
5. Performance Testing
6. Final Approval and Documentation

PROJ. DEV.
EPC
OPERATIONAL PHASE

3. How do we ensure reliability of PV + BESS?

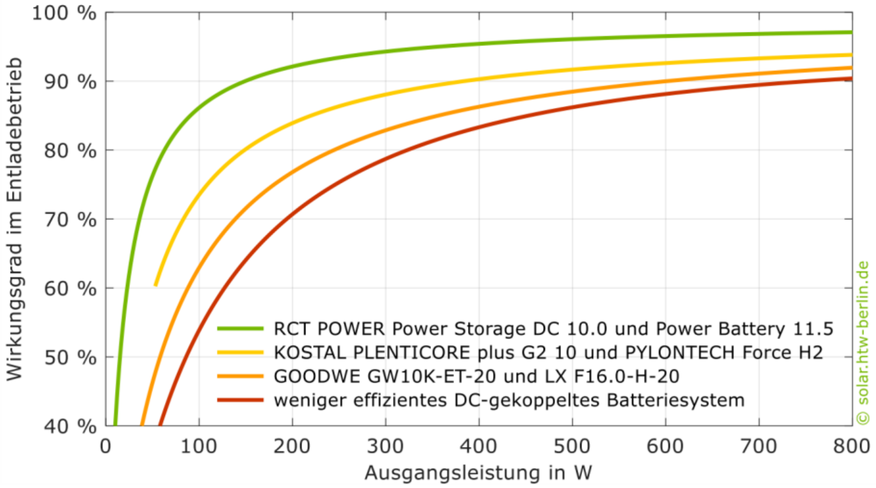


3. How do we ensure reliability of PV + BESS?



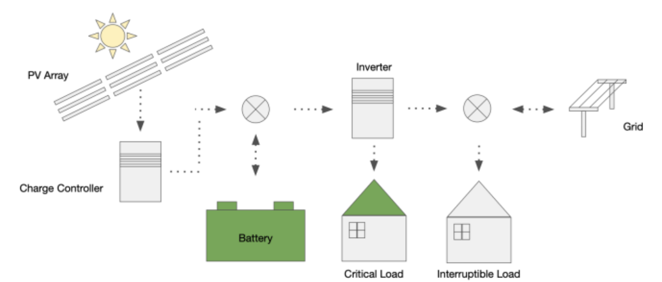
4. Performance, degradation and lifetime

- Chapter on field performance characterization
- Example: residential systems in Germany
  - Battery performance and reliability
  - Inverter performance and reliability



BAT2AC efficiency at low power (HTW Berlin/AIT)

5. CASE STUDIES



Florida Sun Smart Schools
UCF and CWRU
Resilience / shelters

RI:SE villa
RI:SE
Self-consumption / self-sufficiency

CheckWatt

Checkwatt
Grid services / VPP operation

Kenhardt
Scatec
Capacity market operation

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Concluding remarks

- The installed capacity of PV + BESS is increasing rapidly
- Access to real-time information supporting O&M throughout the BESS lifetime is becoming increasingly important
- Predictive models for use case-specific BESS performance and reliability needed
- A field in rapid development
- Complexities
  - Large variation in technology, use case, scale and deployment environment
    - Added complexities: value stacking and change of use cases
  - Large variation in data formats and availability throughout the BESS hierarchy

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