Efficiency guideline for PV storage systems

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1 Preamble

This document is a test guideline for the purpose of characterising the efficiency, standby consumption and controller efficiency of stationary battery storage systems. The focus is on evaluating grid-connected photovoltaic (PV) storage systems that are used to increase own consumption or self-sufficiency. Data sheet specifications can be derived from the results of the test procedures described. Moreover, simulation models for an application-specific determination of system efficiency can be parameterised.

Note: The efficiency guideline only describes test routines for a technical characterisation of system performance. In particular, measurements following the efficiency guideline are no substitute for certifications that comply with national and international safety standards (e.g. IEC 62619, VDE AR E 2510-50, Safety guidelines for lithium-ion home battery storage systems).

2 Area of application

The guideline describes a consistent procedure to measure the energy efficiency of PV storage systems. It covers the most common topologies and battery cell chemistries. System topologies and the associated energy conversion pathways are shown in Figure 1. The energy conversion pathways are defined by the power flows between the respective sources (PV generator, battery or grid) and sinks (battery, load or grid). The following energy conversion pathways result:

PV2AC:	PV grid feed-in or direct use
AC2BAT or PV2BAT:	AC battery charge or PV battery charge
BAT:	Battery storage
BAT2AC or BAT2PV:	AC battery discharge or PV battery discharge[1]

For AC-coupled and PV generator-coupled systems, a conventional PV inverter is required for operation in addition to the actual storage system. Furthermore, not every storage system available on the market features an integrated battery. This means that, depending on the features of a given system, not all conversion pathways may be determined.

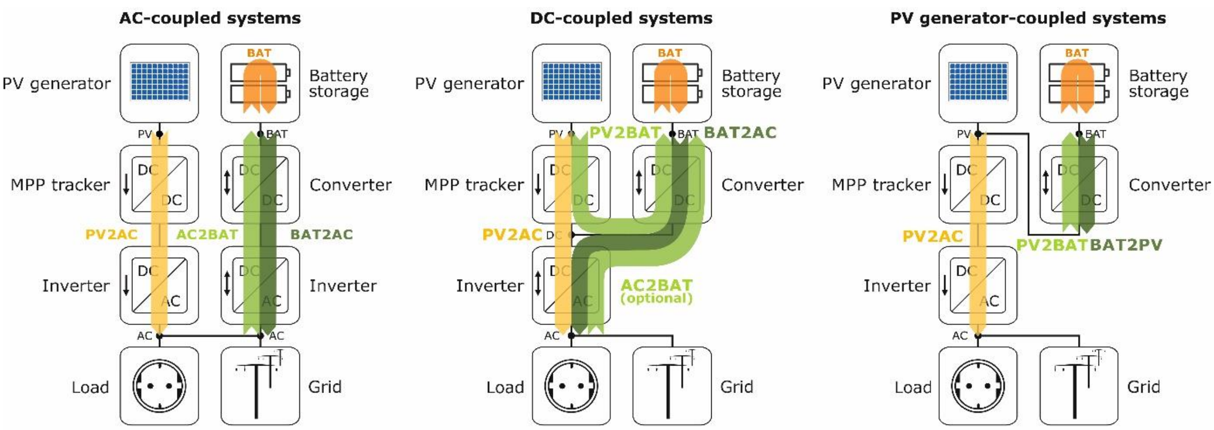

Figure 1: Energy conversion pathways of the individual topologies of PV storage systems. (Source: HTW Berlin)

The purpose of this guideline is to define a consistent and coordinated procedure to determine the energy efficiency of PV storage systems. Apart from the efficiency of the power conversion equipment and the battery, this would include the regulation of the individual components, their control by the energy management system, and power measurement. The power consumption of system components during operation and standby is also taken into account.

Simulation models (not part of this test guideline) can then be parameterised based on the measurement results. Through model-based simulations of the operating behaviour, an improved comparability between different systems can be realised for the respective application. Furthermore, simulation analyses

[1] BAT2PV means that the storage system is connected between the PV modules and the input of the PV inverter, therefore discharging into the DC input of the PV inverter (see Figure 1, right).

can be run to determine the impact of different load profiles, PV system configurations and battery storage systems on the economic benefit of the systems.

3 Abbreviations

BESS	Battery energy storage system
BMS	Battery management system
MPP	Maximum power point
MPPT	Maximum power point tracking
PCE	Power conversion equipment
PV	Photovoltaic
PVS	Photovoltaic simulator
SOC	State of charge

4 Terms and symbols

The following terms are used in this document:

Battery storage system	
Overall system: Contains the battery, the power controllers and all other components required for operation such as energy management and meters. General term for all storage systems—regardless of whether DC, AC or PV generator-coupled system topology.	

4.1 PV connection

Maximum PV input voltage	$U_{\mathrm{PV,max}}$
Maximum DC input voltage.	
Minimum PV input voltage	$U_{\mathrm{PV,min}}$
Minimum required DC input voltage.	
Rated PV input voltage	$U_{\mathrm{PV,nom}}$
Nominal DC input voltage.	
Maximum MPP voltage	$U_{\mathrm{MPP,max}}$
Maximum DC input voltage at which MPPT is active.	
Minimum MPP voltage	$U_{\mathrm{MPP,min}}$
Minimum DC input voltage at which MPPT is active.	
Nominal MPP voltage	$U_{\mathrm{MPP,nom}}$
Nominal DC input voltage at which MPPT is active. This corresponds to the rated PV input voltage, if specified by the manufacturer. Otherwise, it is defined as the arithmetic mean of the minimum and maximum MPP voltage according to DIN EN 50530.	
Rated PV input power	$P_{\mathrm{PV,nom}}$
Nominal, continuous DC input power at cos(φ) = 1 (specified for string 1, ...string n, total). This is also the maximum DC input power.	
Rated PV output power	$P_{\mathrm{PV\text{-}INV,nom}}$
Nominal, continuous AC output power of the PV inverter.	

4.2 AC connection (DC-coupled and generator-coupled systems)

Rated output power (PV)	$P_{\mathrm{AC,nom\ (output)}}$
Nominal AC output power of the PV battery storage system, consisting of PV power.	
Rated output power (battery discharge)	$P_{\mathrm{AC,nom\ (discharging)}}$
Nominal AC output power of the PV battery storage system, consisting of the discharge power of the battery system.	

Rated input power (AC battery charge)	$P_{\mathrm{AC,nom\ (Import)}}$

Nominal AC input power of the PV battery storage system (requires a bidirectional inverter)	

4.3 AC connection (AC-coupled systems)

Maximum discharge power of the battery inverter	$P_{\mathrm{BESS,max\ (discharging)}}$
Maximum permissible short-term AC discharge power of the battery inverter. Requires specification of the period over which the maximum power is available.	
Nominal discharge power of the battery inverter	$P_{\mathrm{BESS,nom\ (discharging)}}$
Nominal, continuous AC discharge power of the battery inverter.	

Maximum charging power of the battery inverter	$P_{\mathrm{BESS,max\ (charging)}}$
Maximum permissible short-term AC charging power of the battery inverter. Requires specification of the period over which the maximum power is available.	
Nominal charging power of the battery inverter	$P_{\mathrm{BESS,nom\ (charging)}}$
Nominal, continuous AC charging power of the battery inverter.	

4.4 DC connection (PV generator-coupled systems)

Nominal discharge power of the battery converter	$P_{\mathrm{BESS,nom\ (discharging)}}$
Nominal, continuous DC discharge power of the battery converter to the inverter.	
Nominal charging power of the battery converter	$P_{\mathrm{BESS,nom\ (charging)}}$
Nominal, continuous DC charging power of the battery converter from the PV generator.	

4.5 Battery part

Battery	BAT
System containing one or more cells, modules or battery packs. It features a battery management unit that interrupts the connection in the event of overcharging, overcurrent and overheating (see IEC 62619).	
Battery management system (BMS)	BMS
An electrical system belonging to a battery to monitor and/or control its condition, to calculate secondary data, to record such data and/or to regulate its environment in order to influence battery performance and/or the life.	
State of charge (SOC)	SOC
The state of charge of the battery (display, web portal, etc., of the storage system) determined and visualised by the storage system or the BMS. Ideally, the SOC can be read and recorded with a communication protocol.	
Maximum battery voltage	$U_{\mathrm{BAT,max}}$
Maximum battery voltage of the battery system employed.	
Minimum battery voltage	$U_{\mathrm{BAT,min}}$
Minimum battery voltage of the battery system employed.	
Nominal battery voltage	$U_{\mathrm{BAT,nom}}$
Nominal battery voltage of the battery system employed.	

Minimum state of charge	SOC_{min}
The minimum SOC down to which the storage system discharges the battery.	
Maximum state of charge	SOC_{max}

The maximum SOC up to which the storage system charges the battery.	
Medium state of charge	SOC_{avg}
The average value of the minimum and maximum state of charge reached during normal operation.	
Medium state of charge range	$SOC_{\mathrm{avg,area}}$
State of charge range around the medium state of charge ±10 percentage points.	
Maximum charging power	$P_{\mathrm{BAT,max\ (charging)}}$
Maximum short-term DC charging power of the battery system employed. Requires specification of the period over which the maximum power is available.	
Maximum discharge power	$P_{\mathrm{BAT,max\ (discharging)}}$
Maximum short-term DC discharge power of the battery system employed. Requires specification of the period over which the maximum power is available.	
Nominal charge power	$P_{\mathrm{BAT,nom\ (charging)}}$
Nominal, continuous power of the used battery system employed at $SOC_{\mathrm{avg,area}}$ during the charging process. Usually specified by $P_{\mathrm{PCE/BAT,nom\ (charging)}}$.	
Nominal discharge power	$P_{\mathrm{BAT,nom\ (discharging)}}$
Nominal, continuous power of the battery system employed at $SOC_{\mathrm{avg,area}}$ during the discharge process. Usually specified by $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$.	
Usable battery capacity (ampere hours)	$C_{\mathrm{BAT,use}}$
The usable battery capacity $C_{\mathrm{BAT\ (discharging)}}$ as the average value of full discharge at power levels $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$ 100%, 50% and 25% according to Table 29	
Usable battery capacity (watt-hours)	$E_{\mathrm{BAT,use}}$
The usable battery capacity $E_{\mathrm{BAT\ (discharging)}}$ as the average value of full discharge at power levels $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$ 100%, 50% and 25% according to Table 29	

4.6 Connection of the battery component to the power conversion system

Maximum battery voltage	$U_{\mathrm{PCE/BAT,max}}$
Maximum battery-side DC voltage of the battery inverter/converter.	
Minimum battery voltage	$U_{\mathrm{PCE/BAT,min}}$
Minimum battery-side DC voltage of the battery inverter/converter.	
Nominal battery voltage	$U_{\mathrm{PCE/BAT,nom}}$
Nominal battery-side DC voltage of the battery inverter/converter employed.	
Maximum short-term charging power	$P_{\mathrm{PCE/BAT,max\ (charging)}}$
Maximum permissible short-term battery-side charging power of the battery inverter/converter. Requires specification of the period over which the maximum power is available.	
Maximum short-term discharge power	$P_{\mathrm{PCE/BAT,max\ (discharging)}}$
Maximum permissible short-term battery-side discharge power of the battery inverter/converter. Requires specification of the period over which the maximum power is available.	

Nominal charge power	$P_{\mathrm{PCE/BAT,nom\ (charging)}}$
Nominal, continuous battery-side charging power of the battery inverter/converter.	

Nominal discharge power	$P_{\mathrm{PCE/BAT,nom\ (discharging)}}$
Nominal, continuous battery-side discharge power of the battery inverter/converter.	

4.7 Parameterisation of the test sequences

In the following, all variables required for the parameterisation of the test sequences are defined. Annex C shows how these can be determined in individual cases.

Nominal PV feed-in power — $P_{\mathrm{PV2AC,nom}}$

Nominal, continuous MPP power of the PV simulator that can be converted into AC output power. The power here is defined in the event that the battery is neither charged nor discharged ($P_{\mathrm{BAT}} \sim 0$).

Nominal PV charge power — $P_{\mathrm{PV2BAT,nom}}$

Nominal continuous MPP power of the PV simulator required to provide the nominal DC charging power of the power conversion system $P_{\mathrm{PCE/BAT,nom\ (charging)}}$.

- When testing components sold without integrated batteries, care should be taken to ensure that the charging power of the battery $P_{\mathrm{BAT,nom\ (charging)}}$ is at least as high as $P_{\mathrm{PCE/BAT,nom\ (charging)}}$.
- If the battery is an integral part of the product under test and if the nominal charge power $P_{\mathrm{BAT,nom\ (charging)}}$ is lower than $P_{\mathrm{PCE/BAT,nom\ (charging)}}$, then the nominal charge power of the battery is the reference value.
- The power $P_{\mathrm{PV2BAT,nom}}$ may depend on the output voltage of the PV simulator $U_{\mathrm{PVS,(min,nom,max)}}$ and is defined accordingly for the required voltage.

Nominal discharge power — $P_{\mathrm{BAT2AC,nom}}$, $P_{\mathrm{BAT2PV,nom}}$

Nominal continuous power of the AC load required to provide the nominal DC discharge power of the power conversion system $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$.

- When testing components sold without integrated batteries, care should be taken to ensure that the discharge power of the battery $P_{\mathrm{BAT,nom\ (discharging)}}$ is at least as high as $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$
- If the battery is an integral part of the component under test and if the nominal discharge power $P_{\mathrm{BAT,nom\ (discharging)}}$ is lower than $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$, then the nominal discharge power of the battery is the reference value.
- The power $P_{\mathrm{BAT2AC,nom}}$ or $P_{\mathrm{BAT2PV,nom}}$ may depend on the input voltage of the power conversion system $U_{\mathrm{PCE/BAT,(min)}}$, $U_{\mathrm{PCE/BAT,(max)}}$, $U_{\mathrm{PCE/BAT,(nom)}}$ and is defined accordingly for the required voltage.

4.8 Measured variables

The following parameters are shown schematically as measuring points in Section 5, depending on the topology. In addition, the following applies to the measured values:

1. The index additions “Charge” and “Discharge” are used as extensions of the designations for the measured parameters depending on the operating status. Example:
   - Current charging power of the battery: $P_{\mathrm{BAT\ (charging)}}$
   - Current discharge power of the battery: $P_{\mathrm{BAT\ (discharging)}}$
2. The arithmetic averages of the recorded, measured values are indicated with a dash above the measured variable. Example:
   - Average charging power over a measuring period: $\overline{P}_{\mathrm{BAT(charging)}}$
3. The specified target values are indicated by the addition “SET”. Example:
   - Target value for load: $P_{\mathrm{LOAD,\ SET}}$

4. The index additions “Import” and “Export” define draw of power from the grid and supply of power into the grid. Example:
   - Grid feed-in: $P_{\mathrm{GRID\ (Export)}}$
   - Grid draw: $P_{\mathrm{GRID\ (Import)}}$

4.8.1 General

MPP power of the PV simulator	$P_{\mathrm{PVS,MPP}}$
Power provided by the PV simulator.	
Output power of the PV simulator	$P_{\mathrm{PVS,DC}}$
Measured DC power of the PV simulator.	
MPP voltage of the PV simulator	$U_{\mathrm{PVS,MPP}}$
Voltage at Maximum Power Point (MPP).	
Output voltage of the PV generator	$U_{\mathrm{PVS,DC}}$
Measured DC voltage of the PV simulator.	
Battery power of the PV battery storage system	P_{BAT}
Measured DC power of the battery.	
Battery voltage of the PV battery storage system	U_{BAT}
Measured DC voltage of the battery.	
Battery amperage of the PV battery storage system	I_{BAT}
Measured DC current of the battery.	
AC output power of the PV battery storage system	P_{AC}
AC-coupled system: AC total power of the PV and battery inverter. DC-coupled system: AC power of the PV battery inverter. PV generator-coupled system: AC power of the PV inverter.	
AC power at the grid connection point	P_{GRID}
Measured AC power at the grid connection point.	
AC power at load	P_{LOAD}
Measured DC power of the load.	

4.8.2 In addition: AC-coupled systems

These values are necessary for a separate determination of the efficiency of the battery inverter, independent of the PV inverter used.

Power at the AC connection point of the battery inverter	P_{BESS}
Measured AC power of the battery inverter.	
Power at the AC connection point of the PV inverter	$P_{\mathrm{PV\text{-}INV}}$
Measured AC power of the PV inverter.	
Voltage at the AC connection point of the PV inverter.	$U_{\mathrm{PV\text{-}INV}}$
Measured AC voltage of the PV inverter.	

4.8.3 In addition: PV generator-coupled systems

Power at the DC connection point of the battery converter to the inverter	P_{BESS}
Measured DC power of the converter.	
Power at the AC connection point of the PV inverter	P_{AC}
Measured AC power of the PV inverter.	
Voltage at the AC connection point of the PV inverter	U_{AC}
Measured AC voltage of the PV inverter.	

4.9 Calculated values

4.9.1 MPPT efficiency

Static MPPT efficiency, energy η_{MPPT}

Ratio of the energy drawn from the test object to the theoretical energy provided by the PV simulator at the Maximum Power Point (MPP) [1]. The energy is integrated over the measurement period t_{M}.

$$\eta_{\mathrm{MPPT}} = \frac{\int_0^{t_{\mathrm{M}}} P_{\mathrm{PVS,DC}}(t) \cdot \mathrm{d}t}{\int_0^{t_{\mathrm{M}}} P_{\mathrm{PVS,MPP}}(t) \cdot \mathrm{d}t} \tag{1}$$

With

DC power drawn from the test object [1].	$P_{\mathrm{PVS,DC}}(t)$
Power theoretically made available at the PV simulator at the MPP [1].	$P_{\mathrm{PVS,MPP}}(t)$
Measuring period.	t_{M}

Dynamic MPPT efficiency

In order to limit the complexity of the measurements, the description, measurement and calculation of dynamic MPPT efficiency is omitted. However, it can be measured following DIN EN 50530 and may be specified in the test report or on the data sheet.

4.9.2 Pathway efficiencies: AC-coupled systems

Pathways AC2BAT and BAT2AC are relevant for AC-coupled systems.

Battery charge (AC2BAT) η_{AC2BAT}

$$\eta_{\mathrm{AC2BAT}} = \frac{\int_0^{t_{\mathrm{M}}} P_{\mathrm{BAT\,(charging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_{\mathrm{M}}} P_{\mathrm{BESS\,(charging)}}(t) \cdot \mathrm{d}t} \tag{2}$$

Battery discharge (BAT2AC) η_{BAT2AC}

$$\eta_{\mathrm{BAT2AC}} = \frac{\int_0^{t_{\mathrm{M}}} P_{\mathrm{BESS\,(discharging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_{\mathrm{M}}} P_{\mathrm{BAT\,(discharging)}}(t) \cdot \mathrm{d}t} \tag{3}$$

Optionally, the pathways PV2AC and PV2BAT can be determined.

PV grid feed-in or direct use (PV2AC) $\eta_{\mathrm{PV2AC,conv}}$

$$\eta_{\mathrm{PV2AC,conv}} = \frac{\int_0^{t_{\mathrm{M}}} P_{\mathrm{PVINV}}(t) \cdot \mathrm{d}t}{\int_0^{t_{\mathrm{M}}} P_{\mathrm{PVS,DC}}(t) \cdot \mathrm{d}t} \tag{4}$$

Battery charge (PV2BAT) η_{PV2BAT}

$$\eta_{\mathrm{PV2BAT}} = \eta_{\mathrm{PV2AC,conv}} \cdot \eta_{\mathrm{AC2BAT}} \tag{5}$$

4.9.3 Pathway efficiencies: DC-coupled systems

Pathways PV2AC, PV2BAT and BAT2AC are relevant for DC-coupled systems.

Battery charge (PV2BAT) $\eta_{\mathrm{PV2BAT,conv}}$

$$\eta_{\mathrm{PV2BAT,conv}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (charging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} \left[P_{\mathrm{PVS,DC}}(t) + P_{\mathrm{AC\ (Import)}}(t) - P_{\mathrm{AC\ (Export)}}(t)\right] \cdot \mathrm{d}t} \quad (6)$$

P_{AC} represents an undesired power flow during the entire measuring period of the battery charge (see Section 6.2).

Battery discharge (BAT2AC) η_{BAT2AC}

$$\eta_{\mathrm{BAT2AC}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{AC\ (Export)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t} \quad (7)$$

PV grid feed-in or direct use (PV2AC) $\eta_{\mathrm{PV2AC,conv}}$

$$\eta_{\mathrm{PV2AC,conv}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{AC\ (Export)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} [P_{\mathrm{PVS,DC}}(t) - P_{\mathrm{BAT\ (Charging)}}(t) + P_{\mathrm{BAT\ (Discharging)}}(t)] \cdot \mathrm{d}t} \quad (8)$$

P_{BAT} represents an undesired power flow during the entire measuring period of the battery charge (see Section 6.2). Optionally, the pathway AC2BAT can be determined if the inverter is bidirectional.

Battery charge (AC2BAT) η_{AC2BAT}

$$\eta_{\mathrm{AC2BAT}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (charging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} P_{\mathrm{AC\ (Import)}}(t) \cdot \mathrm{d}t} \quad (9)$$

4.9.4 Pathway efficiencies: PV generator-coupled systems

Pathways PV2BAT and BAT2PV are relevant for PV generator-coupled systems.

Battery charge (PV2BAT) $\eta_{\mathrm{PV2BAT,conv}}$

$$\eta_{\mathrm{PV2BAT,conv}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (charging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} \left[P_{\mathrm{PVS,DC}}(t) - P_{\mathrm{BESS\ (Export)}}(t)\right] \cdot \mathrm{d}t} \quad (10)$$

Battery discharge (BAT2PV) η_{BAT2PV}

$$\eta_{\mathrm{BAT2PV}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{BESS\ (Export)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t} \quad (11)$$

Optionally, the pathways PV2AC and BAT2AC can be determined.

PV grid feed-in or direct use (PV2AC) $\eta_{\mathrm{PV2AC,conv}}$

$$\eta_{\mathrm{PV2AC,conv}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{AC\ (Export)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} \left[P_{\mathrm{PVS,DC}}(t) + P_{\mathrm{BAT\ (discharging)}}(t) - P_{\mathrm{BAT\ (charging)}}(t)\right] \cdot \mathrm{d}t} \quad (12)$$

P_{BAT} represents an undesired power flow during the entire measurement period of the PV grid feed-in or direct use (see Section 6.2).

Battery discharge (BAT2AC) η_{BAT2AC}

$$\eta_{\mathrm{BAT2AC}} = \frac{\int_0^{t_\mathrm{M}} P_{\mathrm{AC\ (Export)}}(t) \cdot \mathrm{d}t}{\int_0^{t_\mathrm{M}} P_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t} \quad (13)$$

4.9.5 PV total efficiency (MPPT and conversion efficiency)

Total PV efficiency consists of MPPT and the conversion efficiency. It is determined as $\eta_{\mathrm{PV2AC,t}}$ for the conversion pathways of PV grid feed-in and direct use (PV2AC), and as $\eta_{\mathrm{PV2BAT,t}}$ for PV battery charging (PV2BAT). Conversion efficiency is determined according to the topology and pathway using the formulae in Sections 4.9.2 to 4.9.4. Depending on the topology, the total PV efficiency is then calculated for the individual power and voltage levels as follows:

AC-coupled (PV2AC) $\eta_{\mathrm{PV2AC,t}}$

$$\eta_{\mathrm{PV2AC,t}} = \eta_{\mathrm{PV2AC,conv}} \cdot \eta_{\mathrm{MPPT}} \quad (14)$$

AC-coupled (PV2BAT) $\eta_{\mathrm{PV2BAT,t}}$

$$\eta_{\mathrm{PV2BAT,t}} = \eta_{\mathrm{PV2BAT,conv\cdot}} \cdot \eta_{\mathrm{MPPT}} = \eta_{\mathrm{PV2AC,conv}} \cdot \eta_{\mathrm{AC2BAT}} \cdot \eta_{\mathrm{MPPT}} \quad (15)$$

DC-coupled and PV generator-coupled (PV2AC) $\eta_{\mathrm{PV2AC,t}}$

$$\eta_{\mathrm{PV2AC,t}} = \eta_{\mathrm{PV2AC,conv}} \cdot \eta_{\mathrm{MPPT}} \quad (16)$$

DC-coupled and PV generator-coupled: (PV2BAT) $\eta_{\mathrm{PV2BAT,t}}$

$$\eta_{\mathrm{PV2BAT,t}} = \eta_{\mathrm{PV2BAT,conv}} \cdot \eta_{\mathrm{MPPT}} \quad (17)$$

4.9.6 Battery characteristics

Energy charged into the battery $E_{\mathrm{BAT\ (charging)}}$

Charged energy during a given period t_{M}. This period is a limited duration of time. It is expressed in watt-hours (Wh).

$$E_{\mathrm{BAT\ (charged)}} = \int_0^{t_{\mathrm{M}}} P_{\mathrm{BAT\ (charging)}}(t) \cdot \mathrm{d}t \quad (18)$$

Energy discharged from the battery $E_{\mathrm{BAT\ (discharging)}}$

Discharged energy during a given period t_{M}. This period is a limited duration of time. It is expressed in watt-hours (Wh).

$$E_{\mathrm{BAT\ (discharging)}} = \int_0^{t_{\mathrm{M}}} P_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t \quad (19)$$

Capacity charged into the battery $C_{\mathrm{BAT\ (charging)}}$

Charged capacity during a given period t_{M}. This period is a limited duration of time. It is expressed in ampere hours (Ah).

$$C_{\mathrm{BAT\ (charged)}} = \int_0^{t_{\mathrm{M}}} I_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t \quad (20)$$

Capacity discharged from the battery $C_{\mathrm{BAT\ (discharging)}}$

Discharged capacity during a given period t_{M}. This period is a limited duration of time. It is expressed in ampere hours (Ah).

$$C_{\mathrm{BAT\ (discharging)}} = \int_0^{t_{\mathrm{M}}} I_{\mathrm{BAT\ (discharging)}}(t) \cdot \mathrm{d}t \quad (21)$$

Battery energy efficiency - round-trip efficiency $\eta_{\mathrm{BAT,RTE}}$

Battery efficiency (unit: %) expresses the ratio of the amount of energy discharged to the amount of energy charged for a defined number of full cycles. This energy is measured at the terminals of the battery. The power uptake of the BMS can reduce the efficiency.

$$\eta_{\text{BAT,RTE}} = \frac{\int_0^{t_M} P_{\text{BAT (discharging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_M} P_{\text{BAT (charging)}}(t) \cdot \mathrm{d}t} \quad (22)$$

Coulomb battery efficiency - coulomb round-trip efficiency	$\eta_{\text{BAT,RTE (coulomb)}}$
Coulomb battery efficiency (unit: %) expresses the ratio of the capacity discharged to the capacity charged for a defined number of full cycles. This capacity is measured at the terminals of the battery.	

$$\eta_{\text{BAT,RTE (coulomb)}} = \frac{\int_0^{t_M} I_{\text{BAT (discharging)}}(t) \cdot \mathrm{d}t}{\int_0^{t_M} I_{\text{BAT (charging)}}(t) \cdot \mathrm{d}t} \quad (23)$$

4.9.7 Power consumption in standby mode or switched off state

Even when no power conversion is currently taking place, the individual system components consume power on the AC and/or DC side.

Power conversion system
This power consumption can be covered either by the mains or by the battery, whereby a distinction is made between the following modes:

Standby power consumption (standby mode)	$P_{\text{Standby,AC}}$, $P_{\text{Standby,DC}}$
Input power of the power conversion system when the system meets the standby conditions specified by the manufacturer. Depending on the system, there may be several levels of standby.	
Power consumption when switched off (off mode)	$P_{\text{Off,AC}}$, $P_{\text{Off,DC}}$
Input power of the power conversion system if the system has been manually shut down.	

The DC power consumption of the inverter or converter is determined in the same way for all topologies.

DC power consumption of the inverter/converter[2]	$\bar{P}_{\text{Standby,DC}}$

$$\bar{P}_{\text{Standby,DC}} = \frac{\int_0^{t_M} P_{\text{BAT (discharging)}}(t) \cdot \mathrm{d}t}{t_M} \quad (24)$$

The determination of AC power consumption varies depending on the topology. The power consumption of the PV inverter contributes to the AC power consumption of PV generator-coupled systems in the discharged state. The power consumption of the AC auxiliary source of PV generator-coupled systems is included in the power consumption of the other system components.

AC power consumption of the AC-coupled system[2]	$\bar{P}_{\text{Standby,AC}}$

$$\bar{P}_{\text{Standby,AC}} = \frac{\int_0^{t_M} P_{\text{BESS (charging)}}(t) \cdot \mathrm{d}t}{t_M} \quad (25)$$

AC power consumption of the DC-coupled and PV generator-coupled system[2]	$\bar{P}_{\text{Standby,AC}}$

$$\bar{P}_{\text{Standby,AC}} = \frac{\int_0^{t_M} P_{\text{AC (Import)}}(t) \cdot \mathrm{d}t}{t_M} \quad (26)$$

PV inverter

[2] Power consumption off mode is calculated analogously using the same formulae.

For AC-coupled systems, the AC power consumption of the PV inverter in standby mode can be determined optionally.

AC power consumption of the PV inverter of the AC generator-coupled system[2]	$\bar{P}_{\text{PV-INV,Standby,AC}}$

$$\bar{P}_{\text{PV-INV,Standby,AC}} = \frac{\int_0^{t_{\text{M}}} P_{\text{PV-INV (Import)}}(t) \cdot \mathrm{d}t}{t_{\text{M}}} \quad (27)$$

Other system components

Power consumption of other system components	$P_{\text{PERIPH,AC}}$
AC power consumption of additional peripheral components required for operating the system (e.g. power sensors, external energy management system, any necessary AC auxiliary sources or switch devices for emergency power mode)	

With the load switched off and with PV generation, AC power consumption of the other system components can be determined independently of the topology as follows:

AC power consumption of the other system components	$\bar{P}_{\text{PERIPH,AC}}$

$$\bar{P}_{\text{PERIPH,AC}} = \frac{\int_0^{t_{\text{M}}} P_{\text{GRID (Import)}}(t) \cdot \mathrm{d}t - \int_0^{t_{\text{M}}} P_{\text{AC (Import)}}(t) \cdot \mathrm{d}t - \int_0^{t_{\text{M}}} P_{\text{Load}}(t) \cdot \mathrm{d}t + \int_0^{t_M} P_{\text{AC (Export)}}(t) \cdot \mathrm{d}t - \int_0^{t_M} P_{\text{Grid (export)}}(t) \cdot dt}{t_{\text{M}}} \quad (28)$$

Battery management system (BMS)

Standby power consumption	$P_{\text{BMS,standby}}$
BMS standby power consumption. For description, see Section 8.2.	

5 General description of the systems

This section contains the description of the complete system, as it is installed at the user. The main system components include the power conversion system (inverter or converter), the battery and the AC current sensors. Depending on the connection of the battery, a distinction is made between different topologies, which are explained in detail below. The individual topologies are described below specifying the measuring points (current, voltage or power measurement). Which measuring points are required for the analysis depends on the respective test and system topology. All measuring points that are valid for all system topologies are listed in Table 1. Additional, topology-dependent measuring points are described in the respective sub-sections.

Table 1: General measuring points, independent of the system topology.

Measuring points	**Description**	**Signal shape**	**Possible connections**
PVS	PV simulator	DC	String 1 to n
LOAD	Emulated household load	AC	L1, L2, L3
GRID	Grid connection point	AC	L1, L2, L3
BAT	Battery connection terminal	DC	String 1 to n
AC	Storage system AC output	AC	L1, L2, L3

5.1 AC-coupled systems

The AC-coupled storage system is shown in Figure 2. A PV inverter converts the direct current of the PV system into alternating current (PV2AC). Battery charging (AC2BAT) and battery discharge (BAT2AC) are effected by a bidirectional battery inverter. The entire battery charging chain thus consists of the pathways PV2AC and AC2BAT.

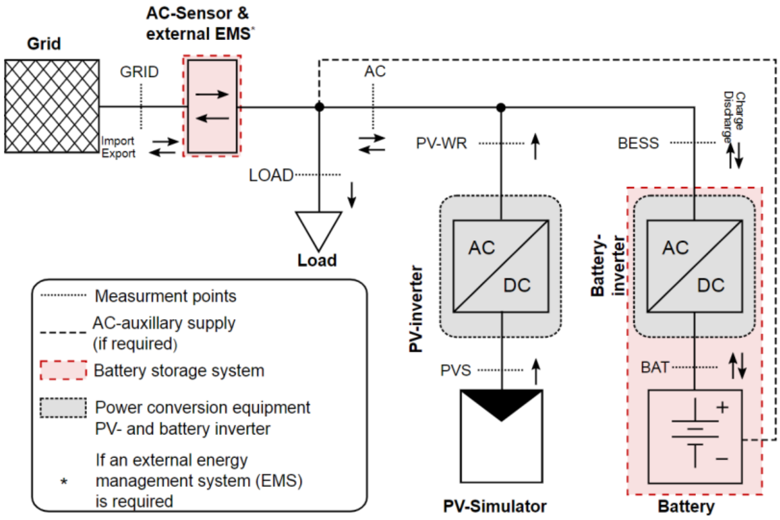

Figure 2: System components and measuring points of AC-coupled storage systems. (Source: AIT)

In addition to the measuring points listed in Table 1, AC-coupled systems have two further measuring points (see Table 2). The total power at the connection point (AC) is the aggregate power of the PV inverter (PV-INV) and the battery inverter (BESS).

Table 2: Additional measuring points for AC-coupled systems.

Measuring points	**Description**	**Signal shape**	**Possible connections**
PV-INV (AC-coupled)	AC connection of the PV inverter	AC	L1, L2, L3
BESS (AC-coupled)	AC connection of the battery inverter	AC	L1, L2, L3

5.2 DC-coupled systems

The DC-coupled storage system is shown in Figure 3. The battery storage system is connected to the DC link of the inverter. The power conversion system consists of one unit. The generated PV energy is charged into the battery (PV2BAT) or used for load coverage or grid feeding (PV2AC). To cover the load, the battery is discharged via the inverter (BAT2AC). The inverter bridge can be unidirectional or bidirectional. If the latter is the case, it is also possible to charge the battery from the AC grid (AC2BAT). All necessary measuring points for DC-coupled storage systems can be found in Table 1.

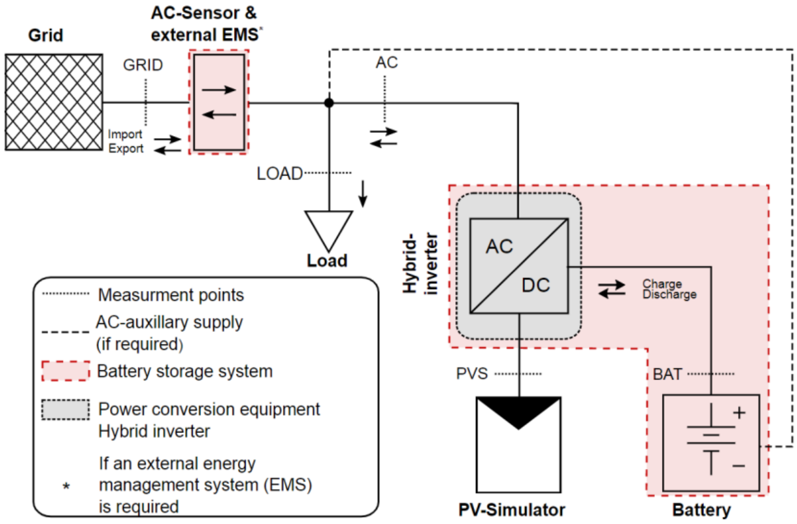

Figure 3: System components and measuring points of DC-coupled storage systems. (Source: AIT)

5.3 PV generator-coupled systems

The PV generator-coupled storage system is shown in Figure 4. The battery system is usually connected via a battery converter between the PV generator and a conventional PV inverter. The battery is charged directly by the converter (PV2BAT). PV grid feed or direct use (PV2AC) as well as battery discharge (BAT2AC) take place via a PV inverter that is compatible with the storage system. The entire battery discharge chain thus consists of the pathways BAT2PV and PV2AC.

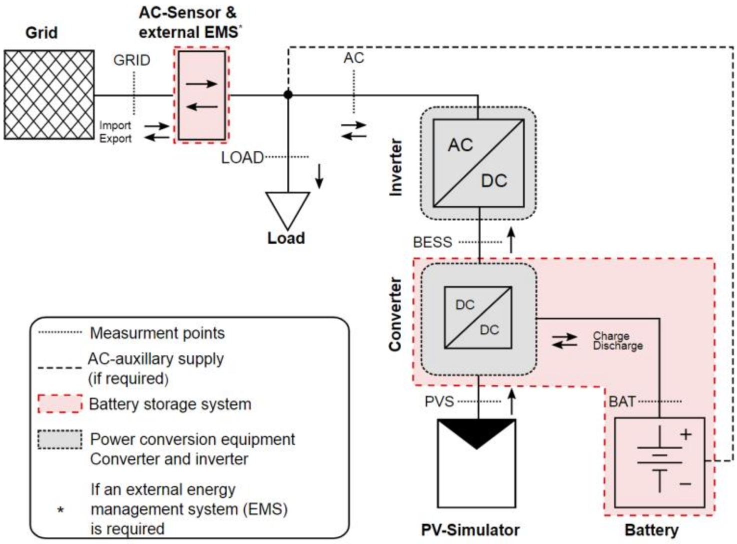

Figure 4: System components and measuring points of PV generator-coupled storage systems. (Source: AIT)

For a PV generator-coupled system, an additional measuring point at the DC input of the PV inverter is used (see Table 3).

Table 3: Additional measuring points for PV generator-coupled systems.

Measuring points	Description	Signal shape	Possible connections
BESS (PV generator-coupled)	DC connection of the battery converter to the PV inverter	DC	String 1 to n

For system topologies not listed here, the person responsible for testing must separately discuss the measuring arrangement with the manufacturer and document it in the test report in accordance with Figure 2 to Figure 4.

6 General description of the test procedure

The test procedure in Table 4 describes a possible sequence of measurements to be carried out. If the boundary conditions and target specifications of the following sections cannot be met due to the system's behaviour or the technical options of the person responsible for testing, this must always be documented in the test report for each case that arises.

Table 4: Possible test sequence.

	Reference
Determination of the rated power	Annex C
Power conversion system	Section 7
Battery	Section 8
Control deviations of the system	Section 9

The specified target temperature T_A should be in the middle of the given tolerance range during the course of the measurement, not at the limits of the range. A power factor of cos φ = 1 must be set for the power conversion system.

Table 5 offers an overview of the topology and pathway-dependent measuring points as well as the formulae to be used to determine the efficiencies. In addition, it describes the rated output power that is used as the basis for the standardisation of efficiency analogous to DIN EN 50530. In the test report and on the data sheet, the rated output powers and, optionally, the rated input powers must be specified.

Table 5: Overview of the measurement of the conversion pathways.[3]

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="5">Measured conversion pathway</th></tr>
<tr><th>PV2AC</th><th>PV2BAT</th><th>AC2BAT</th><th>BAT2AC</th><th>BAT2PV[4]</th></tr>
<tr><th colspan="2">Rated power</th><td>$P_{\text{PV2AC,nom}}$</td><td>$P_{\text{PV2BAT,nom}}$</td><td>$P_{\text{PV2BAT,nom}}$</td><td>$P_{\text{BAT2AC,nom}}$</td><td>$P_{\text{BAT2AC,nom}}$</td></tr>
<tr><th rowspan="3">Output power of the power conversion system</th><td>AC-coupled</td><td>$P_{\text{PV-INV}}$</td><td rowspan="3">P_{BAT}</td><td rowspan="3">P_{BAT}</td><td>P_{BESS}</td><td>-</td></tr>
<tr><td>DC-coupled</td><td rowspan="2">P_{AC}</td><td rowspan="2">P_{AC}</td><td>-</td></tr>
<tr><td>PV generator-coupled</td><td>P_{BESS}</td></tr>
<tr><th rowspan="3">Input power of the power conversion system</th><td>AC-coupled</td><td rowspan="3">$P_{\text{PVS,DC}}$</td><td rowspan="3">$P_{\text{PVS,DC}}$</td><td>P_{BESS}</td><td rowspan="3">P_{BAT}</td><td>-</td></tr>
<tr><td>DC-coupled</td><td rowspan="2">P_{AC}</td><td>-</td></tr>
<tr><td>PV generator-coupled</td><td>P_{BAT}</td></tr>
<tr><th rowspan="3">Calculated efficiency according to formula</th><td>AC-coupled</td><td>(4)</td><td>(5)(5)</td><td>(2)</td><td>(3)</td><td>-</td></tr>
<tr><td>DC-coupled</td><td>(8)</td><td>(6)</td><td>-</td><td>(7)</td><td>-</td></tr>
<tr><td>PV generator-coupled</td><td>(12)</td><td>(10)</td><td>(9)</td><td>(13)</td><td>(11)</td></tr>
<tr><th rowspan="3">Rated output power</th><td>AC-coupled</td><td>$P_{\text{PV-INV,nom}}$</td><td rowspan="3">$P_{\text{BAT,nom (charging}}$</td><td rowspan="3">$P_{\text{BAT,nom (chargin}}$</td><td>$P_{\text{BESS,nom (dischargin}}$</td><td>-</td></tr>
<tr><td>DC-coupled</td><td rowspan="2">$P_{\text{AC,nom (export)}}$</td><td rowspan="2">$P_{\text{AC,nom (discharging)}}$</td><td>-</td></tr>
<tr><td>PV generator-coupled</td><td>$P_{\text{BESS,nom (discharging)}}$</td></tr>
</table>

[3] ACG = AC-coupled, DCG = DC-coupled, PVG = PV generator-coupled
[4] The BAT2PV pathway only occurs in PV generator-coupled systems.

6.1 Power specifications of individual operating points

Option A: Control of test via PV generation and load

The test is carried out solely by specifying the power in the PV simulator and through the electrical load. The energy management system of the PV battery storage system regulates the battery power on the basis of the measured grid exchange power. The battery is discharged to cover the load consumption, and charged with surplus PV energy. This requires that additional charging strategies, such as forecast-based charging, etc., are deactivated. For measurements during which no battery charging or discharging should occur, it is in many cases possible to suppress battery charging or discharging by bypassing or emulating the AC current sensor.

Option A must be selected if all sub-tests are to be carried out following the same control procedure.

Option B: Control of the test via a communication interface

This control option only applies to the efficiency measurement, but not to the determination of control dynamics and deviation (see Section 9). If possible, power specifications are made directly via a standardised communication interface [5]. When measuring efficiency, a more precise actuation of individual operating points is possible, since the control loop of the system with the meter is not required. The interface should also allow the readout of system states, such as SOC, for example.

Option B is only applicable for tests according to Sections 7.5, 7.6 and 8.1. For all other sub-tests, a procedure according to option A is necessary. If option B is chosen, the corresponding result tables for the test report must be adapted where necessary.

6.2 Undesired power flows

During efficiency measurements, undesired power flows may occur that do not belong to the pathway being measured. In DC-coupled systems, losses that then occur cannot usually be assigned to exactly one pathway due to missing measuring points in the DC link. Undesired power flows when determining the efficiency of individual pathways would be the following for DC-coupled and PV generator-coupled systems:

- Battery charging or battery discharging when measuring PV2AC
- AC feed-in or AC draw when measuring PV2BAT

Efficiency calculation is always carried out with values measured during the steady state period (see Annex B). Beyond that, and in order to minimise the error caused by undesired power flows, the average value of the undesired power flow must not permanently exceed 10% of the value of the input power of the respective pathway. If this is not possible, the efficiency cannot be calculated for the entire measurement period t_{M}. Instead, the average value calculation requires at least one sub-segment longer than 40 s or two sub-segments of 20 s each to be available. If this is not the case, the operating point is measured again. If, once again, no calculation is possible, this must be indicated in the test report stating all averaged powers.

6.3 Battery state of charge

Battery fully charged

The battery can be assumed to be fully charged for the purpose of the tests once the storage system has approximately reached the SOC_{max} and the battery charging power P_{BAT} has been lowered to below 1% of nominal power $P_{\mathrm{PCE/BAT,nom\ (charging)}}$ for 5 minutes despite available DC input power. If this threshold value is not fallen below, the battery is considered to be fully charged as soon as the battery charging power has fallen below 3% of the nominal power $P_{\mathrm{PCE/BAT,nom\ (charging)}}$ over a period of 1 hour. If it is still not possible to meet the described criteria (e.g. by continuously alternating between charging and discharging the battery), it is the responsibility of the person in charge of testing to define the fully charged state. The definition can, for example, be made by calculating the moving average over 2 min and then applying one of the previous criteria.

[5] As an example, SunSpec Modbus-TCP can be mentioned, which provides defined models for reading and controlling inverters.

Battery fully discharged
The battery can be assumed to be fully discharged for purposes of testing as soon as the storage system has approximately reached SOC_{min} and the system has automatically reduced the battery discharge power to less than 1% of the nominal power $P_{\mathrm{PCE/BAT,nom\ (discharging)}}$ for at least 5 minutes despite the load being applied, or if the system has initiated recharging.

SOC estimation
In the case of several sub-tests, it is important that the SOC of battery remains in the range $SOC_{\mathrm{avg,area}}$. An estimation is permissible if the battery charge level cannot be read via a communication interface. This is done by integrating the charged or discharged current and the draw for the usable battery capacity $C_{\mathrm{BAT,use}}$.

6.4 Optional: use of a battery simulator

A battery simulator can be beneficial to accelerate and improve the reproducibility of the efficiency determination of the power conversion system (PV2BAT, AC2BAT, etc.). Sometimes it is necessary to keep the battery voltage in a defined voltage band in order to carry out the tests. The battery voltage changes with the charging or discharging power as well as the state of charge of the battery. A battery simulator is therefore preferable where possible. The test can be accelerated, which allows for an efficient measurement of additional operating points with regard to power and voltage. Measurement is also possible at a virtually constant voltage, which improves the reproducibility of the results.

With lithium-ion battery systems, communication between the power conversion system and the battery management system (BMS) is always required. This is usually accomplished via a communication bus (CAN, Modbus, etc.). The battery cannot be charged or discharged if the inverter does not detect any communication. That means that not only the power of the battery, but also the communication interface must be emulated.

If possible, the manufacturer should allow the communication interface (BMS inverter/converter) to be deactivated for tests in this case. It could be implemented, for example, in a special test mode that prevents said mode from being (accidentally) activated by the customer or the installer. The resulting advantage is a more efficient and accurate measurement of the system when using the battery simulator.

7 Sub-test: power conversion system

This section covers the determination of the efficiency or occurring losses of the power conversion system (battery inverter or converter). In principle, it consists of the power electronics, any necessary low-frequency or high-frequency transformers and, where necessary, additional fans for cooling. In fully integrated systems, the energy consumption of individual displays, the energy management system, the communication interfaces used and, if applicable, the AC current sensor is included in the losses of the power conversion system due to the defined measuring points in the fully integrated systems.

The efficiency of the power conversion system is determined at full and partial load for each energy conversion pathways. They are described in Figure 1 and Table 6, and are listed according to system topology.

To determine the conversion efficiencies at the defined supporting points, the resulting power losses must first be determined from the efficiencies. Then the power dependence of power loss can be approximated using a quadratic equation. With the quadratic equation, the power losses and consequently the efficiencies at the exactly defined supporting points can be determined. If a shape-preserving interpolation method (e.g. PCHIP from MATLAB) is used, this decision must be explained by providing a reason.

Table 6: Measurement of the individual conversion pathways for the various topologies.

Conversion pathway	Abbreviation	AC-coupled	DC-coupled	PV generator-coupled
PV grid feed-in and direct use	PV2AC	Optional[6]	Yes	Yes[7]
PV battery charging	PV2BAT	Optional[6]	Yes	Yes
AC battery discharging	BAT2AC	Yes	Yes	Optional
AC battery charging	AC2BAT	Yes	Optional[8]	Optional[9]
DC battery discharging	BAT2PV	No	No	Yes

AC-coupled systems:
In AC-coupled systems, at least the efficiency of the battery inverters AC2BAT and BAT2AC is determined.

PV generator-coupled systems:
In PV generator-coupled systems, the efficiency of the battery converters PV2BAT and BAT2PV is determined. In order to improve comparability with AC- and DC-coupled systems, the discharge efficiency BAT2AC should also be determined from the combination of PV inverter (PV2AC) and battery converter efficiencies during discharge (BAT2PV) and stated in the test report. It is recommended to include the efficiency BAT2AC in the same measurement as for the efficiency BAT2PV. In this case, it should be noted in the test report that, in actual practice, the efficiency may be higher or lower if an alternative PV inverter is used.

7.1 Test setup

The test setup is shown in Figure 2 to Figure 4. When testing PV inverters with multiple independent PV inputs, the measurement is carried out for all input configurations intended by the manufacturer [1]. Unless otherwise specified by the manufacturer, the total power must be distributed evenly between both inputs. Specify accordingly if the actual measurement differs from this. All three input voltages ($U_{MPP,min}$, $U_{MPP,nom}$, $U_{MPP,max}$) must be measured with the same configuration. The manufacturer provides a description of which inputs are used for the PV2BAT and PV2AC operating modes.

[6] An inverter must be provided for characterisation in the overall system.
[7] The exact measuring conditions and the PV inverter must be specified.
[8] Requires a bidirectional inverter.
[9] Requires a bidirectional inverter and a correspondingly adjusted control system.

7.2 Calculation of efficiencies

The efficiency calculations are carried out according to formulae (2) to (13).

7.3 PV direct use and grid feed-in (PV2AC)

PV2AC power flow occurs when PV generation is used directly or fed into the grid. The system must draw as much power as possible from the PV simulator by way of Maximum Power Point Tracking (MPPT). This may result in MPPT matching losses. In addition, losses also occur during the conversion of DC to AC electricity.

Note: AC-coupled systems

The efficiency $\eta_{\mathrm{PV2AC,t}}$ of the AC-coupled system is determined solely by the PV inverter used by the user. If the storage system (battery inverter, battery) is supplied without a PV inverter, no measurement is required for this operating mode. If one or more PV inverters are part of the storage package or are recommended by the manufacturer, the result of the efficiency measurements according to DIN EN 50530 should be used for these PV inverters.

Note: DC-coupled systems

The efficiency $\eta_{\mathrm{PV2AC,t}}$ of the DC-coupled system in real-life operation is also influenced by the no-load losses of the battery-side power controller. In order to get realistic measurement results for PV2AC efficiency, the storage system should be connected to the inverter and remain in standby mode. A disconnection of the battery from the power electronic components during PV2AC efficiency measurement must be noted in the test report.

Note: PV generator-coupled systems

The efficiency $\eta_{\mathrm{PV2AC,t}}$ of the PV generator-coupled system is determined primarily by the employed PV inverter. The storage system connected between PV generator and inverter can, depending on the wiring concept, cause additional losses and possibly influence the MPPT of the PV inverter used. The PV2AC pathway should therefore be tested with an inverter compatible with the storage system. The storage system should be connected to the PV inverter and should remain in standby mode.

7.3.1 Test conditions

PV input voltage and power

The test is carried out by specifying the PV generation power and the voltage at the PV simulator. The measurement conditions specified in the DIN EN 50530 standard apply. The measurement takes place at minimum, nominal and maximum PV input voltage. For each PV voltage level, measurements are carried out at full load and in the partial load range.

Battery state

The test is carried out with the battery fully charged as defined in Section 6.3.

Battery power

Ideally, there will be no battery charging or discharging taking place during the test. In practice, however, this cannot always be avoided and the battery may actually be slightly charged or discharged. Power P_{BAT} is recorded during the test. If charging or discharging of the battery occurs during measurement, follow the procedure described in Section 6.2.

Load

There is no active load during the test. A summary of the test conditions is given in Table 7.

Table 7: Test conditions for the PV2AC pathway.

Parameters	Value
P_{LOAD}	0
$P_{\mathrm{PVS,MPP}}$	Setpoint value
Battery state	Fully charged battery, see Section 6.3
T_{A}	25 °C ± 5 °C

7.3.2 Operating points

The static MPPT efficiency η_{MPPT} and the conversion efficiency $\eta_{\mathrm{PV2AC,conv}}$ are simultaneously measured for the operating points listed in Table 8. The characteristic curve is normalised to maximum power and not to sunlight. The input voltage is therefore constant for each partial measurement ($U_{\mathrm{MPP,min}}$, $U_{\mathrm{MPP,nom}}$ and $U_{\mathrm{MPP,max}}$) and does not depend on sunlight.

Table 8: Operating points for the PV2AC pathway.

MPP power of the simulated I/U characteristic curve in relation to the rated input power $\boldsymbol{P_{\mathrm{PVS,MPP}}/P_{\mathrm{PV2AC,nom}}}$							
0.05	0.10	0.20	0.25	0.30	0.50	0.75	1.00
Respectively at $U_{\mathrm{MPP,min}}$, $U_{\mathrm{MPP,nom}}$ and $U_{\mathrm{MPP,max}}$. If $U_{\mathrm{MPP,max}}$ should not be possible, then $0.8 \cdot U_{\mathrm{PV,max}}$ can be selected.							
simulated I/U characteristic curve: c-Si							

7.3.3 Carrying out the measurements

The measurements are carried out according to the DIN EN 50530 standard.

7.3.4 Evaluation

For each operating point from Table 8, MPPT and conversion efficiency are calculated as energetic average values over the measuring period t_{M}. If a steady state is not achieved within the measurement period or if undesired power flows occur, see the procedure for averaging as described in Section 6.2.

Static MPPT efficiency η_{MPPT} is calculated according to the formula (1). Depending on the topology, the conversion efficiency $\eta_{\mathrm{PV2AC,conv}}$ is calculated using formula (4), (8) or (12) . The total PV efficiency η_{PV2AC} corresponds to the product of the static MPPT efficiency and the conversion efficiency (see formula (14) or (16)). The test report contains the values given in Table 9. The pathway efficiency (PV2AC) as related to the rated output power must be transferred to Table 10 or Table 11 again. If the inverter is operated with two strings, the values $\bar{U}_{\mathrm{PVS,DC}}$, $\bar{P}_{\mathrm{PVS,MPP}}$ and η_{MPPT} in the table of measured values must be specified as the average values of the string related variables.

Table 9: Tabulation of the measurement results for the pathway PV2AC.

$\boldsymbol{P_{\mathrm{PVS,MPP}}/P_{\mathrm{PV2AC,nom}}}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{PV2AC}	%								
η_{MPPT}	%								
$\eta_{\mathrm{PV2AC,conv}}$	%								
$\bar{P}_{\mathrm{PVS,MPP}}$	W								
$\bar{U}_{\mathrm{PVS,DC}}$	V								
$\bar{P}_{\mathrm{PVS,DC}}$	W								
$\bar{P}_{\mathrm{AC}}$[10]	W								
$\bar{P}_{\mathrm{PV\text{-}INV}}$[11]	W								
$\bar{P}_{\mathrm{BAT\ (charging)}}$[10]	W								
$\bar{P}_{\mathrm{BAT\ (discharging)}}$[10]	W								
$\bar{U}_{\mathrm{BAT}}$	V								
$\bar{P}_{\mathrm{AC}}/\bar{P}_{\mathrm{AC,nom}}$[10]	-								
$\bar{P}_{\mathrm{PV\text{-}INV}}/\bar{P}_{\mathrm{PV\text{-}INV,nom}}$[11]	-								
Respectively at $U_{\mathrm{MPP,min}}$, $U_{\mathrm{MPP,nom}}$ and $U_{\mathrm{MPP,max}}$. If $U_{\mathrm{MPP,max}}$ should not be possible, then $0.8 \cdot U_{\mathrm{PV,max}}$ can be selected.									
simulated I/U characteristic curve: c-Si									

[10] Only for DC-coupled and PV generator-coupled systems
[11] Only for AC-coupled systems

Table 10: Summary of PV2AC efficiency for DC-coupled and PV generator-coupled systems.

$P_{AC}/P_{AC,nom}$	-	**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\eta_{PV2AC,t}$	%								

Table 11: Summary of PV2AC efficiency for AC-coupled systems.

$P_{PV\text{-}INV}/P_{PV\text{-}INV,nom}$	-	**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\eta_{PV2AC,t}$	%								

7.4 Battery charging and discharging (general)

The following section describes the general procedure for measuring the conversion pathways for charging and discharging the battery. The test for both pathways (charging and discharging) is carried out according to the test sequence described below. The exact test conditions are explained separately for battery discharging (Section 7.5) and battery charging (Section 7.6).

7.4.1 Test conditions

Battery voltage has an impact on efficiency when measuring the following conversion pathways: PV2BAT, AC2BAT, BAT2AC and BAT2PV. Efficiency is therefore measured in a voltage range that corresponds to a medium state of charge range $SOC_{avg,area}$ of the battery. The battery is fully charged before the test starts and is then discharged to SOC_{avg} +10% (estimation of SOC, see Section 6.3). The SOC and the voltage at the start of the test must be stated in the test report. In addition, measurements in the upper or lower state of charge range can be taken for further battery voltages.

Battery system/module configuration

For high-voltage systems with modular battery modules connected in series, the efficiency curves are recorded for at least a medium number of modules. In addition, measurements with a minimum and maximum number of modules are recommended. For each configuration, the test is performed at a battery voltage corresponding to a medium state of charge range $SOC_{avg,area}$.

7.4.2 Test sequence

In order to improve the reproducibility of the efficiency measurements, the procedure for determining the charging efficiency (PV2BAT, AC2BAT) and the discharging efficiency (BAT2AC, BAT2PV) is described below.

1) **Establishing the initial condition**
    a) Fully charge battery (see Section 6.3)
    b) The battery is discharged to approx. the medium SOC_{avg} + 10 %
    c) Pause (~30 min)
2) **Stair-shaped profile discharge efficiency**
    a) Pause (~30 min)
3) **Stair-shaped profile charge efficiency** at $U_{MPP,nom}$
    a) Pause (~30 min)
4) **Stair-shaped profile discharge efficiency**
    a) Pause (~30 min)
5) **Stair-shaped profile charge efficiency** at $U_{MPP,min}$
    a) Pause (~30 min)
6) **Stair-shaped profile discharge efficiency**
    a) Pause (~30 min)
7) **Stair-shaped profile charge efficiency** at $U_{MPP,max}$
8) **End of test**

Note: AC-coupled systems

Since AC-coupled systems only measure the AC2BAT and BAT2AC conversion pathway, steps 1-3 are sufficient for this topology.

Stair-shaped profile

The stair-shaped profile shown in Figure 5 is used to determine charge and discharge efficiency. The first step is held for a duration of 6 minutes. A three-minute lead time t_V should give the system sufficient time after the pause to transition to the respective operating mode (e.g. starting the PV inverter). All following steps are held for a duration t_H of 3 minutes each. The system has 40 seconds at its disposal to reach a steady state. The measuring period to calculate the efficiency (energetic averaging) and to carry out the corresponding averaging of power and voltage for the specification in the test protocol is carried out over the measuring period t_{M} and amounts to 140 seconds.

Note
With certain systems, it may happen that a holding period of 3 minutes per step is not sufficient to achieve a steady state (see Annex B). If this is the case, the steps may have to be held for longer than 3 minutes. Ensure that the test is carried out within the middle SOC range $SOC_{\mathrm{avg,area}}$.

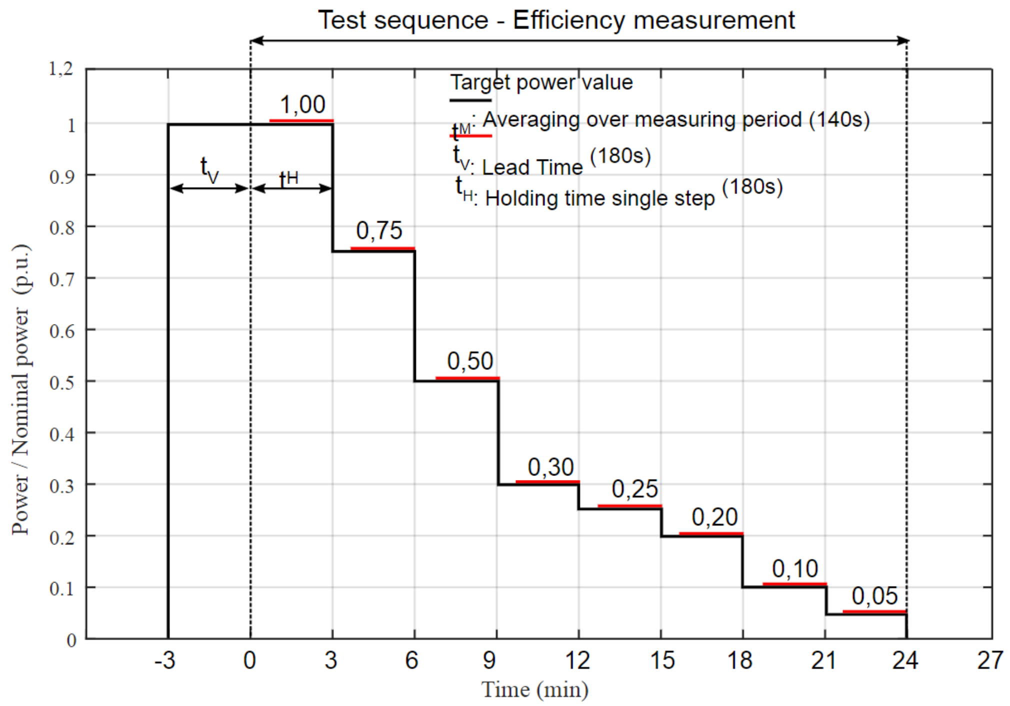

Figure 5: Stair-shaped profile to determine the efficiency of the PV2BAT, AC2BAT, PV2AC, BAT2PV and BAT2AC pathways. Information on determining the rated power can be found in Annex C. (Source: AIT)

7.5 Battery discharge (BAT2AC, BAT2PV)

This section describes the test conditions for discharging the battery (see Table 12). A description of the test conditions when charging the battery is given in Section 7.6. The efficiency of the system during battery discharge depends on the discharge power of the battery P_{BAT} and the battery voltage U_{BAT}, which in turn depends on the state of charge SOC, the battery current I_{BAT} and the battery configuration.

7.5.1 Test conditions

PV input voltage and power
No PV generation is required during the test.

Battery state
The initial state of the battery is defined in the Section 7.4.1.

Battery power
Due to the control concept of battery storage systems, battery power can fluctuate within a certain range. If the fluctuations are too large (see Annex B), it may not be possible to achieve a sufficient averaging and reproducibility of the results. Such behaviour is recorded and indicated in the test report.

AC or DC output power
AC or DC output power can fluctuate as can battery power. The same requirements as in Annex B apply accordingly.

Load
The test is carried out by specifying the load. The battery is discharged to cover consumption.

Table 12: Test conditions for the BAT2AC and BAT2PV pathways.

Parameters	Value
P_{LOAD}	Setpoint value
$P_{\mathrm{PVS,MPP}}$	0
P_{AC}[12]	$P_{\mathrm{AC}} \sim P_{\mathrm{LOAD}}$
Battery state	$SOC_{\mathrm{avg,area}}$
T_{A}	25 °C ± 5 °C

7.5.2 Operating points

The test requires measurements of the operating points from Table 13.

Table 13: Operating points for the pathways BAT2AC and BAT2PV.

Normalised power of the load $\boldsymbol{P_{\mathrm{LOAD}}/P_{\mathrm{BAT2AC,nom}}}$ **or.** $\boldsymbol{P_{\mathrm{LOAD}}/P_{\mathrm{BAT2PV,nom}}}$							
0.05*	0.10	0.20	0.25	0.30	0.50	0.75	1.00

7.5.3 Carrying out the measurements

The test is carried out by specifying the load. The test sequence is designed so that the SOC remains within the range $SOC_{\mathrm{avg,area}}$. The holding time of the step is at least 3 minutes for each specific power value.

7.5.4 Evaluation

For each operating point following Table 13, the conversion efficiency η_{BAT2AC} or η_{BAT2PV} is calculated as the energetic average value over the measuring period t_{M}. If a steady state is not reached within the measuring period (see Annex B) or if undesired power flows occur, see the procedure for averaging as described in Section 6.2.

The calculation for AC-coupled systems is carried out according to formula (3), for DC-coupled systems according to formula (7) and for PV generator-coupled systems according to formula (13) or (11). The measurement and calculation results for the conversion pathway BAT2AC or BAT2PV are to be created according to Table 14 to Table 18.

Table 14: Tabulation of the measurement results for the pathway BAT2AC.

$\boldsymbol{P_{\mathrm{LOAD}}/P_{\mathrm{BAT2AC,nom}}}$		**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2AC}	%								
$P_{\mathrm{LOAD,SET}}$	W								
$\bar{P}_{\mathrm{LOAD}}$	W								
$\bar{P}_{\mathrm{BESS}}$[13]	W								
$\bar{P}_{\mathrm{BESS}}/P_{\mathrm{BESS,nom\ (discharging)}}$[13]	%								
$\bar{P}_{\mathrm{AC}}$[14]	W								
$\bar{P}_{\mathrm{AC}}/P_{\mathrm{AC,nom\ (Discharging)}}$	%								
$\bar{P}_{\mathrm{BAT}}$	W								

[12]For an AC-coupled system, the power corresponds to the power P_"BESS" if no PV generation is available and if the self-consumption of the PV inverter is zero.

* If the measuring point 0.05 cannot be measured, then this fact must be noted. These values must be ignored when interpolating.

[13] Only for AC-coupled systems

[14] Only for DC-coupled and PV generator-coupled systems

$\bar{U}_{\mathrm{BAT}}$	V								
$C_{\mathrm{BAT\ (discharging)}}$	Ah								
$C_{\mathrm{BAT\ (discharging)}}/C_{\mathrm{BAT,\ use}}$	%								
$\bar{P}_{\mathrm{GRID}}$ (Import)	W								
$\bar{P}_{\mathrm{GRID\ (export)}}$	W								

Table 15: Summary of BAT2AC efficiency for AC-coupled systems.

$\boldsymbol{P}_{\mathbf{BESS}}/\boldsymbol{P}_{\mathbf{BESS,nom\ (discharging)}}$	**-**	**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2AC}	%								

Table 16: Summary of BAT2AC efficiency for DC-coupled systems.

$\boldsymbol{P}_{\mathbf{AC}}/\boldsymbol{P}_{\mathbf{AC,nom\ (discharging)}}$	**-**	**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2AC}	%								

Table 17: Tabulation of the measurement results for the pathway BAT2PV.

$\boldsymbol{P}_{\mathbf{LOAD}}/\boldsymbol{P}_{\mathbf{BAT2PV,nom}}$		**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2PV}	%								
$P_{\mathrm{LOAD,SET}}$	W								
$\bar{P}_{\mathrm{LOAD}}$	W								
$\bar{P}_{\mathrm{BESS}}$	W								
$\bar{P}_{\mathrm{BESS}}/P_{\mathrm{BESS,nom\ (discharging)}}$	%								
$\bar{P}_{\mathrm{AC}}$	W								
$\bar{P}_{\mathrm{BAT}}$	W								
$\bar{U}_{\mathrm{BAT}}$ or $\bar{U}_{\mathrm{BESS}}$ [15]	V								
$C_{\mathrm{BAT\ (discharging)}}$	Ah								
$C_{\mathrm{BAT\ (discharging)}}/C_{\mathrm{BAT,\ use}}$	%								
$\bar{P}_{\mathrm{GRID}}$ (Import)	W								
$\bar{P}_{\mathrm{GRID\ (export)}}$	W								

Table 18: Summary of BAT2PV efficiency for PV generator-coupled systems.

$\boldsymbol{P}_{\mathbf{BESS}}/\boldsymbol{P}_{\mathbf{BESS,nom\ (discharging)}}$	**-**	**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2PV}	%								

7.6 Battery charging (PV2BAT, AC2BAT)

This section describes the test conditions for charging the battery. The efficiency of PV battery charging (PV2BAT) depends on the MPP power $P_{\mathrm{PVS,MPP}}$ and output voltage $U_{\mathrm{PVS,DC}}$ of the PV simulator and the battery voltage U_{BAT}, which in turn depends on the state of charge SOC, the battery current I_{BAT} and the battery configuration. The efficiency of AC battery charging (AC2BAT) in AC-coupled systems corresponds to the conversion efficiency η_{AC2BAT} of the battery inverter.

7.6.1 Test conditions

PV input voltage and power

[15] $\bar{U}_{\mathrm{BESS}}$ Specify for PV generator-coupled system

The test is carried out by specifying PV generation power and voltage. The efficiency of PV battery charging (PV2BAT) is measured at minimum, nominal and maximum PV input voltage. For each voltage level, measurements are carried out at full load and in the partial load range.

Battery state
The initial state of the battery is defined in the Section 7.4.1.

Battery power
Due to the control concept of battery storage systems, battery power can fluctuate within a certain range. If the fluctuations are too large (see Annex B), it may not be possible to achieve a sufficient averaging and reproducibility of the results. Such behaviour is recorded and indicated in the test report.

AC output power
Ideally, the AC output power P_{AC} of the storage system is zero. Deviations are recorded and stated in the test report.

Load
There is no active load during the test. The test conditions are summarised in Table 19.

Table 19: Test conditions for the PV2BAT and AC2BAT pathways.

Parameters	Value
P_{LOAD}	0
$P_{\mathrm{PVS,MPP}}$	Setpoint value
Battery state	$SOC_{\mathrm{avg,area}}$
T_{A}	25 °C ± 5 °C

7.6.2 Operating points

The test requires measurements of the operating points from Table 20 or Table 21.

Table 20: Operating points for the PV2BAT pathway.

MPP power of the simulated I/U characteristic curve in relation to the rated input power $P_{\mathrm{PVS,MPP}}/P_{\mathrm{PV2BAT,nom}}$							
0.05	0.10	0.20	0.25	0.30	0.50	0.75	1.00
Respectively at $U_{\mathrm{MPP,min}}$, $U_{\mathrm{MPP,nom}}$ and $U_{\mathrm{MPP,max}}$. If $U_{\mathrm{MPP,max}}$ should not be possible, then $0.8 \cdot U_{\mathrm{PV,max}}$ can be selected.							
simulated I/U characteristic curve: c-Si							

Table 21: Operating points for the pathway AC2BAT when specifying the charging power at the PV simulator.

MPP power of the simulated I/U characteristic curve in relation to the rated input power $P_{\mathrm{PVS,MPP}}/P_{\mathrm{AC2BAT,nom}}$							
0.05	0.10	0.20	0.25	0.30	0.50	0.75	1.00
at $U_{\mathrm{MPP,nom}}$							

7.6.3 Carrying out the measurements

The test is carried out by specifying PV generation power and voltage at the PV simulator. The test sequence is designed so that the SOC remains within the range $SOC_{\mathrm{avg,area}}$. The holding time of the step is at least 3 minutes for each specific power value.

7.6.4 Evaluation

For each operating point from Table 20, the static MPPT and conversion efficiencies are calculated as energetic average values over the measuring period t_{M}. If a steady state is not reached within the measuring period (see Annex B) or if undesired power flows occur, see the procedure for averaging as described in Section 6.2.

Static MPPT efficiency η_{MPPT} is calculated according to the formula (1). Depending on the topology, the conversion efficiency η_{PV2BAT} or $\eta_{\mathrm{PV2BAT,conv}}$ is calculated using formula (5), (6) or (10). The total PV efficiency $\eta_{\mathrm{PV2BAT,t}}$ corresponds to the product of the static MPPT efficiency and the conversion efficiency (see formula (15) or (17)). The conversion efficiency η_{AC2BAT} for AC-coupled systems is calculated according to the formula (2). For DC-coupled systems with bidirectional inverters, the formula (9) for determining the pathway is used optionally.

The measurement and calculation results for the conversion pathway PV2BAT or AC2BAT are to be created according to Table 22 to Table 25. If the inverter is operated with two strings, the values $\bar{U}_{\mathrm{PVS,DC}}$, $\bar{P}_{\mathrm{PVS,MPP}}$ and η_{MPPT} in the table of measured values must be specified as the average values of the string related variables.

Table 22: Tabulation of the measurement results for the pathway PV2BAT.

$\boldsymbol{P_{\mathrm{PVS,MPP}}/P_{\mathrm{PV2BAT,nom}}}$		**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\eta_{\mathrm{PV2BAT,t}}$	%								
η_{MPPT}	%								
$\eta_{\mathrm{PV2BAT,conv}}$	%								
$\bar{P}_{\mathrm{PVS,MPP}}$	W								
$\bar{U}_{\mathrm{PVS,DC}}$	V								
$\bar{P}_{\mathrm{PVS.DC}}$	W								
$\bar{P}_{\mathrm{AC}}$ (Import)	W								
$\bar{P}_{\mathrm{AC\ (export)}}$	W								
$\bar{P}_{\mathrm{BAT}}$	W								
$\bar{P}_{\mathrm{BAT}}/P_{\mathrm{BAT,nom\ (charging)}}$	%								
$\bar{U}_{\mathrm{BAT}}$	V								
$C_{\mathrm{BAT\ (charging)}}$	Ah								
$C_{\mathrm{BAT\ (charging)}}/C_{\mathrm{BAT,\ use}}$	%								
$\bar{P}_{\mathrm{GRID}}$ (Import)	W								
$\bar{P}_{\mathrm{GRID\ (export)}}$	W								
Respectively at $U_{\mathrm{MPP,min}}$, $U_{\mathrm{PV,nom}}$ and $U_{\mathrm{MPP,max}}$. If $U_{\mathrm{MPP,max}}$ should not be possible, then $0.8 \cdot U_{\mathrm{PV,max}}$ can be selected.									
simulated I/U characteristic curve: c-Si									

Table 23: Summary of PV2BAT efficiency for DC-coupled and PV generator-coupled systems.

$\boldsymbol{P_{\mathrm{BAT}}/P_{\mathrm{BAT,nom}}}$	-	**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\eta_{\mathrm{PV2BAT,t}}$	%								

Table 24: Tabulation of the measurement results for the pathway AC2BAT.

$\boldsymbol{P_{\mathrm{PVS,MPP}}/P_{\mathrm{AC2BAT,nom}}}$		**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{AC2BAT}	%								
$\bar{P}_{\mathrm{PVS,MPP}}$	W								
$\bar{U}_{\mathrm{PVS,DC}}$	V								
$\bar{P}_{\mathrm{PVS,DC}}$	W								
$\bar{P}_{\mathrm{PV\text{-}INV}}$	W								
$\bar{P}_{\mathrm{AC}}$	W								
$\bar{P}_{\mathrm{BESS}}$	W								

$\bar{P}_{\text{BAT}}$	W								
$\bar{P}_{\text{BAT}}/P_{\text{BAT,nom (charging)}}$	%								
$\bar{U}_{\text{BAT}}$	V								
$C_{\text{BAT (charging)}}$	Ah								
$C_{\text{BAT (charging)}}/C_{\text{BAT, use}}$	%								
$\bar{P}_{\text{GRID (Import)}}$	W								
$\bar{P}_{\text{GRID (export)}}$	W								

Table 25: Summary of AC2BAT and PV2BAT efficiencies for AC-coupled systems.

$\bar{\boldsymbol{P}}_{\textbf{BAT}}/\boldsymbol{P}_{\textbf{BAT,nom}}$	**-**	**0.05***	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{AC2BAT}	%								
η_{PV2BAT}	%								

7.7 Power consumption in standby mode or switched off state

In addition to the conversion efficiencies, the power consumption of the overall system in standby mode and in its switched-off state must also be determined. Depending on the system, a distinction can be made between the following states (definitions: see Section 4.9.7):

- Standby (standby mode)
- Switched off (off mode)

There may be several different standby modes for certain systems. In principle, the transition conditions between the various operating states must be specified by the manufacturer and confirmed by the testing institute. AC and DC power consumption for the individual system components in the respective system operating states must be documented separately.

7.7.1 Carrying out the measurements

Power losses in standby mode are measured when the battery is at SOC_{max} and SOC_{min}. After the system has reached a stable state, the powers $P_{\text{PVS,DC}}$, P_{Load}, P_{BAT}, P_{AC}, $P_{\text{PV-INV}}$, P_{BESS} and P_{GRID} must be measured and averaged over t_{M} (1 min), depending on the topology. The following list describes the chronological procedure of the measurement:

1) **Battery storage system charged to $\boldsymbol{SOC}_{\textbf{max}}$**
   a) $P_{\text{PVS,DC}} = 0.75\ P_{\text{PV2AC,nom}}$ and $P_{\text{Load}} = 0.25\ P_{\text{BAT2AC,nom}}$
   b) Follow manufacturer's instructions to activate standby mode
   c) Measurement of standby power consumption for 1 min
   d) optional: test additional standby modes according to manufacturer's specifications
2) **Battery storage system discharged to $\boldsymbol{SOC}_{\textbf{min}}$**
   a) $P_{\text{PVS,DC}} = 0$ and $P_{\text{Load}} = 0.25\ P_{\text{BAT2AC,nom}}$
   b) Follow manufacturer's instructions to activate standby mode
   c) Measurement of standby power consumption for 1 min
   d) optional: test additional standby modes according to manufacturer's specifications
3) **Hold battery storage system at $\boldsymbol{SOC}_{\textbf{min}}$ to determine peripheral consumption**
   a) $P_{\text{PVS,DC}} = 0$ and $P_{\text{Load}} = 0$
   b) Follow manufacturer's instructions to activate standby mode
   c) Measure power consumption of other system components for 1 min
4) **Manual deactivation of battery storage system according to manufacturer's specifications (off mode)**
   a) $P_{\text{PVS,DC}} = 0$ and $P_{\text{Load}} = 0$
   b) Measurement of power consumption for 1 min

Note

If there are no applicable manufacturer's specifications for the transition into standby mode, a different test procedure applies. First, the battery storage system is recharged to SOC_{max}. Then the standby power consumption is averaged over t_{M} (1 min) in accordance with 1). The measurement of the relevant powers (see Table 26) is still carried out for a duration of 3 hours. If the power consumption changes within this time compared to the standby power consumption determined at the beginning, the corresponding value as well as the duration must be documented. The new standby power consumption is to be averaged over a period of t_{M} (1 min). The same procedure is repeated according to 2) after the battery storage system has been discharged to SOC_{min}.

7.7.2 Evaluation

The measurement and calculation results are presented in Table 26. In addition to the AC standby power consumption of the power conversion system, the measured values of $P_{\mathrm{GRID\ (Import)}}$ and, if applicable, $P_{\mathrm{GRID\ (export)}}$ also include the power consumption of the other system components (e.g. current sensor and, if applicable, external energy manager).

Table 26: A tabular presentation of the measurement results of losses in standby and off mode [16].

Measurement		**1**	**2**	**3**	**4**
State of charge		$\boldsymbol{SOC}_{\mathrm{max}}$	$\boldsymbol{SOC}_{\mathrm{min}}$	$\boldsymbol{SOC}_{\mathrm{min}}$	$\boldsymbol{SOC}_{\mathrm{min}}$
Operating mode		**Standby**	**Standby**	**Standby**	**Off mode**
$\bar{P}_{\mathrm{PVS,DC}}$	W				
P_{Load}	W				
$P_{\mathrm{BAT\ (discharging)}}$	W				
$P_{\mathrm{BAT\ (charging)}}$	W				
$P_{\mathrm{GRID\ (Import)}}$	W				
$P_{\mathrm{GRID\ (export)}}$	W				
$P_{\mathrm{AC\ (Import)}}$	W				
$P_{\mathrm{AC\ (export)}}$	W				
$P_{\mathrm{BESS\ (charging)}}$ [17]	W				
$P_{\mathrm{BESS\ (discharging)}}$ [17]	W				
$P_{\mathrm{PV\text{-}INV\ (Import)}}$ [18]	W				
		Calculation according to formulae (24) to (28)			
		$P_{\mathrm{Standby,AC}}$ [18]	$P_{\mathrm{Standby,AC}}$	$P_{\mathrm{PERIPH,AC}}$	$P_{\mathrm{Off,AC}}$
AC power	W				
		$P_{\mathrm{Standby,DC}}$	$P_{\mathrm{Standby,DC}}$		$P_{\mathrm{Off,DC}}$
DC power	W				

[16] If several standby modes are available, the table must be extended accordingly.
[17] Only for AC-coupled and PV generator-coupled systems.
[18] Only for AC-coupled systems.

8 Sub-test: Battery

The following part serves the characterisation of independent battery modules as well as of batteries that are integrated as a complete system into various system topologies.

8.1 Battery efficiency

The efficiency of batteries varies depending on the charging and discharging power, among other things e.g. temperature. In the following, tests for the characterisation of the power-dependent battery efficiency are described. The initial state of the test is a fully charged battery. During the test, the battery is fully discharged by specifying a constant load (generation equal to zero) (see Section 6.3) and then fully recharged (full cycle) by specifying a constant generation (load equal to zero). The efficiency is determined by the ratio of supplied and withdrawn DC-side energy.

8.1.1 Calculations

The calculation of battery efficiency is carried out according to the formula (22).

8.1.2 Test conditions

Depending on the system topology, see Figure 2 to Figure 4 for the test setup. A constant generation output is specified for charging the battery. By specifying a constant load, the battery is fully discharged. If the storage system to be measured has a seasonal adjustment of the minimum permissible state of charge, then this feature must be deactivated.

PV input voltage and power
PV generation is kept constant during the charging phase, and the test is carried out at nominal input voltage. No PV generation is required during the discharging process.

Battery voltage
The battery voltage increases across the entire SOC range while charging and decreases across the entire SOC range while discharging.

Battery power
Battery power results by specifying generation and load.

Load
The discharge process is brought about by the specification of a constant load. The battery is discharged to cover the load. There is no active load during the charging phase.

Table 27: General test configuration for measuring battery efficiency.

Parameters	Value
Battery state	Start with SOC_{max}
T_{A}	25 °C ± 5 °C

8.1.3 Carrying out the measurement

Battery efficiency is measured at the power levels indicated in Table 28.

Table 28: Operating points for the pathways BAT2AC and PV2BAT.

	Cycle 1	Cycle 2	Cycle 3
Discharge power	$P_{\mathrm{BAT2AC,nom}}$	$0.5 \cdot P_{\mathrm{BAT2AC,nom}}$	$0.25 \cdot P_{\mathrm{BAT2AC,nom}}$
Charging power	$P_{\mathrm{PV2BAT,nom}}$	$0.5 \cdot P_{\mathrm{PV2BAT,nom}}$	$0.25 \cdot P_{\mathrm{PV2BAT,nom}}$
Iterations	3	3	3

In order to limit the effort involved in testing modular systems in which a storage system (otherwise identical) with different battery capacities is supplied, it is recommended to test a medium battery capacity. The configuration with which the test was carried out must be specified.

8.1.4 Evaluation

For each iteration of each cycle as per Table 28, the energetic battery efficiency $\eta_{\mathrm{BAT,RTE}}$ and the coulomb efficiency $\eta_{\mathrm{BAT,RTE\ (coulomb)}}$ are calculated. Efficiency is calculated using formula (22) or (23). The measurement results are to be specified according to Table 29. For the calculation of the average values (table, right side), only the 2nd and 3rd iterations of each cycle are used. If the first cycle cannot be completed because the maximum cell temperatures have been exceeded, these values should not be included in the evaluation.

Table 29: Tabular presentation of the measurement results of the battery efficiency.

		Cycle									Average values			
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	1	2	3	1-3
$\eta_{\mathrm{BAT,RTE}}$	%													
$\eta_{\mathrm{BAT,RTE\ (coulomb)}}$	%													
$\bar{P}_{\mathrm{BAT\ (charging)}}$	W													
$\bar{P}_{\mathrm{BAT\ (discharging)}}$	W													
$t_{\mathrm{(charging)}}$	s													
$t_{\mathrm{(discharging)}}$	s													
$E_{\mathrm{BAT\ (charging)}}$	Wh													
$E_{\mathrm{BAT\ (discharging)}}$	Wh													
$C_{\mathrm{BAT\ (charging)}}$	Ah													
$C_{\mathrm{BAT\ (discharging)}}$	Ah													
$\max(U_{\mathrm{BAT}})$	V													
$\min(U_{\mathrm{BAT}})$	V													

For the purpose of visualising a possible power limitation due to a constant voltage or constant power phase, a graphical representation of P_{BAT} while charging and discharging for the 1st cycle (2nd iteration) is provided in addition to the tabular evaluation. The representation shows the charged or discharged energy quantity E_{BAT}.

The values relevant for the data sheet (battery efficiency and usable battery capacity) are derived from the average values of $\eta_{\mathrm{BAT,RTE}}$ and $E_{\mathrm{BAT\ (discharging)}}$, which can be taken from the last column in Table 29 for each case. The average value of $E_{\mathrm{BAT\ (discharging)}}$ corresponds to $E_{\mathrm{BAT,use}}$.

8.2 Other losses

The battery management system of the battery also consumes energy, which is usually supplied from the DC side by the battery, or from the AC side. If it is technically possible to measure these consumption values and if the manufacturer specifies the measuring points, they should be measured separately and documented in the test report. If fluctuating values are observed, then the arithmetic mean value must be determined.

If it is not possible to measure BMS consumption, the manufacturer must provide a detailed description of the level of the BMS's consumption. If the power consumption of the BMS varies depending on the operational state, the manufacturer must specify the switching conditions between those states. Validation of data by examining the technical documentation of the BMS is permissible.

Table 30: Tabular presentation of BMS consumption.

		$P_{\mathrm{BMS,standby}}$
Power	W	

9 Control deviations of the storage system

For reasons of limited measurement accuracy or control settings, stationary and dynamic deviations between required and provided AC-side battery power occur in practice when storage systems are used. Depending on the power balance, this may result in an undesired exchange of energy between the battery storage system and the grid. Control quality under stationary and dynamic conditions is therefore a further criterion required to characterise the efficiency of battery storage systems.

9.1 Determining dynamic control deviations

Storage systems exhibit dynamic control deviations. Due to lags in measured value acquisition and querying as well as control, the charging and discharging power of the battery storage cannot follow power steps without time delays. In addition, damped adjustment of battery power is often required for control reasons, which can lead to further delays.

As a first approximation, the step response behaviour can be described using a dead time, a settling time and the achievable steady-state accuracy, which are determined in a step response test. A characterisation of the dynamic control behaviour requires testing the system while grid-connected without control via a communication interface.

9.1.1 Carrying out the measurement

The battery storage system must have a medium state of charge SOC_{avg}. A preliminary test (jump from 10% of the nominal discharge power $P_{\mathrm{BAT2AC,nom}}$ to 90% and back to 10%) determines the approximate settling time $t_{\mathrm{E,ref}}$ rounded to whole seconds (see Annex B). The step response behaviour of the system is then recorded according to the step profile shown in Figure 6. The generation $P_{\mathrm{PVS,MPP,SET}}$ and load $P_{\mathrm{LOAD,\,SET}}$ of the individual steps S1 to S14 to be set is calculated according to formulae (29) to (31):

Generation profile[19] $P_{\mathrm{PVS,MPP\ (profile)}}$

$$P_{\mathrm{PVS,MPP,SET}} = f_{P_{\mathrm{PV2BAT}}} \cdot P_{\mathrm{PV2BAT,nom}} \tag{29}$$

Load profile $P_{\mathrm{LOAD\ (profile)}}$

$$P_{\mathrm{LOAD,SET}} = f_{P_{\mathrm{BAT2AC}}} \cdot P_{\mathrm{BAT2AC,nom}} \cdot k \tag{30}$$

k compensates for any differences in nominal charging and discharging power so that the battery's state of charge remains within the range of $SOC_{\mathrm{avg,area}}$ during the test.

Power compensation k

$$k = \frac{P_{\mathrm{PV2BAT,nom}}}{P_{\mathrm{BAT2AC,nom}}} \tag{31}$$

[19] In the case of DC-coupled and PV generator-coupled systems, the load for the case of $1.4 \cdot P_{\mathrm{PV2BAT,nom}} > P_{\mathrm{PV\text{-}INV,nom}}$ cannot be covered. Then $P_{\mathrm{PV\text{-}INV,nom}}/1.4$ must be used instead of $P_{\mathrm{PV2BAT,nom}}$ and noted accordingly in the log.

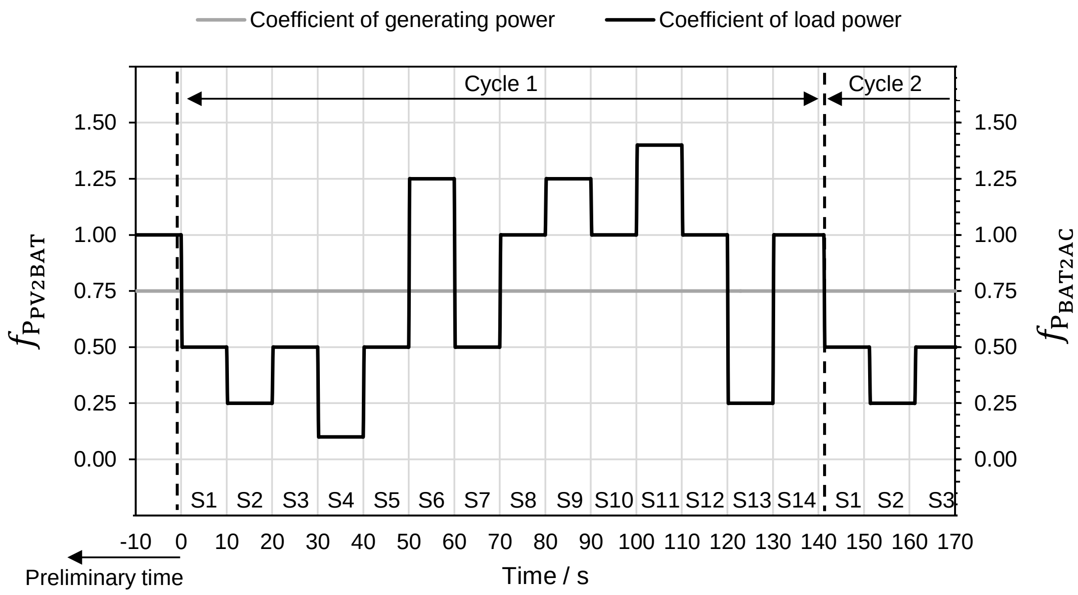

Figure 6: Step profile to characterise dynamic control deviation.

The holding time t_{H} of the individual steps corresponds to twice the settling time $t_{\mathrm{E,ref}}$ determined beforehand but at least 10 seconds. The last step (S14) is 1 second longer and should, if possible, be extended by the selected sampling rate of the measurement, since this makes a static sampling rate of the energy management system visible. The test profile is run seamlessly ten times in a row. The temporal resolution of the measured value sampling should be constant and not exceed 200 ms.

9.1.2 Evaluation

The measurement results of the grid exchange P_{GRID} and the load P_{LOAD} must be represented graphically in the test report as an example for the second cycle, following the example given in Figure 7. In addition, an evaluation is carried out according to Table 31 and Table 32 (see Annex B). During the entire test, the state of charge should remain in the medium state of charge range $SOC_{\mathrm{avg,area}}$. Deviations from this should be recorded in the test report.

Some systems temporarily do not correct P_{GRID} at all over one or more steps. In contrast to stationary control deviation, this control deviation is significantly greater than usual (e.g. P_{GRID} > 10 % · $P_{\mathrm{PV2BAT,nom}}$). Steps that exhibit this behaviour remain unconsidered in Table 31 and Table 32 when averaging. The measurement (ten passes of the step profile including a longer step 14) may have to be repeated several times so that at least 8 measured values are available for each step. When averaging, all values must then be taken into account for each step, unless it is a temporary and unusual control deviation as described above. The number of values considered per step and the total number of cycles completed must be stated in the test report.

Table 31: Power measurement results for the dynamic control deviation test.

		Steps													
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
		Average power values [20]													
$\bar{P}_{\mathrm{Load}}$	W														
$\bar{P}_{\mathrm{GRID\ (Import)}}$	W														
$\bar{P}_{\mathrm{GRID\ (export)}}$	W														
$\bar{P}_{\mathrm{PVS,DC}}$	W														
$\bar{P}_{\mathrm{BAT}}$	W														

Table 32: Measurement results of dead time and settling time for the dynamic control deviation test.

		Steps														
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S1-S14
		Temporal analysis of the grid exchange power														
$\bar{t}_{\mathrm{T}}$	s															
$\max(t_{\mathrm{T}})$	s															
$\min(t_{\mathrm{T}})$	s															
$\bar{t}_{\mathrm{E}}$	s															
$\max(t_{\mathrm{E}})$	s															
$\min(t_{\mathrm{E}})$	s															

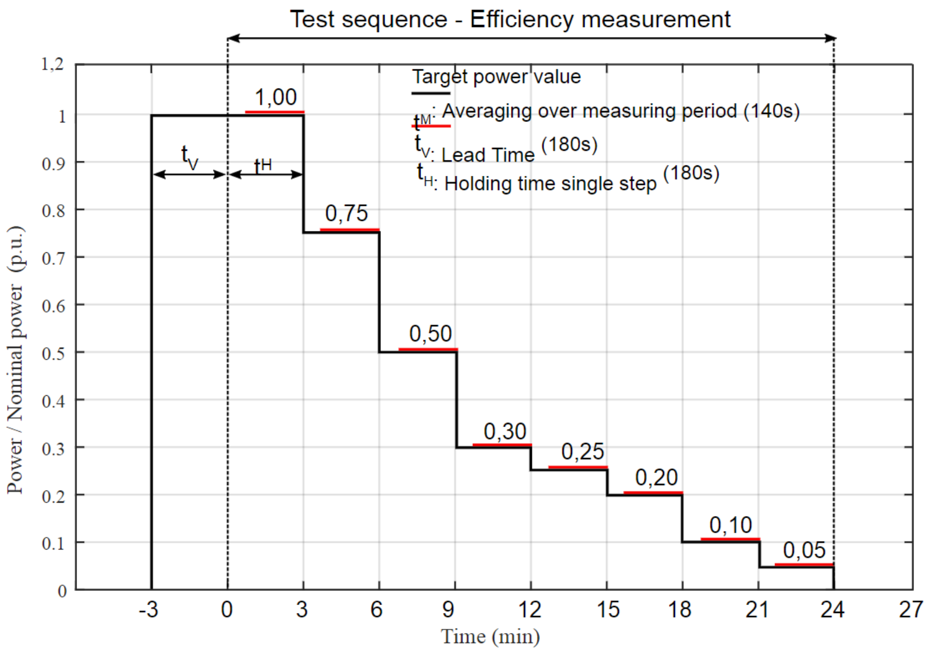

Figure 7: Exemplary visualisation of the power curves for a system with a nominal charging and discharging power of 2,500 W.

[20] For the duration in the steady state

9.2 Determination of stationary control deviations for mixed pathways

The load profile from Figure 6 is used with two iterations and the test configuration from Table 33 in order to determine the values of the stationary control deviations in real operating states of the storage system.

Table 33: General test configuration to measure stationary control deviation.

Parameters	Value
$P_{PVS,DC}$	0.75 * $P_{\mathrm{PV2BAT,nom}}$
t_H	160 s
t_{Int}	80 s
Battery state	SOC_{avg} + 5%

The average values for a load condition (LS) are calculated from the two iterations using formulae (32) and (33) and are then entered in Table 35. The variable t_{sb} describes the beginning of a step, the variable t_{Int} the integration time and *It* the iteration. If the settling time of a step exceeds 60 seconds, the integration period starts 20 seconds after the settling time and ends with the end of the step. Due to the characteristics of the profile from Figure 6, some load conditions are described by several steps. A suitable step must be selected for each respective load state. An allocation of steps to individual load conditions is provided in Table 34.

$$\bar{P}_{GRID(\mathrm{Import}),LS} = \frac{1}{2t_{Int}} \left(\int_{t_{sb}+60\,s}^{t_{sb}+140\,s} P_{GRID(\mathrm{Import}),It\,1} dt + \int_{t_{sb}+60\,s}^{t_{sb}+140\,s} P_{GRID(\mathrm{Import}),It\,2} dt \right) \tag{32}$$

$$\bar{P}_{GRID(\mathrm{export}),LS} = \frac{1}{2t_{Int}} \left(\int_{t_{sb}+60\,s}^{t_{sb}+140\,s} P_{GRID(\mathrm{export}),It\,1} dt + \int_{t_{sb}+60\,s}^{t_{sb}+140\,s} P_{GRID(\mathrm{export}),It\,2} dt \right) \tag{33}$$

with: LS: $load\ state$; t_{sb}: $Step\ beginning$; It: $iteration$; t_{Int}: $Integrating\ time$

Table 34: Allocation of the individual steps to the occurring load conditions.

	Discharging			Charging		
Load state (LS)	E1	E2	E3	L1	L2	L3
Corresponding steps	S11	S6, S9	S8, S10, S12, S14	S1, S3, S5, S7	S2, S13	S4

The calculated variables are then used to calculate the arithmetic mean of the power exchange with the grid according to formulae (34) to (37) over the various load states for the operating states “discharge” and “charge”. The results are entered in Table 35.

	$\bar{\bar{P}}_{GRID\ (\text{Import},charging)}$
$\bar{\bar{P}}_{GRID\ (\text{Import},charging)} = \frac{\sum_{n=1}^{3} \bar{P}_{GRID\ (\text{Import}),LS\ L\ n}}{3}$ (Values from "Charge" column)	(34)
	$\bar{\bar{P}}_{GRID\ (\text{export},charge)}$
$\bar{\bar{P}}_{GRID\ (\text{export},charging)} = \frac{\sum_{n=1}^{3} \bar{P}_{GRID\ (\text{export}),LS\ L\ n}}{3}$ (Values from "Charge" column)	(35)
	$\bar{\bar{P}}_{GRID\ (\text{Import},discharge)}$
$\bar{\bar{P}}_{GRID\ (\text{Import},discharge)} = \frac{\sum_{n=1}^{3} \bar{P}_{GRID\ (\text{Import}),LS\ E\ n}}{3}$ (Values from "Discharge" column)	(36)
	$\bar{\bar{P}}_{GRID\ (\text{export},discharge)}$
$\bar{\bar{P}}_{GRID\ (\text{export},discharging)} = \frac{\sum_{n=1}^{3} \bar{P}_{GRID\ (\text{export}),LS\ E\ n}}{3}$ (Values from "Discharge" column)	(37)

Finally, the stationary control deviations $P_{\text{dev. (charging)}}$ for the charge and $P_{\text{dev. (discharging)}}$ for the discharge case result according to formula (38) and (39). The results are also entered in Table 35.

Stationary deviation of the charging power in charging mode	$P_{\text{dev. (charging)}}$
$P_{\text{dev. (charging)}} = \bar{\bar{P}}_{\text{GRID (Import, charging)}} + \bar{\bar{P}}_{\text{GRIF (export, charging)}}$	(38)
Stationary deviation of the discharging power in discharging mode	$P_{\text{dev. (discharging)}}$
$P_{\text{dev. (discharging)}} = \bar{\bar{P}}_{\text{GRID (Import, discharging)}} + \bar{\bar{P}}_{\text{GRIF (export, discharging)}}$	(39)

Table 35: Tabular representation of the measurement results for stationary control deviation

	Stationary control deviations with mixed pathways						
Load state (LS)		**E1**	**E2**	**E3**	**L1**	**L2**	**L3**
$\bar{P}_{PVS,DC}$ / $\bar{P}_{LOAD}$	-						
$\bar{P}_{PVS,DC}$	W						
$\bar{P}_{LOAD}$	W						
$\bar{P}_{BAT}$	W						
$\bar{P}_{GRID\ (\text{Import}),LS\ n}$	W						
$\bar{P}_{GRID\ (\text{export}),LS\ n}$	W						
		Discharging			**Charging**		
$\bar{\bar{P}}_{GRID\ (\text{Import},discharging)}$	W				-		
$\bar{\bar{P}}_{GRID\ (\text{export},discharging)}$	W				-		
$\bar{\bar{P}}_{GRID\ (\text{Import},charging)}$	W	-					
$\bar{\bar{P}}_{GRID\ (\text{export},charging)}$	W	-					
$\boldsymbol{P_{dev.(discharging)}}$	W				-		
$\boldsymbol{P_{dev.(charging)}}$	W	-					

Annex A Requirements for the measuring instruments and the test stand

I. PV simulator

The conditions specified in the DIN EN 50530 standard apply.

II. Alternating current supply

The conditions specified in the DIN EN 50530 standard apply.

III. Electrical load

A resistive, controllable load is required to discharge the battery. If the storage system operates according to the balanced measuring principle [4], the type of load plays a subordinate role.

In order to prevent asymmetries at the grid connection point, a three-phase symmetrical load should be used for three-phase systems. For single-phase systems, the load should be connected to the phase of the storage system. A three-phase symmetrical load can also be used here, taking into account any unbalanced load limits.

IV. Accuracy and data recording

The accuracy classes required by DIN EN 61683:2000-08 must be complied with. The measurement technology employed (current transformers, shunts, devices, etc.) including their accuracy must be indicated in the test report, with a reference to this on the data sheet. Depending on the type of power calculation, there are two options for calculating efficiency [2]. In general, the differences are marginal. However, the chosen method should be indicated in the test report.

Power efficiency:
Ratio of output levels to input levels of fundamental power.

Conversion factor:
Ratio of effective output power to effective input power.

Annex B Handling dynamic power flows

Ideally, a PV storage system is controlled in such a way that a grid exchange power of exactly zero watts is achieved. The operating states targeted in a test cannot be set or can only be set with insufficient accuracy due to inaccuracies in the measurement of the household energy balance, the processing of the measurement data or of storage control. The following describes how the reproducible measurement of such storage systems is to be conducted.

In order to evaluate the control deviations, some definitions based on signal analysis definitions are established. Figure 8 provides an example of a jump during a measurement and illustrates the temporal definitions. Tolerance bands are specified around the two signal levels of the causal signal (PV or load power) and of battery power. The tolerance band $\pm 5\% \cdot |Level_1 - Level_2|$ covers the respective signal level [21]. Based on this, three points in time are defined in the measurement process:

t_1: Final exit from the tolerance band of the cause or of the causal signal (load) at the beginning of the jump.

t_2: Final exit from the tolerance band of the effect (battery power first signal level) after occurrence of the jump.

t_3: Final entry into the tolerance band (battery power 2nd level) until the next jump of the causal signal (load).

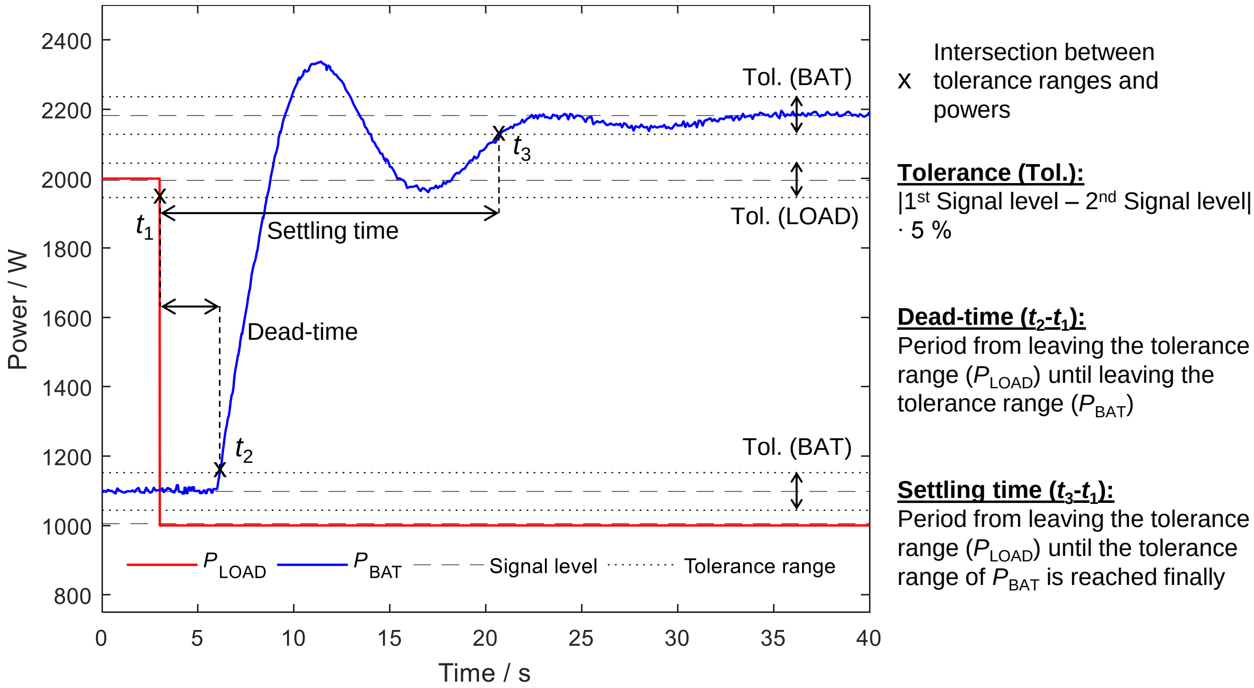

Figure 8: Definition of the tolerance bands. (Source: KIT/ Battery Technical Center)

The following variables for purposes of comparing the systems can be calculated based on these time definitions. **Dead time** ($t_{\mathrm{T}} = t_2 - t_1$) describes the duration required by a system to react to a power change. **Settling time** ($t_{\mathrm{E}} = t_3 - t_1$)) indicates the time the system takes to compensate for the power change. This is the interval between leaving the tolerance band of the cause up to the final entry of battery power into the tolerance band.

Some systems are not able to provide a constant output power $P(t) \sim P(t-1)$. If the tolerance band definitions cannot therefore be met, upstream signal smoothing (the sliding median is recommended)

[21] The signal levels can be determined according to the histogram method (IEEE® Standard on Transitions, Pulses, and Related Waveforms, IEEE Standard 181, 2003, pp. 15-17), for which there are corresponding pre-implemented evaluation routines, for example within the MATLAB programming environment.

can help to determine the points in time $t_1 \dots t_3$. If this step is insufficient, then the tolerance of the respective step can be raised. $\bar{P}_{\mathrm{BAT}}$ in Table 35 must be calculated on the basis of the original signal.

Because these two possible exceptions influence the times determined, great care must be taken when selecting suitable parameters. The necessity of this must be demonstrated using a graphical example from the measurement. The selected smoothing methods including parameters and selected tolerances must be specified as well.

Annex C Determination of rated power

Each testing institute is responsible for the technically correct determination of rated power. Annex C is an aid to the automated determination of rated power.

When determining rated power in each respective case, the recording of instantaneous values can lead to erroneous values. This behaviour occurs, for example, in systems that generate heavily oscillating battery and PV input powers even in the range of their rated power on the DC side. It is therefore generally recommended to extract the rated power using continuous data recording at a sufficiently high sampling rate.

The procedure described below for determining the rated power when measuring the PV2AC and PV2BAT pathways is explained for $U_{\mathrm{MPP,nom}}$. Since the rated powers are only conditionally dependent on U_{MPP}, the determined rated voltage can be used as a substitute for all voltage ranges that are to be tested.

I. Nominal PV feed-in power (PV2AC)

Calculation of rated power
If the nominal AC output power and the corresponding rated efficiency are specified, then the rated power can be determined by

$$P_{\mathrm{PV2AC,nom}} = \frac{P_{\mathrm{AC,nom}}}{\eta_{\mathrm{r}}} \quad (40).$$

If the rated efficiency is not given, the rated power can be determined using the method described below.

Rated power for DC-coupled and PV generator-coupled systems
MPP power $P_{\mathrm{PVS,MPP}}$ at the operating state defined by the stagnation of P_{AC} and $P_{\mathrm{PVS,DC}}$ as the MPP power of the PV simulator $P_{\mathrm{PVS,MPP}}$ continues to rise.

Rated power for AC-coupled systems
MPP power $P_{\mathrm{PVS,MPP}}$ at the operating state defined by the stagnation of $P_{\mathrm{PV\text{-}INV}}$ and $P_{\mathrm{PVS,DC}}$ as the MPP power of the PV simulator $P_{\mathrm{PVS,MPP}}$ continues to rise.

a. Preparation

The characteristic curve of the PV generator must be set to $P_{\mathrm{PVS,MPP,max}} = 1.2 \cdot P_{\mathrm{PV\text{-}INVR,\,nom}}$.

If this value does not yet saturate the AC output power P_{AC}, the working load can be further increased. If the required output power exceeds the maximum permissible DC input power, then this power is used.

$P_{\mathrm{BAT}}{\sim}0$ applies during the determination of $P_{\mathrm{PV2AC,nom}}$. To do this, the battery must first be fully charged. Furthermore, SOC_{max} must be held for ~30 min with continuous PV power in order to compensate for the successive recharging of the battery.

Note:
PV power should not fall below 30% of the nominal AC output power ($P_{\mathrm{PV\text{-}INV,nom}}$ or $P_{\mathrm{AC,nom}}$) of the system once the battery is fully charged and before the rated power is determined in order to prevent battery discharge and keep the downstream inverter in its active mode. The rated power is determined on the basis of this state.

b. Procedure

$P_{\mathrm{PVS,DC}}$ is run at 70% to 80% of the specified nominal power and is held there for 180 seconds for settling time reasons. A linear gradient of 1.2 times the nominal power per 540 seconds is then followed, ending on a plateau at 1.2 times the nominal power. This plateau should be held for a further 360 seconds.

$P_{\mathrm{PV2AC,nom}}$ corresponds to the MPP power $P_{\mathrm{PVS,MPP}}$ applied the moment the system enters the operating point described above.

$P_{\mathrm{PV2AC,nom}}$ can be directly read at the step-down threshold if $P_{\mathrm{PVS,DC}}$ or P_{AC} does not exhibit any noticeable oscillating behaviour after reaching the maximum convertible DC power. Otherwise, the PV or AC power before and after reaching saturation can be described by a linear fit. The operating point is then determined by the intersection of the fit functions (see Figure 9).

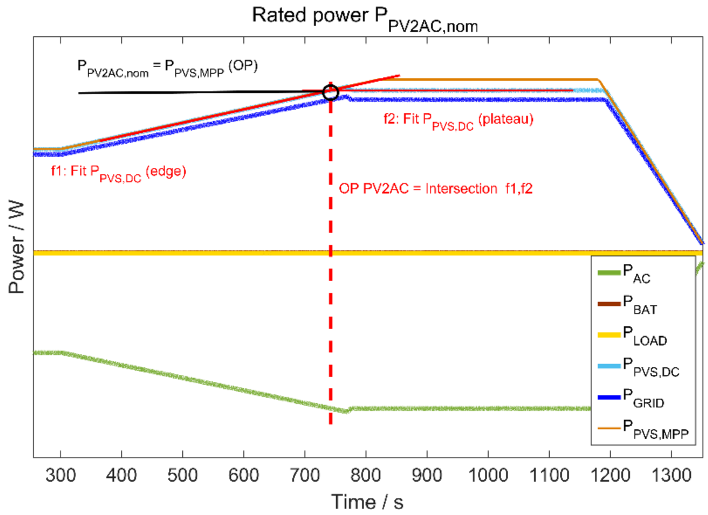

Figure 9: Exemplary extraction of the rated power $P_{PV2AC,nom}$ by fitting the PV power before and after reaching the step-down threshold due to overshoot (OP = operating point)

II. Nominal PV charging power((PV2BAT)

Rated power for DC-coupled and PV generator-coupled systems
MPP power $P_{PVS,MPP}$ at the operating point at which the battery power P_{BAT} does not continue to increase, or stagnates as the PV power $P_{PVS,DC}$ continues to rise.

Rated power for AC-coupled systems
MPP power $P_{PVS,MPP}$ at the operating point at which the battery inverter P_{BESS} does not continue to increase, or stagnates as the PV power $P_{PVS,DC}$ continues to rise.

With some systems, heavy fluctuations or peak-shaped deviations of the PV and battery outputs may occur. In these cases, the measurement can be repeated with a less steep slope of the ramp, or it can be carried out manually step by step. Alternatively, peak-shaped deviations can be removed using peak filters as part of post-processing before the rated power is extracted. Otherwise, as well as with a high dynamic deviation, the desired operating point should be defined by the time at which there is a linear increase of P_{GRID} with $P_{PVS,DC}$(see IV. Handling control deviations and short-term maximum outputs).

a. Preparation

To determine $P_{PV2BAT,nom}$, the battery must be brought to a medium SOC_{avg}. The characteristic curve of the PV generator must be set to $P_{PVS,MPP,max} = 1.2 \cdot P_{BAT,nom\,(charging)}$ or $P_{PVS,MPP,max} = 1.2 \cdot P_{PCE/BAT,nom\,(charging)}$ at nominal voltage $U_{MPP,nom}$ in the range of the limits of the MPP tracker, see Section 4.7.

b. Procedure

$P_{PVS,DC}$ is run at 70% to 80% of the specified nominal power and is held there for 180 seconds for settling time reasons. A linear gradient of 1.2 times the nominal power per 540 seconds is then followed, ending on a plateau at 1.2 times the nominal power. This plateau should be held for a further 360 seconds.

$P_{PV2BAT,nom}$ corresponds to the MPP power $P_{PVS,MPP}$ applied the moment the system enters the operating point described above.

III. Nominal PV discharge power (BAT2AC)

Rated power for DC-coupled and PV generator-coupled systems
Load power P_{LOAD} at the operating point at which the battery power P_{BAT} does not continue to increase, or stagnates as the AC load P_{LOAD} continues to rise.

Rated power for AC-coupled systems
Load power P_{LOAD} at the operating point at which the battery power P_{BESS} does not continue to increase, or stagnates as the AC load P_{LOAD} continues to rise.

With some systems, heavy fluctuations of the AC and battery outputs may occur. In case of , as well as with a high dynamic deviation, the desired operating point should be defined by the point in time at which P_{GRID} begins to fall linearly with increasing load power P_{LOAD} (see IV. Handling control deviations and short-term maximum outputs).

c. Preparation

To determine $P_{\mathrm{BAT2AC,nom}}$, the battery must be brought to a medium SOC_{avg}.

DC-coupled systems
The maximum load is $P_{\mathrm{LOAD,max}} = 1.2 \cdot P_{\mathrm{BAT,nom\ (discharging)}}$.

AC-coupled and PV generator-coupled systems
The maximum load is $P_{\mathrm{LOAD,max}} = 1.2 \cdot P_{\mathrm{PCE/BAT,nom\ (discharging)}}$.

d. Procedure

For P_{LOAD}, a linear gradient of 1.2 times the nominal power per 540 seconds is then followed, ending on a plateau at 1.2 times the nominal power ($m = 1.2 \cdot P_{\mathrm{Load,max}}\ /\ 540\ s$). This plateau should be held for a further 360 seconds.

$P_{\mathrm{BAT2AC,nom}}$ corresponds to the load power P_{LOAD} applied the moment the system enters the operating point described above.

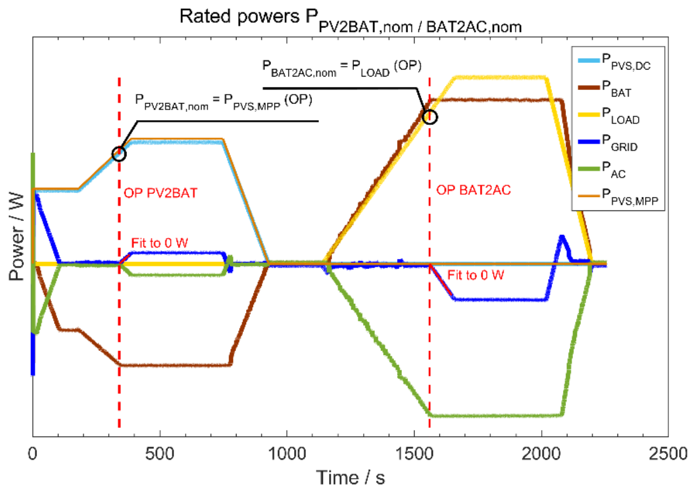

Figure 10: Example of extraction of the rated powers $P_{\mathrm{PV2BAT,nom}}$ and $P_{\mathrm{BAT2AC,nom}}$ by linear fitting of the grid exchange powers (OP = operating point)

IV. Handling control deviations and short-term maximum outputs

Determining the operating point via grid power

The operating point for determining the rated charging and discharge powers can generally and should be determined by a linear fit of the increasing or decreasing grid power and its intersection with the x-axis (see Figure 10). For large stationary control deviations or PV generator-coupled systems, the point of intersection must be determined using the grid power level at constant PV or load power (see Figure 11 a)). When applying a ramp profile, additional background grid power can occur in very slow systems due to dynamic control deviations. This is not taken into account when determining the desired operating point (see Figure 11 b)). The respective rated power then corresponds to the MPP power $P_{\mathrm{PVS,MPP}}$ or the load power P_{LOAD} at the operating point thus determined.

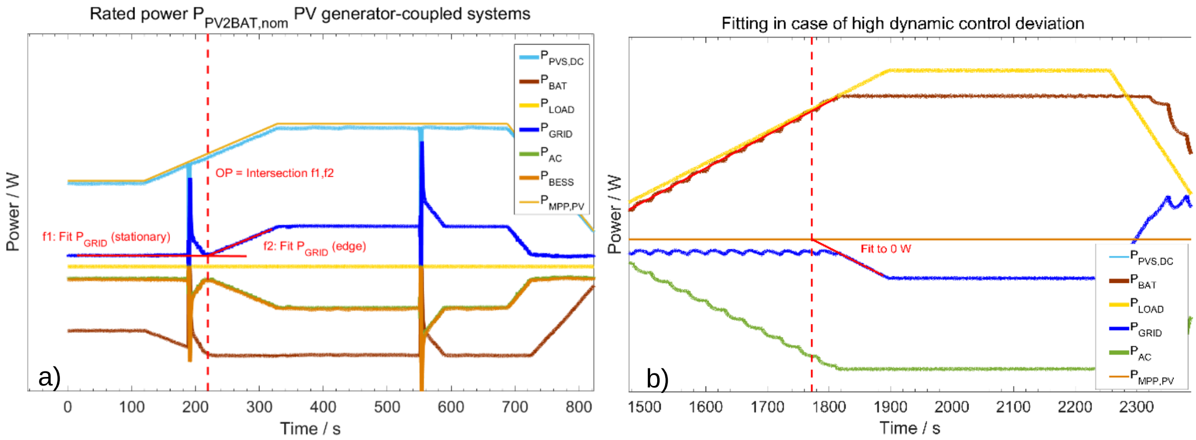

Figure 11: a) Determination of the operating point via grid power in systems with a high stationary control power level b) Purely dynamic control deviation is not taken into account when extrapolating grid power in systems with long reaction times

Correction of the operating point for short-term maximum outputs

In some systems, the charging or discharge power of the battery decreases over the holding time of the plateau after the operating point has been reached, as the systems briefly charge or discharge at maximum powers that exceed the continuous nominal powers $P_{\mathrm{BAT,nom\ (charging/\ discharging)}}$. If in this case the relaxation of the discharge power to a constant level up until the end of the holding time of the plateau is not finished, the holding time must be extended accordingly but should not exceed 420 seconds. If the relaxed value of the charging or discharge power to be read at point P2 at the end of the plateau has a deviation of more than 2% from the value determined at operating point OP 1, then the operating point should be corrected.

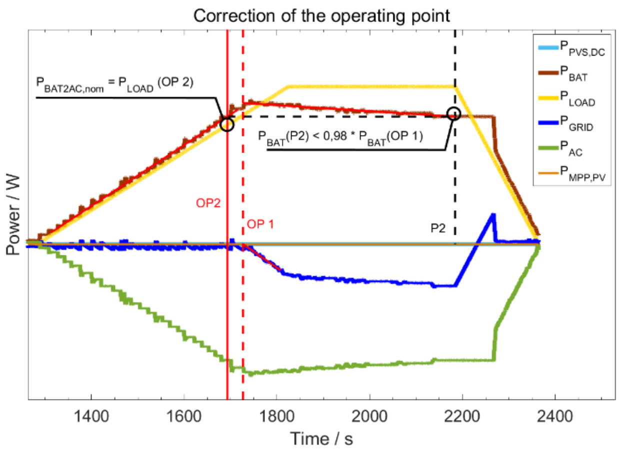

Figure 12: Example of the correction of the operating point when determining the rated discharge power $P_{\mathrm{BAT2AC,nom}}$

The new operating point OP 2 is defined as the point on the rising side of the battery power at which the charging or discharge power corresponds to the relaxed battery power at P2 (see Figure 12).

The respective rated power then corresponds to the MPP power $P_{\mathrm{PVS,MPP}}$ or the load power P_{LOAD} at the newly determined operating point. If the continuous relaxation of discharge power is caused by a steeper slope of the voltage curve of the battery used, no correction should be made. In this case, however, care should be taken to perform the efficiency measurement at nominal power and at the same battery voltage.

Annex D Determination of parameters and data sheet specifications

Average pathway efficiencies

To determine the average path efficiencies, the arithmetic mean of the efficiencies at the supporting points (0.05; 0.15; 0.25; 0.35; 0.45; 0.55; 0.65; 0.75; 0.85; 0.95) is formed and specified for each measured energy pathway. The total efficiencies at nominal PV input voltage including the MPP efficiencies must be used for the PV2AC and PV2BAT pathways.

Average battery efficiency

The arithmetic mean of the battery efficiencies of cycles 1 to 3 of Table 29 must be used to determine the average battery efficiency.

Settling time (dynamic control deviation)

To determine the average settling time, the arithmetic mean of the settling times of steps 1 to 14 from Figure 6 must be used.

System consumption in standby mode

In order to determine system consumption in standby mode in the discharged state, the sum of the AC and DC standby power consumption of the power conversion system and the power consumption of all other system components (e.g. current sensor and, if applicable, external energy manager) is calculated using Table 26.

System consumption in standby mode	P_{System}

$$P_{\mathrm{System}} = P_{\mathrm{Standby,DC}} + P_{\mathrm{Standby,AC}} + P_{\mathrm{PERIPH,AC}} \quad (41)$$

Annex E Normative references

The following documents, cited in part or as a whole in this guide, are required in order to use this document. In the case of dated references, only the edition referred to shall apply. For undated references, the latest edition of the referenced document (including any amendments) applies.

[1] DIN EN 50530 (VDE 0126-12:2013-12):2013-12, Overall efficiency of grid connected photovoltaic inverters; German language version EN 50530:2010 + A1:2013

[2] DIN EN 61683:2000-08 Photovoltaic systems - Power conditioners - Procedure for measuring efficiency (IEC 61683:1999); German version EN 61683:2000

[3] DIN EN 61427-2 (VDE 510-41):2016-09; Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications (IEC 61427-2:2015); German version EN 61427-2:2015

[4] VDE-AR-N 4400:2011-09, Electricity Metrology (Metering Code), VDE Verlag, 2009.

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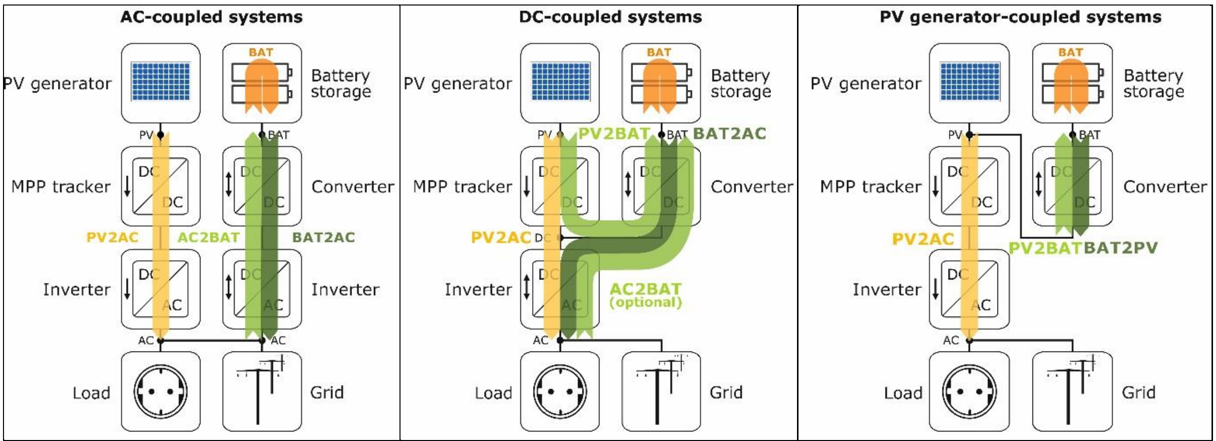
Annex G Summary of test results according to the efficiency guide

The basis for comparable data sheet specifications are test reports based on the efficiency guide for PV storage systems. The information listed below is the minimum information to be included in the summary of test results. Further characteristic values or information from the test report can be added. The terms must always be chosen in accordance with the specifications of the efficiency guideline. The individual system components for which the listed measured values were determined must be named. Since many system properties depend on the selection and dimensioning of the individual system components, the summary must be prepared separately for each measured system configuration. In the case of a battery storage system without an inverter/converter, the properties listed in the "Battery" section must be specified.

bold:	This specification is mandatory.
normal:	Specification whether or not the component or function is part of the data sheet product.
No details:	No specification required.
green:	Tabular representation of the conversion efficiencies depending on the output power relative to the rated output power.



Topological information		
Graphical overview of pathways the data sheet component is used for and which pathways are still required to cover the PV-DC to AC load route.		
PV connection		
No details	$\boldsymbol{U}_{\mathbf{PV,min}}$, $\boldsymbol{U}_{\mathbf{PV,nom}}$, $\boldsymbol{U}_{\mathbf{PV,max}}$	$\boldsymbol{U}_{\mathbf{PV,min}}$, $\boldsymbol{U}_{\mathbf{PV,nom}}$, $\boldsymbol{U}_{\mathbf{PV,max}}$
No details	$\boldsymbol{U}_{\mathbf{MPP,min}}$, $\boldsymbol{U}_{\mathbf{MPP,max}}$	$U_{\mathrm{MPP,min}}$, $U_{\mathrm{MPP,max}}$
No details	$\boldsymbol{P}_{\mathbf{PV,nom}}$	$P_{\mathrm{PV,nom}}$
AC connection		
$\boldsymbol{P}_{\mathbf{BESS,nom\ (discharging)}}$	$\boldsymbol{P}_{\mathbf{AC,nom}}$ (export)	$P_{\mathrm{AC,nom\ (export)}}$
$\boldsymbol{P}_{\mathbf{BESS,nom\ (charging)}}$	$P_{\mathrm{AC,nom\ (Import)}}$	No details
	$\boldsymbol{P}_{\mathbf{AC,nom\ (discharging)}}$	$P_{\mathrm{AC,nom\ (discharging)}}$
DC connection		
No details	No details	$\boldsymbol{P}_{\mathbf{BESS,nom\ (discharging)}}$
No details	No details	$\boldsymbol{P}_{\mathbf{BESS,nom\ (charging)}}$
Battery connection		
$\boldsymbol{U}_{\mathbf{PCE/BAT,min}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,nom}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,max}}$	$\boldsymbol{U}_{\mathbf{PCE/BAT,min}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,nom}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,max}}$	$\boldsymbol{U}_{\mathbf{PCE/BAT,min}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,nom}}$ $\boldsymbol{U}_{\mathbf{PCE/BAT,max}}$

$P_{\text{PCE/BAT,nom (charging)}}$ $P_{\text{PCE/BAT,nom (discharging)}}$	$P_{\text{PCE/BAT,nom (charging)}}$ $P_{\text{PCE/BAT,nom (discharging)}}$	$P_{\text{PCE/BAT,nom (charging)}}$ $P_{\text{PCE/BAT,nom (discharging)}}$
Battery		
According to the efficiency guide, the battery-related specifications must be provided for at least one system configuration with a medium battery capacity.		
$P_{\text{BAT,nom (charging)}}$, $P_{\text{BAT,nom (discharging)}}$		
$U_{\text{BAT,min}}$, $U_{\text{BAT,nom}}$, $U_{\text{BAT,max}}$		
$E_{\text{BAT,use}}$		
$\eta_{\text{BAT,RTE}}$		
$P_{\text{BMS,standby}}$		
Efficiencies		
No details	$\eta_{\text{PV2AC,t}}(P)$	$\eta_{\text{PV2AC,t}}(P)$[1]
$\eta_{\text{BAT2AC}}(P)$	$\eta_{\text{BAT2AC}}(P)$	$\eta_{\text{BAT2AC}}(P)$[1]
No details	No details	$\eta_{\text{BAT2PV}}(P)$
No details	$\eta_{\text{PV2BAT,t}}(P)$	$\eta_{\text{PV2BAT,t}}(P)$
$\eta_{\text{AC2BAT}}(P)$	$\eta_{\text{AC2BAT}}(P)$	No details
Standby losses		
$P_{\text{Standby,AC}}\ (SOC_{max})$		
$P_{\text{Standby,DC}}\ (SOC_{max})$	$P_{\text{Standby,DC}}\ (SOC_{max})$	$P_{\text{Standby,DC}}\ (SOC_{max})$
$P_{\text{Standby,AC}}\ (SOC_{min})$	$P_{\text{Standby,AC}}\ (SOC_{min})$	$P_{\text{Standby,AC}}\ (SOC_{min})$
$P_{\text{Standby,DC}}\ (SOC_{min})$	$P_{\text{Standby,DC}}\ (SOC_{min})$	$P_{\text{Standby,DC}}\ (SOC_{min})$
$P_{\text{PERIPH,AC}}$	$P_{\text{PERIPH,AC}}$	$P_{\text{PERIPH,AC}}$
Control properties		
$\bar{\bar{P}}_{\text{GRID (Import, charging)}}$ $\bar{\bar{P}}_{\text{GRID (export, charging)}}$ $\bar{\bar{P}}_{\text{GRID (Import, discharging)}}$ $\bar{\bar{P}}_{\text{GRID (export, discharging)}}$	$\bar{\bar{P}}_{\text{GRID (Import, charging)}}$ $\bar{\bar{P}}_{\text{GRID (export, charging)}}$ $\bar{\bar{P}}_{\text{GRID (Import, discharging)}}$ $\bar{\bar{P}}_{\text{GRID (export, discharging)}}$	$\bar{\bar{P}}_{\text{GRID (Import, charging)}}$ $\bar{\bar{P}}_{\text{GRID (export, charging)}}$ $\bar{\bar{P}}_{\text{GRID (Import, discharging)}}$ $\bar{\bar{P}}_{\text{GRID (export, discharging)}}$
$\bar{t}_{\text{T}}$, $\bar{t}_{\text{E}}$	$\bar{t}_{\text{T}}$, $\bar{t}_{\text{E}}$	$\bar{t}_{\text{T}}$, $\bar{t}_{\text{E}}$
Application-independent characteristics		
No details	$\bar{\eta}_{\text{PV2AC,t}}$	$\bar{\eta}_{\text{PV2AC,t}}$
$\bar{\eta}_{\text{BAT2AC}}$	$\bar{\eta}_{\text{BAT2AC}}$	$\bar{\eta}_{\text{BAT2AC}}$
No details	No details	$\bar{\eta}_{\text{BAT2PV}}$
No details	$\bar{\eta}_{\text{PV2BAT,t}}$	$\bar{\eta}_{\text{PV2BAT,t}}$
$\bar{\eta}_{\text{AC2BAT}}$	$\bar{\eta}_{\text{AC2BAT}}$	No details
$\eta_{\text{BAT,RTE}}$	$\eta_{\text{BAT,RTE}}$	$\eta_{\text{BAT,RTE}}$
$\bar{t}_{\text{E}}$	$\bar{t}_{\text{E}}$	$\bar{t}_{\text{E}}$
$P_{\text{System}}\ (SOC_{min})$	$P_{\text{System}}\ (SOC_{min})$	$P_{\text{System}}\ (SOC_{min})$

[1] If listed, specify the PV inverter used. The value may vary if other PV inverters are used.

Example of an AC-coupled system with an integrated storage

Characterisation of the PV storage system						
	PV2AC	PV2BAT	AC2BAT	BAT	BAT2AC	BAT2PV
Energy conversion pathways	missing[1]	--	✓	✓	✓	--

Unless otherwise indicated, all information is based on the “Efficiency Guideline for PV Storage Systems 2.0”.

AC connection		
Nominal charging power (AC)	2,500	W
Nominal discharge power (AC)[2]	2,500	W
Battery connection		
Battery input voltage[3]	30 / 48 / 60	V
Nominal charging power (DC)[4]	2,325	W
Nominal discharge power (DC)	2,600	W
Battery		
Battery voltage[3]	40 / 48 / 52	V
Usable battery capacity (DC)[5]	5.0	kWh
Battery efficiency[5]	94.0	%
Power consumption of the BMS in standby mode	5	W
Standby losses		
Power consumption in the fully charged state (AC / DC)	10 / 2	W
Power consumption in the fully discharged state (AC / DC)	5 / 1	W
Power consumption of the other system components (AC)	2	W
Control characteristics of the power conversion system		
Average stationary deviation of the charging power (Import / export)	12 / 1	W
Average stationary deviation of the discharge power (Import / export)	14 / 3	W
Average dead time	2	s
Average settling time	10	s

Efficiencies of the energy conversion pathways

Pathway	Average voltage		normalised output power							
	PV	Battery	0.05	0.1	0.2	0.25	0.3	0.5	0.75	1
AC2BAT	-	50 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
BAT2AC	-	48 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%

Application-independent characteristics		
Average AC2BAT conversion efficiency[6]	93.2	%
Average BAT2AC conversion efficiency[6]	92.8	%
Battery efficiency[5]	94	%
Average settling time	10	s
System consumption in standby mode	8	W

[1] Is not part of the product but is required for a functional overall system.
[2] Rated output power BAT2AC
[3] Minimum / nominal / maximum voltage
[4] Rated output power AC2BAT
[5] Average value of the measurements at 100%, 50% and 25% of the nominal charge/discharge power.
[6] Average value of the efficiency at the ten equally distributed supporting points between 5% and 95% of the nominal power.

Example of a DC-coupled system with an integrated storage

Characterisation of the PV storage system	PV2AC	PV2BAT	AC2BAT	BAT	BAT2AC	BAT2PV
Energy conversion pathways	✓	✓	--	✓	✓	--

Unless otherwise indicated, all information is based on the "Efficiency Guideline for PV Storage Systems 2.0".

PV connection		
Rated PV input power	5,000	W
PV input voltage[1]	200 / 350 / 500	V
MPP voltage[2]	250 / 450	V
AC connection		
Rated PV output power[3]	4,600	W
Nominal discharge power (AC)	3,000	W
Battery connection		
Battery input voltage[1]	35 / 48 / 60	V
Nominal charging power (DC)[4]	3,300	W
Nominal discharge power (DC)[5]	3,300	W
Battery		
Battery voltage[1]	40 / 48 / 52	V
Usable battery capacity[6]	5.0	kWh
Battery efficiency[6]	94.0	%
Power consumption of the BMS in standby mode	5	W
Standby losses		
Standby power consumption in the fully charged state (DC)	2	W
Standby power consumption in the fully discharged state (AC / DC)	5 / 1	W
Power consumption of the other system components (AC)	2	W
Control properties		
Average stationary deviation of the charging power (Import / export)	12 / 1	W
Average stationary deviation of the discharge power (Import / export)	14 / 3	W
Average dead time	2	s
Average settling time	10	s

Efficiencies of the energy conversion pathways

Pathway	Average voltage		normalised output power							
	PV	Battery	0.05	0.1	0.2	0.25	0.3	0.5	0.75	1
PV2AC	200 V (min.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2AC	350 V (nom.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2AC	500 V (max.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	200 V (min.)	52 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	350 V (nom.)	52 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	500 V (max.)	52 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
BAT2AC	-	48 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%

Application-independent characteristics		
Average PV2AC conversion efficiency[7]	94.1	%
Average PV2BAT conversion efficiency[7]	93.2	%
Average BAT2AC conversion efficiency[7]	92.8	%
Battery efficiency[6]	94	%
Average settling time	10	s
System consumption in standby mode	8	W

[1] Minimum / nominal / maximum voltage
[2] Minimum / maximum voltage
[3] Rated output power PV2AC
[4] Rated output power PV2BAT
[5] Rated output power BAT2AC
[6] Average value of the measurements at 100%, 50% and 25% of the nominal charge/discharge power.
[7] Average value of the efficiency at the ten equally distributed supporting points between 5% and 95% of the nominal power.

Example of an PV generator-coupled system with an integrated storage

Characterisation of the PV storage system						
	PV2AC	PV2BAT	AC2BAT	BAT	BAT2AC	BAT2PV
Energy conversion pathways	✓[1]	✓	--	✓	--	✓

Unless otherwise indicated, all information is based on the "Efficiency Guideline for PV Storage Systems 2.0".

PV connection		
Rated PV input power	5,000	W
PV input voltage[2]	200 / 350 / 500	V
MPP voltage[3]	250 / 450	V
AC connection		
Rated PV output power[4]	4,600	W
Nominal discharge power (AC)[5]	1,900	W
Battery connection		
Battery input voltage[2]	40 / 120 / 220	V
Nominal charging power (DC)[6]	2,000	W
Nominal discharge power (DC)[7]	2,000	W
Battery		
Battery voltage[2]	50 / 60 / 70	V
Usable battery capacity[8]	5.0	kWh
Battery efficiency[8]	94.0	%
Power consumption of the BMS in standby mode	7	W
Standby losses		
Standby power consumption in the fully charged state (DC)	2	W
Standby power consumption in the discharged state (DC)	1	W
Power consumption of the other system components (AC)	2	W
Control properties		
Average stationary deviation of the charging power (Import / export)	12 / 1	W
Average stationary deviation of the discharge power (Import / export)	14 / 3	W
Average dead time	2	s
Average settling time	10	s

Efficiencies of the energy conversion pathways

Pathway	Average voltage		normalised output power							
	PV	Battery	0.05	0.1	0.2	0.25	0.3	0.5	0.75	1
PV2AC	200 V (min.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2AC	350 V (nom.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2AC	500 V (max.)	-	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	200 V (min.)	65 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	350 V (nom.)	65 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
PV2BAT	500 V (max.)	65 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
BAT2PV	-	60 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%
BAT2AC	-	60 V	80.4%	85.6%	90.2%	92.1%	93.2%	95.4%	95.6%	95.5%

[1] Is not part of the product but is required for a functional overall system.
[2] Minimum / nominal / maximum voltage
[3] Minimum / maximum voltage
[4] Rated output power PV2AC
[5] Rated output power BAT2AC
[6] Rated output power PV2BAT
[7] Rated output power BAT2PV
[8] Average value of the measurements at 100%, 50% and 25% of the nominal charge/discharge power.

Application-independent characteristics		
Average PV2AC conversion efficiency[1]	94.1	%
Average PV2BAT conversion efficiency[1]	93.2	%
Average BAT2PV conversion efficiency[1]	95.3	%
Average BAT2AC conversion efficiency[1]	92.8	%
Battery efficiency[8]	94	%
Average settling time	10	s
System consumption in standby mode	8	W

Example for one battery

Characterisation of the PV storage system						
	PV2AC	PV2BAT	AC2BAT	BAT	BAT2AC	BAT2PV
Energy conversion pathways	--	--	--	✓	--	--

Unless otherwise indicated, all information is based on the "Efficiency Guideline for PV Storage Systems 2.0".

Battery		
Nominal charging power (DC)	3,000	W
Nominal discharge power (DC)	3,000	W
Battery voltage[2]	38 / 48 / 58	V
Usable battery capacity[3,4]	5.0	kWh
Battery efficiency[3]	94.0	%
Power consumption of the BMS in standby mode	5	W
Application-independent characteristics		
Battery efficiency[3]	94	%

[1] Average value of the efficiency at the ten equally distributed supporting points between 5% and 95% of the nominal power.
[2] Minimum / nominal / maximum voltage
[3] Average value of the measurements at 100%, 50% and 25% of the nominal charge/discharge power.
[4]The usable battery capacity depends on the system's control settings and may vary depending on the inverter.