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Towards Reproducible Performance of Grid Connected Photovoltaic Battery Storage

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***Abstract*— Several attempts have been made to define and measure performance parameters of photovoltaic home storage systems. Ideally, performance parameters are accepted by the scientific community as well as by manufacturers, test laboratories and customers. The German industry association for energy storage (BVES) filed guidelines for performance evaluation in cooperation with research institutions and manufacturers. However, most storage systems are tested only once and in one test lab, so reproducibility cannot be taken for granted. In addition, the current version of the standardized report on performance parameters does not consider measurement uncertainty, which may lead to misleading interpretations of the relative performance of different storage systems. Performance parameter deviations between different storage systems are not huge, at least for some parameters. [1] In our work, conversion efficiencies of all system paths have been measured in the SOLARWATT Innovation laboratory and for the same generator coupled storage system at an independent research institution. Here, three photovoltaic generator voltage levels between 285 V and 640 V as well as three battery voltage levels between 107 V and 151 V were measured in both laboratories. Resulting charge and discharge efficiencies were also evaluated for a storage capacity of 2.4 kWh as well as a storage capacity of 7.2 kWh. Measurement uncertainty was calculated in reference to absolute conversion pathway efficiency as defined in the guidelines for performance evaluation. For direct AC usage of photovoltaic generation or grid feed in a maximum efficiency of 97.56±1.66% was measured at maximum MPP voltage and nominal power. For photovoltaic battery charge (i.e. DC usage) a maximum efficiency of 95.04±0.28% was found at nominal MPP voltage and half nominal power. The authors recommend including measurement uncertainty evaluations into an updated version of the guideline for performance evaluation of photovoltaic home storage systems. This way, scientific evaluation of storage systems will become more transparent.**

Keywords*— *performance, efficiency, measurement uncertainty, reproducibility

I. INTRODUCTION

The price for lithium-ion batteries has decreased over the past years, while the efficiency has increased. [2] 200,000 residential photovoltaic (PV) home storage systems were installed in Germany at the beginning of 2020 and experts expect a continuous increase of installations over the next few years. [3] [4] In 2017 the BVES filed the first guideline to evaluate the performance of home storage systems called ‘Efficiency Guideline for PV storage systems’ (Efficiency Guideline). [5] The document was developed in a joint working group of manufacturers, test facilities, and scientists in order to ensure more transparency and comparability between all systems in the market. The evaluation and calculation of the information in data sheets are now examined according to the given boundaries and methods stated in this Efficiency Guideline. The test facilities and also the product developer generates a better understanding of the entire system, the battery in collaboration with an inverter, the PV-emulator, the load-emulator and the grid. It facilitates potential customers to compare available storage systems and the resulting parameters can also be used as input sets for simulations, e.g., the System Performance Index (SPI) calculation from the HTW Berlin. Currently, the Efficiency Guideline does not include measurement uncertainties. The investigations presented in this paper support the inclusion of these uncertainties and a calculation method for the deviation of the efficiencies. If graphs are included in the final report of a system, the layout of the graphs should also be defined in the Guideline.

Two similar systems of the SOLARWATT MyReserveMatrix, each with three connected battery packs were measured according to the Efficiency Guideline at the Karlsruhe Institute of Technology (KIT) in 2017 and at SOLARWATT Innovation (SWI) Hürth in 2020. The results were compared and for all measurements performed at SWI the efficiency deviations were determined. The authors derive recommendations that may serve during the process of integrating the Efficiency Guideline into a technical Standard.

II. CURRENT STATUS OF EFFICIENCY GUIDELINE

During the operation of every PV home storage system losses occur. These losses usually depend on control, power conversion, or dimensioning issues, they can also result from energy management or standby power consumption. The main objective of the Efficiency Guideline is to provide a common set of methods for making those losses comparable. It provides the procedures to measure and calculate the efficiencies for power pathways and battery, standby consumption, and control deviations. All test-procedures specify test conditions for the start and the duration of the test. Here, the state of charge for the battery is defined, as well as the target power profiles at the PV-and load-emulator. For most tests either the PV-emulator is generating power, or the load-emulator is giving a certain power-request to achieve the required power at the dedicated measurement points, according to option A (page 19) in the Efficiency Guideline [5].

All PV home storage systems can be classified into three topologies: AC-coupled, DC-coupled and PV generator coupled. The outlines of the defined topologies in the Efficiency Guideline are shown below in the three figures (1-3). The main difference between the topologies is the connection point of the PV storage system to the surrounding system of the PV-emulator, the load-emulator, the inverter and the grid. As shown in figureFig. *1* the AC-coupled PV storage system is connected between the PV-inverter and the load-emulator. This type of PV storage system is connected with alternating current, has its own inverter and is therefore independent of the any current providing source.

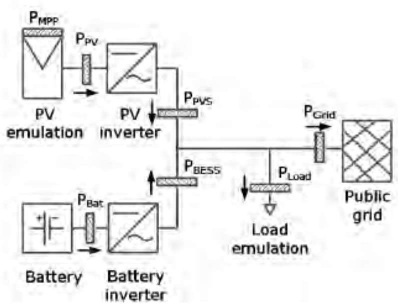

Fig. 1. AC-coupled system

A DC-coupled PV storage system is shown in figureFig. *2*. The storage system itself includes the components: Battery, MPP-Tracker, Battery-converter, and Inverter. It is therefore connected between the PV-emulator and the load. There is no additional PV-Inverter needed in this topology.

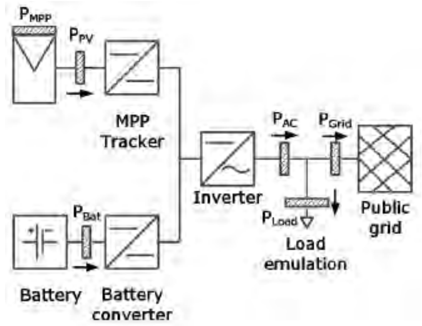

Fig. 2. DC-coupled system

The third topology is shown in figure Fig. *3*. In contrary to the topologies above PV generator-coupled systems are connected between the PV-emulator and the PV-inverter. The PV home storage system "MyReserveMatrix from SOLARWATT" considered in this work is a PV generator-coupled system, therefore figure Fig. *3* is marked orange.

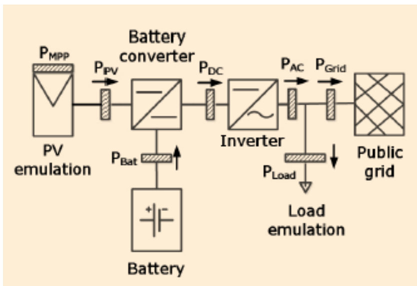

Fig. 3. PV generator-coupled system

The figures above include all the measurement points and the direction of the arrows indicate positive measurement values. The four defined conversion pathways of the considered PV generator-coupled system are PV2AC, PV2BAT, BAT2PV and BAT2AC. The paper focuses on these four efficiency pathways and their uncertainties. During the tests a charging of the battery from the grid is not considered. As electricity tariffs per kWh exceed the revenues for PV feed-in (in Germany) this power flow is mostly avoided by the system control.

III. METHODOLOGY

The energy conversion pathway PV2AC quantifies the efficiency of the direct grid-feed-in of PV power. As a result, the efficiency of the PV-inverter is calculated in this investigation. The storage system needs to be fully charged in order not to influence the measurements. For the measurements analyzed in this paper the used PV-inverter at SWI was a PIKO 4.6 from Kostal. The pathway PV2BAT describes the efficiency for battery charging operation. For all measurements presented here the MyReserveMatrix was operated with three battery packs. The test conditions for battery charging and discharging require a state of charge of around 50%. The pathways for battery discharging are called BAT2PV (only for PV generator-coupled systems) and BAT2AC. Both pathways differ concerning their measurement points. While for BAT2PV power is measured at the DC-input of the PV-inverter, it is measured at its AC-output for BAT2AC. As a result, the pathway BAT2AC, also includes a DC/AC conversion and thus generally leads to lower efficiencies than BAT2PV. The required formulas for calculating the efficiency pathways are displayed below in formula 1 to 4. [5]

A. Pathway efficiencies

$$\eta_{PV2AC,conv} = \frac{\int_0^{t_M} P_{AC\,(Export)}(t)\cdot dt}{\int_0^{t_M}[\,P_{PVS,DC}(t)+P_{BAT\,(discharging)}(t)-P_{BAT\,(charging)}(t)]\cdot dt} \quad (1)$$

$$\eta_{PV2BAT,conv} = \frac{\int_0^{t_M} P_{BAT\,(charging)}(t)\cdot dt}{\int_0^{t_M}[\,P_{PVS,DC}(t)-P_{BESS\,(Export)}(t)]\cdot dt} \quad (2)$$

$$\eta_{BAT2PV} = \frac{\int_0^{t_M} P_{BESS\,(Export)}(t)\cdot dt}{\int_0^{t_M} P_{BAT\,(discharging)}(t)\cdot dt} \quad (3)$$

$$\eta_{BAT2AC} = \frac{\int_0^{t_M} P_{AC\,(Export)}(t)\cdot dt}{\int_0^{t_M} P_{BAT\,(discharging)}(t)\cdot dt} \quad (4)$$

All measurements are subjected to systematical and statistical deviations. The statistical deviation may be determined by repeating the same measurement several times and thus can be corrected if enough samples are available. Since most of the measurements are only performed once, it is not possible to specify these statistical deviations in many cases. Thus, mainly the systematical deviations are considered in this paper, which are here calculated by summing up the absolute value of the partial derivation of each variable and multiplied by its respective deviation. Below a simplification of the above stated calculation is shown.

$$\Delta\eta = \sum \begin{matrix} absolute\ of\ all\ partial\ derivations\ of\ P_{AC},\ U_{DC},\ I_{DC} \\ multiplied\ with\ the\ respective\ deviation \end{matrix}$$

By applying the simplified formula above to the pathway efficiencies (shown in formula 1 to 4), the efficiency deviation for all pathways may be calculated (see below formula 5 to 8).

$$\Delta\eta_{PV2AC,conv} = \quad (5)$$

$$\left|\frac{100}{I_{PVS,DC}U_{PVS,DC}+I_{BAT}U_{BAT}}\,\Delta P_{AC}\right| + \left|\frac{P_{AC}*100*U_{PVS,DC}}{\left(I_{PVS,DC}U_{PVS,DC}+I_{BAT}U_{BAT}\right)^2}\,\Delta I_{PVS,DC}\right| + \left|\frac{P_{AC}*100*I_{PVS,DC}}{\left(I_{PVS,DC}U_{PVS,DC}+I_{BAT}U_{BAT}\right)^2}\,\Delta U_{PVS,DC}\right| + \left|\frac{P_{AC}*100*U_{BAT}}{\left(I_{PVS,DC}U_{PVS,DC}+I_{BAT}U_{BAT}\right)^2}\,\Delta I_{BAT}\right| + \left|\frac{P_{AC}*100*I_{BAT}}{(I_{PVS,DC}U_{PVS,DC}+I_{BAT}U_{BAT})^2}\,\Delta U_{BAT}\right|$$

$$\Delta\eta_{PV2BAT,conv} = \left|\frac{100*\,U_{BAT}}{I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS}}\,\Delta I_{BAT}\right| + \left|\frac{100*\,I_{BAT}}{I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS}}\,\Delta U_{BAT}\right| + \left|\frac{U_{BAT}*\,I_{BAT}*100*U_{PVS,DC}}{\left(I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS}\right)^2}\,\Delta I_{PVS,DC}\right| + \left|\frac{U_{BAT}*\,I_{BAT}*100*I_{PVS,DC}}{\left(I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS}\right)^2}\,\Delta U_{PVS,DC}\right| + \left|\frac{U_{BAT}*\,I_{BAT}*100*U_{BESS}}{\left(I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS}\right)^2}\,\Delta I_{BESS}\right| + \left|\frac{U_{BAT}*\,I_{BAT}*100*I_{BESS}}{(I_{PVS,DC}U_{PVS,DC}-I_{BESS}U_{BESS})^2}\,\Delta U_{BESS}\right| \quad (6)$$

$$\Delta\eta_{BAT2PV} = \left|\frac{100*\,U_{BESS}}{I_{BAT}U_{BAT}}\,\Delta I_{BESS}\right| + \left|\frac{100*\,I_{BESS}}{I_{BAT}U_{BAT}}\,\Delta U_{BESS}\right| + \left|\frac{U_{BESS}*\,I_{BESS}*100}{(I_{BAT})^2\,U_{BAT}}\,\Delta I_{BAT}\right| + \left|\frac{U_{BESS}*\,I_{BESS}*100}{(U_{BAT})^2\,I_{BAT}}\,\Delta U_{BAT}\right| \quad (7)$$

$$\Delta\eta_{BAT2AC} = \left|\frac{100}{I_{BAT}U_{BAT}}\,\Delta P_{AC}\right| + \left|\frac{P_{AC}*100}{(I_{BAT})^2\,U_{BAT}}\,\Delta I_{BAT}\right| + \left|\frac{P_{AC}*100}{(U_{BAT})^2\,I_{BAT}}\,\Delta U_{BAT}\right| \quad (8)$$

As seen in the formulas above, the deviation is calculated differently for the DC and AC power. On the AC-side the overall power deviation is used, and, on the DC-side, the same deviation is used for the DC-current and -voltage. For simplicity reasons only the deviation of the measuring device or the current transducer is used, which ever value is worse. The used DC-measuring device has an "industrial deviation" of 0.05 % [6]. The DC-transducer on the other hand has a deviation of 0.1 %. The worst deviation of the measuring device and the transducer appears for the DC-current and DC-voltage: here the deviation is specified as 0.1 % (see table 1) each. The measuring deviation class for the AC power measuring device is class 1, which means at 5% of the rated current an error of 3% occurs, at 20% of the rated current an error of 1.5% and at 100% of the rated current an error of 1% occurs. Since the transducer has a better deviation class, the AC measuring device does have the worst deviation. For simplicity reasons it was decided to use a constant AC power deviation of 1.5% in the following investigations. Table 1 gives an overview for the deviations used.

TABLE I. DEVIATION OVERVIEW

Parameter	Value
Δ DC-Current [%]	0.1
Δ DC-Voltage [%]	0.1
Δ AC-Power [%]	1.5

IV. RESULTS

The overall deviation for the calculated efficiency of the pathways PV2BAT and BAT2PV are below 0.4%. Therefore, the graphs for those two pathways have error bars, which are not much bigger than the coloured measuring points. The calculated efficiencies for the pathways PV2AC and BAT2AC have a maximum deviation of 1,.66 %. All measurements have been performed according to the test conditions specified in the Efficiency Guideline. The configuration tested was a MyReserveMatrix connected with three battery modules. The efficiency for the four pathways (PV2AC, PV2BAT, BAT2PV and BAT2AC) were measured and calculated at full and partial loads at the given MPP-voltages (minimal 285 V, nominal 400 V and maximal 640 V). The entire report is available in the master thesis "Automated performance measurements on a PV storage system in compliance with the efficiency guidelines". [7] Only the graphs with the maximum efficiency for each pathway are shown below. As a different PV inverter was used for the measurements at KIT and the battery system is the focus of this study, the graph in figure 4 does only include the calculated efficiencies for the pathway PV2AC measured at SWI in Hürth.

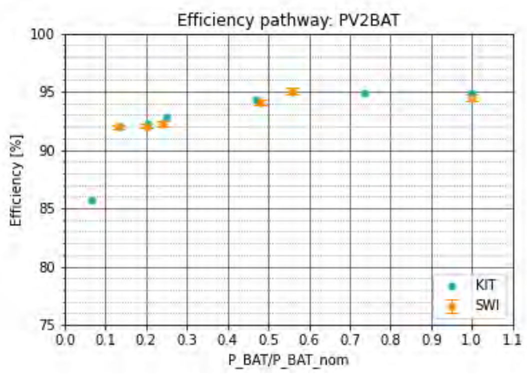

Fig. 4. Efficiency of the pathway PV2AC at maximum MPP-voltage with three connected batteries

The graph above includes the error bars calculated according to formula 5. The maximum deviation of 1.66% occurs at the highest efficiency, when the nominal power is applied. The efficiencies follow a typical efficiency curve of an PV-inverter. At lower power ratios, (i.e., smaller values on the x-axis), the efficiency drops rapidly. Below a ratio of 0.2, the efficiency drops from 95% down to about 88% at a ratio of 0.1 and then an additional 10% at a ratio of 0.05. Above a power ratio of 0.5, the efficiency of the PV-inverter stays around 97%.

In figure 5 the calculated efficiencies for the pathway PV2BAT (battery charging) are shown. The blue dots represent the resulting efficiencies from KIT and the orange dots the once from SWI. The error bars included for the SWI measurements were calculated to yield a deviation of a maximum of 0.28%. Mainly responsible for this is the small deviation of 0.1% for the DC-current and DC-voltage shown in table 1. For all power ratios above of 0.1, the largest difference between the calculated efficiencies is 0.54%. Again, the results follow the typical inverter efficiency curve as well. The efficiency for power ratios above 0.5 is between 94 and 95%.

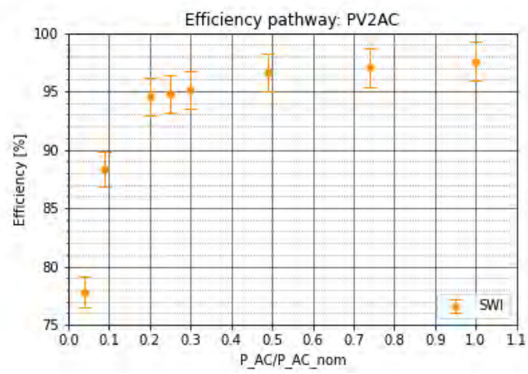

Fig. 5. Efficiency of the pathway PV2BAT at nominal MPP-voltage with three connected batteries

The highest efficiency for the pathway BAT2PV (battery discharging) has been measured at minimal MPP-voltage. Here, a main reason is the DC-DC-converter of the MyReserveMatrix. This converter performs best when the difference between the PV-voltage and the battery voltage is small. The calculated efficiencies for the KIT and SWI measurements are shown in figure 6 below. The discharging efficiency is about 3 % higher than the charging efficiency. Except for the efficiencies at full power, all results at SWI are a bit above the ones from KIT. The largest difference between the efficiencies is almost 4% and appears at the lowest power ratio of 0.05. For all power ratios above 0.1, the differences between the calculated efficiencies are less than one percent. The error bars for this pathway were also calculated to be 0.39% since the DC-measurement devices are so accurate.

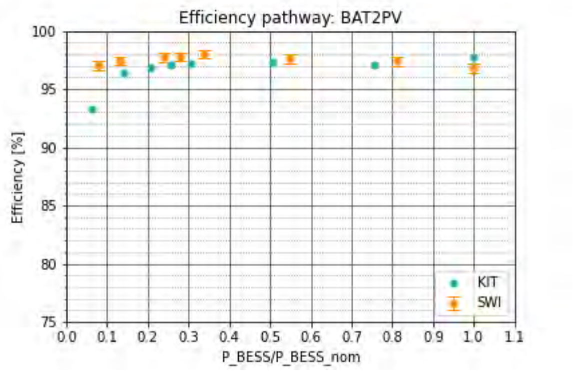

Fig. 6. Efficiency of the pathway BAT2PV at minimal MPP-voltage with three connected batteries

For the last pathway, BAT2AC, the efficiencies are shown in figure 7 below. This pathway includes the PV-inverter when calculating the efficiency of discharging the battery. As stated for the pathway PV2AC, the PV-inverter used at the KIT differs and therefore the efficiencies are not included in this graph. The error bars are larger and more noticeable, since the AC-measurement device is not as accurate as the DC-devices. The inverter reduces the discharge efficiency from 98 % to about 90%. The maximum deviation of 1.56% occurs at the highest efficiency, when the nominal power is applied.

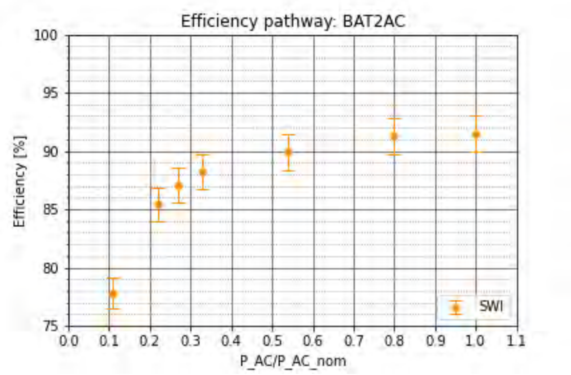

Fig. 7. Efficiency of the pathway BAT2AC at nominal MPP-voltage with three connected batteries

V. Discussion

As seen in figure 5 and 6 the results measured at KIT and SWI are similar. Since the difference between the two results are below one percent for all measurement points above a power ratio of 0.1, the results appear comparable and reproduceable. Unfortunately, the Efficiency Guideline does not state, which graphs should be plotted within a datasheet or a report and it does not include any guidance for indicating the uncertainty either. Sometimes not all power ratios exactly correspond to the step profile in the Guideline (figure 5, page 25 of the Efficiency Guideline), (e. g. in figure 5 for the efficiency at a power ratio of 0.55, which should be at 0.75 according to the Guideline). The maximum power depends on the determined rated power for the pathway according to appendix C of the Efficiency Guideline. [5] As seen in figure 5 not all steps can be met, therefore interpolation between the measured points becomes necessary. A method for interpolation is currently not specified in the Efficiency Guideline, it needs to be included in future when a transfer of the Guideline to a technical Standard takes place.

The calculated efficiency sampling points may be connected in different ways in a graph to provide a better idea of the system behaviour. In figure 8 three options are shown to connect the measurement points of the pathway PV2BAT at nominal MPP-voltage.

Fig. 8. Three options for interpolation between measurement points at nominal MPP Voltage for the pathway PV2BAT

The orange colour indicates a linear connection between the efficiency sampling points including error bars. The maroon colour represents a quadratic spline over the efficiency points. For most points this function fits very well, but the bulge at a power ratio of 0.8 is due to the quadratic projection and does not represent the actual behaviour. The blue spline is generated by fitting the calculated losses at each measurement point with a quadratic curve. This may be used in the next step to derive an efficiency curve. It shows a smoother shape and probably indicates the efficiency for the battery charging the best, but it increases the efficiency at the points at a power ratio of 0.2 and 0.25 and decreases the efficiency of the point at 0.55. Therefore, the graphs above in figure 4 to 7 representing the results measured at SWI and KIT do not include any connections between the samples.

To calculate the efficiency for battery charging (pathway PV2BAT), the power at P_BAT is divided by the difference of P_PVS and P_BESS as stated in formula 2 and shown in figure 9 below. To get a better understanding of the calculated efficiency the mean power value at the measurement point P_BESS is essential. However, in table 22 (measurement results for the pathway PV2BAT) of the Guideline (page 29) [5] the power of P_BESS is not included. All tables for the pathway PV2BAT shown in the appendix do include the mean power of P_BESS. For a future

Standard the mean power at the measurement point P_BESS should be included in the overview table of the results for the pathway PV2BAT.

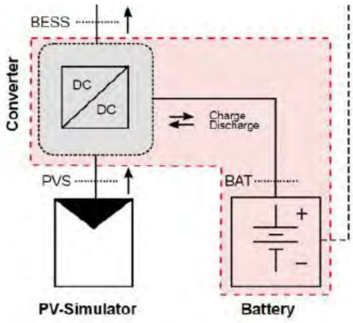

Fig. 9. Measurement points to calculate the efficiency for battery charging (PV2BAT) (figure 4, page 16 Efficiency Guideline) *[5]*

In the Guideline the state of charge for the battery is defined for all measurements. It is stated on page 20 of the Guideline that "An estimation is permissible if the battery charge level cannot be read via a communication interface". [5] For the MyReserveMatrix five LED at the bottom of the system indicate the state of charge of the battery. Unfortunately, this is not really accurate. The battery state can also be defined via the cell voltages of the used battery cells in a state of rest. According to the measured battery voltage the state of charge can be defined. The battery voltage can either be determined via the used test stand or via a data connection to the BMS within the system. In any case the testing laboratory needs to state exactly how they determined the state of charge of the battery.

VI. Conclusion and Outlook

For all measurement results presented in this paper, all test conditions in the Efficiency Guideline were followed and the pathway efficiencies were calculated accordingly. The measurement results at SWI and KIT are reasonable and comparable. The maximum difference for all power ratios above 0.1 is 1.07 %, when the battery is discharging at minimal MPP-Voltage. When the Guideline is updated to a technical Standard, the accuracy of the measurement devices should be used to calculate the deviation and should then be included as error bars into graphs. The Efficiency Guideline should specify the calculation of measurement deviations and which graphs should be present in a report or datasheet including error bars. If an interpolation between the sample points is necessary, it should also be defined. The mean power at the measurement point P_BESS should be included in the resulting overview table for battery charging (PV2BAT). The state of charge of the battery could potentially be determined using cell voltages in a state of rest, to increase accuracy.

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Appendix

Table 1: Resulting table according to the Efficiency Guidelines for the pathway PV2AC at maximum MPP with three connected battery packs

$P_{PVS,MPP}/P_{PV2AC,nom}$		0.05	0.10	0.20	0.25	0.30	0.50	0.75	1.00
$\eta_{PV2AC,t}$	%	77.00	87.44	93.57	93.80	94.20	95.63	96.08	96.59
$\eta_{PV2AC,MPPT}$	%	104.14	101.35	100.53	100.78	100.65	100.43	100.32	100.01
$\eta_{PV2AC,conv}$	%	77.78	88.33	94.52	94.74	95.15	96.60	97.05	97.56
$P_{PVS,MPP}$ *	W	184	369	799	983	1,167	1,905	2,888	3,871

$U_{PVS,DC}$ *	V	633.2	626.5	635.2	641.1	644.0	638.0	640.5	638.7
$P_{PVS,DC}$ *	W	192	374	803	991	1,175	1,913	2,897	3,871
P_{AC} *	W	149	330	759	939	1,118	1,848	2,812	3,776
P_{BAT} *	W	0	0	0	0	0	0	0	0
U_{BAT} *	V	150.5	150.6	149.9	150.5	150.5	150.5	150.5	150.2
$P_{AC}/P_{AC,nom}$	-	0.04	0.09	0.20	0.25	0.30	0.49	0.74	1.00
$P_{AC}/P_{AC,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\Delta\eta_{PV2AC,conv}$	%	1.33	1.50	1.62	1.61	1.62	1.64	1.65	1.66

All marked values with (*) represent the mean value over the measurement time.

$Deviation_{PV2AC}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
P_{AC} *	W	149	330	759	939	1,118	1,848	2,812	3,776
ΔP_{AC}	W	2	5	11	14	17	28	42	57
$I_{PVS,DC}$ *	A	0.3	0.6	1.3	1.5	1.8	3.0	4.5	6.0
$\Delta I_{PVS,DC}$	A	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0
$U_{PVS,DC}$ *	V	633.2	626.5	635.2	641.1	644.0	638.0	640.5	638.7
$\Delta U_{PVS,DC}$	V	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
I_{BAT} *	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ΔI_{BAT}	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U_{BAT} *	V	150.5	150.6	149.9	150.5	150.5	150.5	150.5	150.2

ΔU_{BAT}	V	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2

TABLE 2: DEVIATION-TABLE FOR THE PATHWAY PV2AC AT MAXIMUM MPP WITH THREE CONNECTED BATTERY PACKS

Deviation$_{PV2BAT}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
I_{BAT} *	A	0.0	0.1	1.9	3.0	3.5	7.0	8.2	14.6
ΔI_{BAT}	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U_{BAT} *	V	134.8	134.9	134.8	135.1	135.3	135.3	135.1	136.3
ΔU_{BAT}	V	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
$I_{PVS,DC}$ *	A	0.3	0.6	1.2	1.6	1.7	3.0	4.8	6.1
$\Delta I_{PVS,DC}$	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$U_{PVS,DC}$ *	V	399.0	288.0	387.0	397.0	421.0	408.0	283.0	402.0
$\Delta U_{PVS,DC}$	V	0.4	0.3	0.4	0.4	0.4	0.4	0.3	0.4
I_{BESS} *	A	-0.3	-0.6	-0.5	-0.5	-0.5	-0.5	-0.8	-0.9
ΔI_{BESS}	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U_{BESS} *	V	398.2	286.8	386.2	395.6	420.2	407.0	281.5	400.5
ΔU_{BESS}	V	0.4	0.3	0.4	0.4	0.4	0.4	0.3	0.4

TABLE 3: RESULTING TABLE ACCORDING TO THE EFFICIENCY GUIDELINES FOR THE PATHWAY PV2BAT AT NOMINAL MPP WITH THREE CONNECTED BATTERY PACKS

TABLE 4: DEVIATION-TABLE FOR THE PATHWAY PV2BAT AT NOMINAL MPP WITH THREE CONNECTED BATTERY PACKS

$P_{PVS,MPP}/P_{PV2BAT,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\eta_{PV2BAT,t}$	%	~~65.535~~	56.79	91.04	91.14	89.54	93.14	70.11	93.49
$\eta_{PV2BAT,MPPT}$	%	103.33	76.67	100.00	100.48	97.07	99.59	73.76	100.33
$\eta_{PV2BAT,conv}$	%	~~65.535~~	74.07	91.96	92.06	92.25	94.08	95.04	94.44
$P_{PVS,MPP}$ *	W	120	240	480	630	750	1,230	1,860	2,460
$U_{PVS,DC}$ *	V	399.0	288.0	387.0	397.0	421.0	408.0	283.0	402.0
$P_{PVS,DC}$ *	W	124	184	480	633	728	1,225	1,372	2,468
P_{BESS} *	W	124	157	194	192	212	212	202	364
$P_{AC\ (Import)}$	W	0	0	0	0	0	0	0	0
$P_{AC\ (Export)}$	W	9	106	148	146	166	167	146	316
P_{BAT} *	W	0	20	263	406	476	953	1,112	1,987
$P_{BAT}/P_{BAT,nom\ (Charging)}$ *	-	0.00	0.01	0.13	0.20	0.24	0.48	0.56	1.00
U_{BAT} *	V	134.8	134.9	134.8	135.1	135.3	135.3	135.1	136.3
$C_{BAT\ (Charding)}$	Ah	~~0.00~~	0.01	0.11	0.17	0.20	0.39	0.46	0.81
$C_{BAT\ (Charging)}/C_{BAT,use}$	%	~~0.00~~	0.02	0.22	0.33	0.39	0.78	0.91	1.62

$P_{NETZ\ (Import)}$ *	W	0	0	0	0	0	0	0	0
$P_{NETZ\ (Export)}$ *	W	1	68	131	130	150	150	123	300
$P_{BAT}/P_{BAT,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\Delta\eta_{PV2BAT,conv}$	%	0.00	0.02	0.16	0.20	0.20	0.27	0.28	0.28

TABLE 5: RESULTING TABLE ACCORDING TO THE EFFICIENCY GUIDELINES FOR THE PATHWAY BATPV AT MINIMAL MPP WITH THREE CONNECTED BATTERY PACKS

$Deviation_{BAT2AC}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
P_{AC} *	W	89	210	414	514	615	1,011	1,516	1,896
ΔP_{AC}	W	1	3	6	8	9	15	23	28
I_{BAT} *	A	-1.29	-2.06	-3.72	-4.43	-5.33	-8.58	-12.79	-15.93
ΔI_{BAT}	A	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02
U_{BAT} *	V	131.49	131.64	131.43	131.28	131.26	131.05	130.54	130.60
ΔU_{BAT}	V	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

TABLE 6: DEVIATION-TABLE FOR THE PATHWAY BAT2PV AT MINIMAL MPP WITH THREE CONNECTED BATTERY PACKS

$P_{LAST}/P_{BAT2PV,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2PV}	%	97.04	97.42	97.75	97.77	98.00	97.60	97.37	96.83
η_{BAT2AC}	%	52.71	77.58	84.63	88.39	87.80	89.84	90.73	91.13
$P_{LOAD,SET}$	W	101	202	403	504	605	1,008	1,512	2,016
P_{LAST} *	W	98	200	400	502	603	1,003	1,507	2,014
P_{BESS} *	W	164	264	478	569	686	1,098	1,627	2,014
$P_{BESS}/P_{BESS,nom}$ *	-	0.08	0.13	0.24	0.28	0.34	0.55	0.81	1.00
P_{AC} *	W	89	210	414	514	615	1,011	1,516	1,896
$P_{AC}/P_{AC,nom}$ *	-	0.05	0.11	0.22	0.27	0.32	0.53	0.80	1.00
P_{BAT} *	W	169	271	489	582	700	1,125	1,671	2,080
U_{BAT} *	V	131.5	131.6	131.4	131.3	131.3	131.0	130.5	130.6
$C_{BAT\ (Discharging)}$	Ah	0.07	0.11	0.21	0.25	0.30	0.48	0.71	0.88
$C_{BAT\ (Disch.)}/C_{BAT,use}$	%	0.14	0.23	0.41	0.49	0.59	0.95	1.42	1.77
$P_{NETZ\ (Import)}$ *	W	16	5	2	1	1	6	10	138
$P_{NETZ\ (Export)}$ *	W	0	0	0	0	0	0	0	0
$P_{BESS/AC}/P_{BESS/AC,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\Delta\eta_{BAT2PV}$	%	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39

TABLE 7: RESULTING TABLE ACCORDING TO THE EFFICIENCY GUIDELINES FOR THE PATHWAY BAT2AC AT NOMINAL MPP WITH THREE CONNECTED BATTERY PACKS

$Deviation_{BAT2AC}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
P_{AC} *	W	110	210	413	514	615	1,013	1,518	1,889
ΔP_{AC}	W	2	3	6	8	9	15	23	28
I_{BAT} *	A	-1.41	-2.04	-3.68	-4.49	-5.30	-8.58	-12.69	-15.76
ΔI_{BAT}	A	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02
U_{BAT} *	V	132.02	131.68	131.34	131.45	131.58	131.24	130.77	130.87
ΔU_{BAT}	V	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

TABLE 8: DEVIATION-TABLE FOR THE PATHWAY BAT2AC AT NOMINAL MPP WITH THREE CONNECTED BATTERY PACKS

$P_{LAST}/P_{BAT2PV,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
η_{BAT2PV}	%	96.26	96.30	96.49	96.79	97.13	96.98	96.57	96.08
η_{BAT2AC}	%	58.94	77.79	85.43	87.04	88.17	89.91	91.31	91.47
$P_{LOAD,SET}$	W	101	202	403	504	605	1,008	1,512	2,016
P_{LOAD} *	W	98	200	400	502	603	1,003	1,508	2,014
P_{BESS} *	W	180	260	467	572	678	1,093	1,605	1,984
$P_{BESS}/P_{BESS,nom}$ *	-	0.09	0.13	0.24	0.29	0.34	0.55	0.81	1.00
P_{AC} *	W	110	210	413	514	615	1,013	1,518	1,889
$P_{AC}/P_{AC,nom}$ *	-	0.06	0.11	0.22	0.27	0.33	0.54	0.80	1.00
P_{BAT} *	W	187	270	484	591	698	1,127	1,662	2,065
U_{BAT} *	V	132.0	131.7	131.3	131.4	131.6	131.2	130.8	130.9
$C_{BAT\ (Discharging)}$	Ah	0.08	0.11	0.20	0.25	0.29	0.48	0.70	0.88
$C_{BAT\ (Disch.)}/C_{BAT,use}$	%	0.16	0.23	0.41	0.50	0.59	0.95	1.41	1.75
$P_{NETZ\ (Import)}$ *	W	0	5	2	0	0	3	9	146
$P_{NETZ\ (Export)}$ *	W	3	0	0	0	0	0	0	0
$P_{BESS/AC}/P_{BESS/AC,nom}$		**0.05**	**0.10**	**0.20**	**0.25**	**0.30**	**0.50**	**0.75**	**1.00**
$\Delta\eta_{BAT2AC}$	%	1.00	1.33	1.46	1.48	1.50	1.53	1.55	1.56