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International Consistency of Validation Platform of PV-Battery Hybrid System Efficiency Testing

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All Authors/Partners **Dai Orihara**

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Table of contents

Abbreviations

AIT	*Austrian Institute of Technology*
AIST	*National Institute of Advanced Industrial Science and Technology*
BESS	*Battery Energy Storage System*
PV	*Photovoltaic generation*
PVS	*PV Simulator*
DuT	*Device under the Test*

Executive Summary

Installation of PV-battery systems is accelerated as PV owners are getting to be interested in self-consumption of PV generation for economic reason. Meanwhile, it becomes important to develop standardized methods for efficiency measurements. This project carries out round-robin testing between AIT and AIST according to the German efficiency guideline for PV storage systems. The round robin tests shall analyse the influence of the testing environment to the efficiency. The testing procedures are also evaluated from the aspect of reproducibility and if improvements can be made in future PV battery efficiency standards. Furthermore, uncertainty calculation of the efficiency measurement is seen important for reproducible results but not covered from the efficiency guideline. Hence, uncertainty calculations and the influence of accuracy of the test environment to the efficiency results is evaluated.

During the Transnational Access program, the efficiency measurement was carried out in the SmartEST laboratory of AIT. The device under test (DuT) is a PV-battery system, manufactured by TABUCHI ELECTRIC, which was shipped from AIST to AIT. Before and during testing at AIT the same tests were done at AIST with a second inverter, which is the same product. Within this work the measured efficiencies at AIT are compared then with the test results of AIST. As first conclusions it was seen that the accuracy of the AIST Photovoltaic Simulator (PVS) output and electrical load was low at low output power levels, the measured efficiency is largely different for this case at both institutes. The power noise injected from the PV simulator is larger than at AIT, and it also causes differences. This is because the nominal power of the AIST PV Simulator is quite large(300kW) compared with the power level in the testing(up to a few kW) and resolution was not high enough. The necessity of changing the PV simulator in the next testing at AIST.

Although almost all tests were carried out without major difficulties and the test procedures could be applied without problems, for the control speed test it was necessary to decrease the recommended sample time of 200ms to values below 100ms. It was the case, as the reaction time of the TABUCHI system was very fast. It was able to change its output power after changes of load power faster than 200ms. High frequency sampling is needed for this case to measure the dynamic behaviour. Beyond the tests of the efficiency guideline also additional tests were performed to evaluate the influence of several conditions as e.g. the AC voltage to the efficiency. Furthermore an interesting issue, not covered from the efficiency guideline is the inverter conversion efficiency for mixed power flow conditions e.g. that Photovoltaic power charges the battery and is simultaneously fed into the grid or Photovoltaic power and battery power supplies the electrical load simultaneously.

At last, the measurement uncertainty for the AIST testing environment was computed, considering elements causing dispersion of measured efficiency. It was clarified that accuracy of the efficiency measuring is high for the tests in which large amount of power is dealt with. However, for the test in which PVS and electrical load use small amount power, the uncertainty is very high and exceeds 10% in some cases. This is because the accuracy of PVS is low at low output level and sensitivity of the efficiency increases as the power level decreases. As a next step, uncertainty will be computed for the testing environment in AIT and compared with that of AIST to reveal more closely how the accuracy is different between testing environments.

1 General Information of the User Project

USER PROJECT PROPOSAL	
User Project acronym	ICVP
User Project title	**I**nternational **C**onsistency of **V**alidation **P**latform for PV - Battery Hybrid System efficiency testing
Host Infrastructure	AIT Austrian Institute of Technology: SmartEST
Main scientific/technical field	Laboratory testing,
Keywords (5 max., free text)	PV, Battery Energy Storage System (BESS), Efficiency, Validation, Standardization
Period	2020/02/03 ~ 2020/02/14
User Group Members	Dai Orihara

2 Research Motivation

Over the past few years, installations of Battery Energy Storage Systems (BESS) strongly enlarged especially in the residential sector. This is because large number of Photovoltaic (PV) generation owners are interested in self-consumption for their economic advantage. The owner of combined systems of PV and BESS (PV-battery system) can reduce the energy purchase by charging surplus PV-energy and discharging it to cover a lack of energy. Subsidy programs are also one of the reasons for the acceleration of the BESS installation.

The energy efficiency of the PV-battery system is one of the most important Key Performance Indexes (KPI) which affects the charge-discharge operating functions and/or modes e.g. peak shift, dynamic pricing, etc. However, there is no international standard to cover the efficiency of PV-battery systems, although IEC published standards for PV and BESS itself. In April 2017, the first version of a guideline for efficiency testing of PV-battery systems is issued in Germany. It provides testing procedures for determining the conversion efficiency of inverters, charge/discharge efficiency of the battery and the control system performance. A missing point in the efficiency guideline is the uncertainty of the measurements due to the testing environment.

2.1 Objectives

- Evaluation of the efficiency testing procedure described in the BSW/BVES guideline

  In general, for testing standards reproducible results are required. Therefore, the testing procedures in the BSW/BVES guideline are evaluated from a perspective of reproducibility. Since the efficiency of the PV-battery system depends on various elements in the testing environment, the dependency should be analyzed and considered in the procedures.

- Validation of the influence of measurement uncertainty on the test results

  All measurement devices have a measurement uncertainty which differs from each other. And power noise from power sources such as grid simulator, PV simulator and electrical load are also different among devices. Indeed, different testing environments provide to a certain level different testing results even if the DuT is identical. For fair comparison of the results gotten in different environments, the difference between the results needs to be able to be judged whether it comes from the uncertainty or not. This project aims to evaluate the difference of measurement uncertainties of AIT and AIST through the efficiency testing of the same type of PV-battery system and to look up for the cause of it to make recommendations for future standardization of PV battery efficiency testing.

2.2 Scope

Efficiency testing will be carried out according to the published guideline for evaluation of the testing procedures. The results are compared with AIST's ones gotten in testing of the same type of BESS for evaluating the measurement uncertainty.

The proposed project is expected to contribute to the development of international efficiency testing standards, including the determination and management of measurement uncertainties for accurate and reproducible test results.

3 State-of-the-Art/State-of-Technology

BESS Deployment

With the reduction of the PV system price, the cost of PV generated energy is declining as well as feed-in tariffs. This is a significant reason why the PV owners have interests in own consumption of PV-generated energy by using BESS [1]. In addition, many countries promote subsidy programs for BESS installations for spreading efficient use of green energy. The recently installed BESS capacity in 2018 is almost three times higher than in 2017 [2].

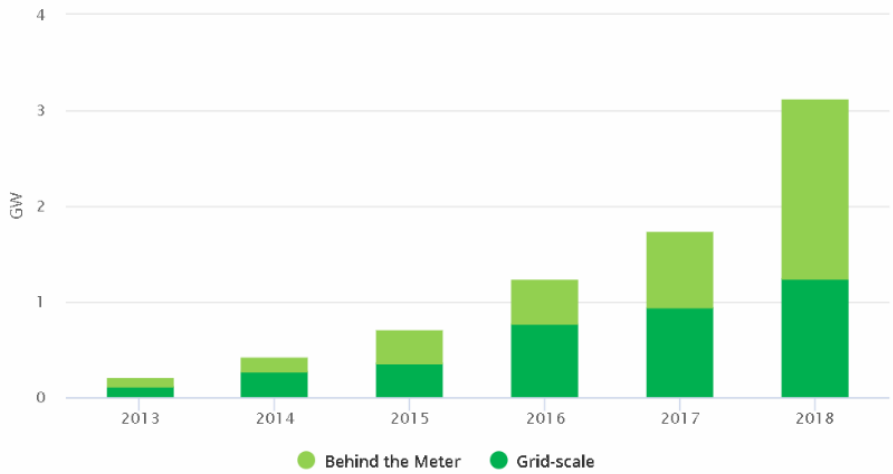

Figure 1 Annual storage deployment [2]

PV-Battery System Installation

The charging and discharging of the battery in PV-storage systems is controlled by the Energy Management System (EMS). It monitors the exchange power of the building with the grid, the PV generation and the SOC of BESS. Based on this it determines the charge/discharge power to reduce the power flow from and into the grid. When the PV generation is higher than the load demand, the EMS requests the battery to charge. If the PV generation is lower than the load demand, the battery covers the lack of power. Source [1][3] mentioned that installations of PV-battery systems are an attractive option from the economic perspective, compared with buying the entire electricity from the grid due to the transition to higher electricity retail prices and lower feed-in tariffs.

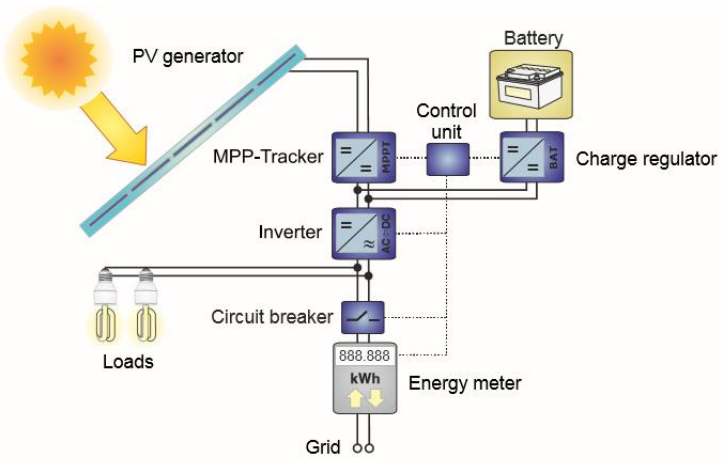

Figure 2 PV-storage system [3]

Efficiency Testing

Efficiency is one of the most important KPI of PV-battery systems. Energy losses in the system are: sizing loss, conversion loss, control loss, and standby loss [4]. The losses prevent efficient use of PV generated energy or increase the grid exchange power leading to economic losses of the owner. However, there is no international standard for efficiency testing even though IEC issued efficiency testing standard IEC 62933-2-1[5] for battery and IEC 61683[6] for PV. In Germany, BVES (German Energy Storage Association) and BSW-Solar (German Solar Association) published a guideline for efficiency testing of PV-battery systems in 2017[7] and 20 systems were already tested following the guideline [8]. The development of the guideline is done by mostly German research institutes as Fraunhofer IEE, KIT, RWTH Aachen and manufactures as SMA, Sonnen, Varta, Kostal etc. AIT was an active member in the development and delivered a first draft. A revised and updated version, at the first time also in English language is published in April 2019[9]. But uncertainty of the measurements is still an open issue in this version and not extensive enough considered in the German guideline. The German standardization working group DKE/AK 371.0.9 (Characteristic values of stationary battery storage systems) started recently their work with the aim to develop a possible future German standard for characteristic values of stationary storage systems with the focus on efficiency.

In order to develop an and international testing standard, evaluation of the testing procedure should be done widely in form of round-robin tests. For world-wide inspection of PV-battery system efficiency, consideration of uncertainty in the evaluation of testing results is necessary to be discussed.

4 Executed Tests and Experiments

4.1 Test Plan

The efficiency test for a PV-battery hybrid system was carried out for the battery-inverter set manufactured by TABUCHI ELECTRIC brought to AIT from AIST in Japan. Following the guideline issued by BVES and BSW Solar, the conversion efficiency test and control deviation test were done. Additionally, conversion efficiency in mixed power flow state was tested.

4.2 Standards, Procedures, and Methodology

The testing was carried out following the BSW/BVES efficiency test guideline for PV-battery systems.

4.2.1 Conversion efficiency test

In this test, the energy conversion efficiency of the inverter was measured under three types of power flow conditions; PV2AC, PV2BAT and BAT2AC. For each case, one element outputs power and another element absorb the power. For example, PV2AC means PV output power and grid or loads absorbs the power. For BAT2AC the electrical loads absorb the power. The test profile of the PVS and electrical load was given as shown in Figure 3. It has 8 power steps and the efficiency was computed for each step.

Additionally, this test was done under low AC voltage condition. This is because reduction of AC voltage occurs in rural area applicable for large scale PV system and the influence on the efficiency should be evaluated. The efficiency guideline also does not declare the AC voltage range in which the inverter has to be tested. This can lead to differences of the test in different test institutes, which are not using an AC simulator with a constant voltage but the utility grid as AC source with a varying voltage.

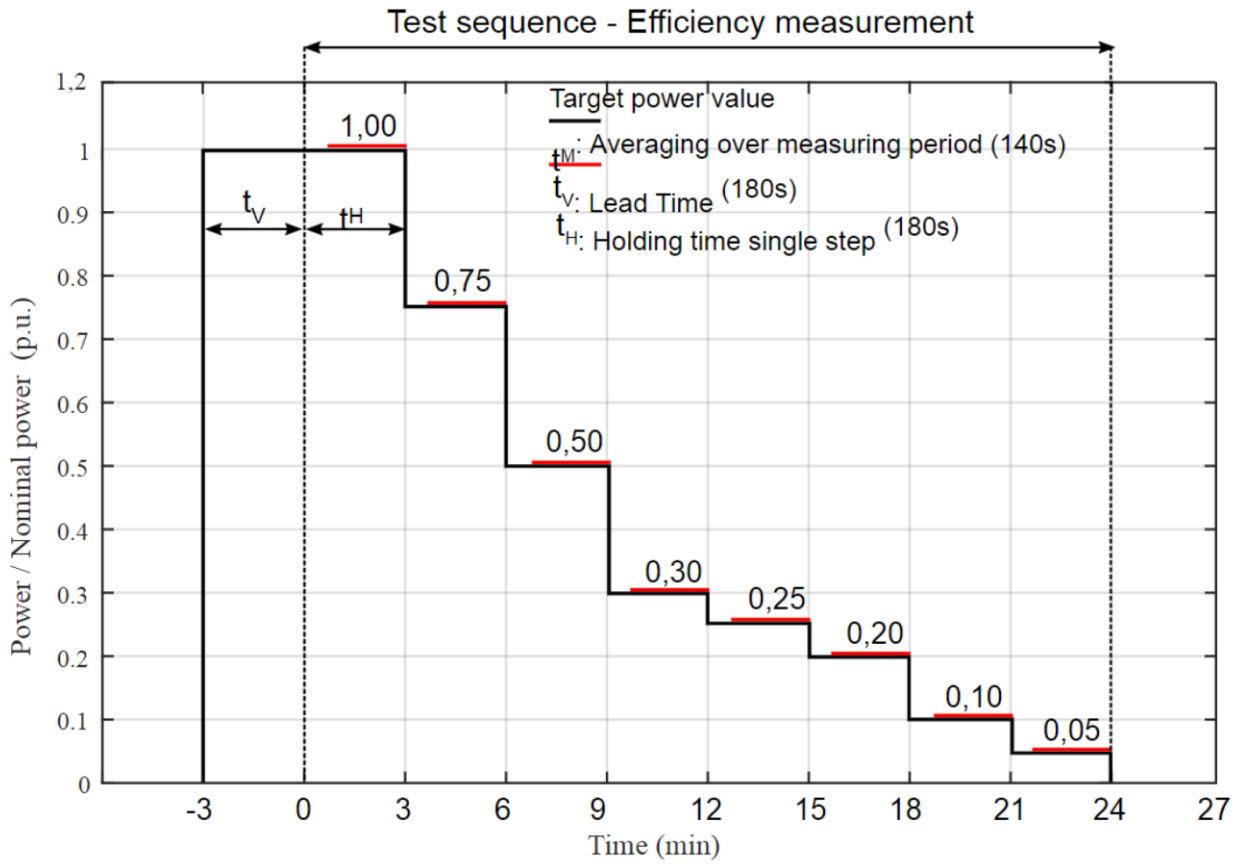

Figure 3 Profile of output of power of power source[8]

4.2.2 Control Deviation test

While the EMS controls the battery output to reduce energy exchange with the grid, measurement and control errors of the EMS cause an increase of the power exchange. The performance of the control system was divided into dynamic and stationary control performance, and measured respectively. The test profile of the PVS and electrical load was set as shown in Figure 4. In the dynamic control deviation test, the holding time of the steps was set to a short value and the transient behaviour after load changes was evaluated. In the stationary control deviation test, holding time was set to longer values (160 s) and power flow in steady state was evaluated.

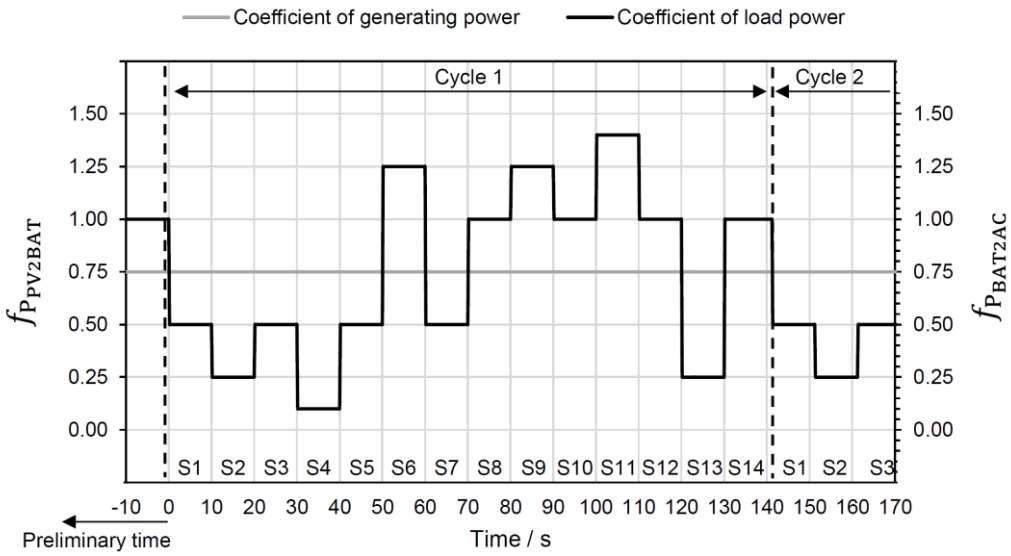

Figure 4 Profile of PVS and electrical load in control deviation test [8]

4.2.3 Conversion efficiency test in mixed power flow state(additional)[10]

The conversion efficiency test in the guideline does not include efficiency assessment under mixed power flow conditions. However, such a condition is expected to appear frequently during real operation in homes. It is assumed that loss-models in simulations based on such a test give a more accurate result than the standard efficiency curves for the main energy conversion paths alone. Hence, a profile of PVS and electrical load was developed that all available operational points were included as shown in Figure 5.

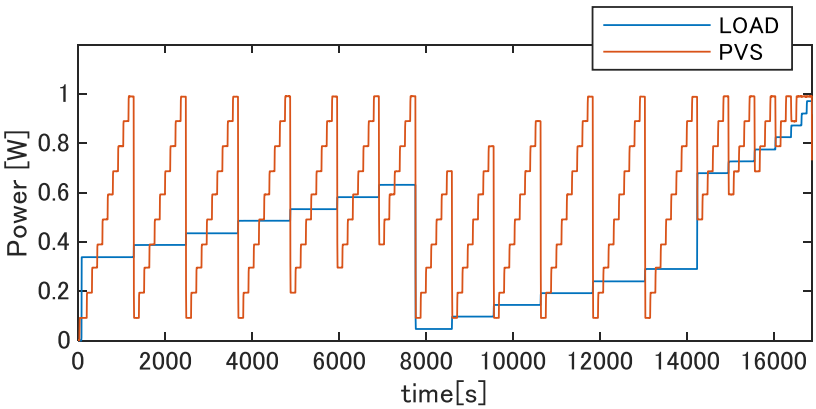

Figure 5 Generated test profile of the PVS- and electrical load output for the mixed power flow conversion efficiency test.

4.3 Test Set-up(s)

4.3.1 Configuration

The test bed is composed of (1)Battery-Inverter set, (2)PV simulator, (3)AC load, (4)Grid simulator and (5)DAQ system. Table 1 shows the detailed information of the equipment in both environments of AIT and AIST. The battery-inverter set used in AIT(DuT1) is the identical model as the one used in AIST(DuT2) but not the same device is used.

Table 1 Infrastructures in test bed

	AIT	AIST (Preliminary test)
Battery-Inverter set	TABUCHI ELECTRIC EIBS16GU - DuT1 - Model number is same as DuT2	TABUCHI ELECTRIC EIBS16GU - DuT2 - Model number is same as DuT1
Grid Simulator	TC.ACS Regatron - 3-phase 4-wire - 50kW	AMETEK MX30 - 3-phase 3 wire - 30kW
PV Simulator	AIT PVAS3 - 0-800V(output) - 0-32A(output) - Max. 12kW per string(output)	SanRex PV simulator - 0-1000V(output) - 0-750A(output) - Max. 300kW(output)
Load	AIT 3-phase load - 11kW (per phase)	KEISOKU GIKEN Ene-phant - 10kW
DAQ	PC: Dewetron DEWE-808 Software: Dewesoft measurement analysis software Voltage module: Dewetron DAQP-HV **Input ranges:** ±20 V, ±50 V, ±100 V, ±200 V, ±400 V, ±800 V, ±1400 V **Accuracy:** ±0.05 % of reading ±0.05 % of range (100V to 1400 V range) Current module: Dewetron DAQP-LA-B-S1 **Input ranges:** 2 mA, 6 mA, 20 mA, 60 mA, 200 mA, 0.6 A (5 Ohm Shunt integrated) **Accuracy:** ±0.05 % of reading ±0.05 % of range (for 20 mA to 600 mA range)	PC: EPSON Endeaver Pro5700 Software: WTViewerE Analyzer: Yokogawa WT3000 & WT3000E Voltage element **Input ranges:** ±15V, ±30V, ±60V, ±100V, ±150V, ±300V, ±600V, ±1000V **Accuracy:** ±0.01 % of reading ±0.03 % of range Current element **Input ranges:** ±50mV, ±100mV, ±200 mV, ±500 mV, ±1V, ±2V, ±5V, ±10V (2 Ohm Shunt is connected to the input terminal) **Accuracy:** ±0.01 % of reading ±0.03 % of range
Current Sensor	LEM Ultrastab IT-205S Primary current 200 A Secondary current 200mA Accuracy 0.01 %	GRID, AC, LOAD node: HIOKI 9660 Primary current 100 A Rate: 1 mV/A Accuracy: 0.3% of reading +0.02% of full scale BAT node: HIOKI CT6843 Primary current 200 A Rate: 0.01 V/A Accuracy: 0.3% of reading +0.01% of full scale PVS node: YOKOGAWA CT1000 Primary current 1000 A Secondary current 666.6mA Accuracy: 0.05% of reading +30μA

The test setup is shown in Figure 6. The inverter has two DC-side channels. One is for the battery and the other is for PV. The PV channel has 3 strings with independent MPPT function, and each string accept 2.5 kW input in maximum. In this test, one string was used. Because the inverter is for single-phase, AC load and grid simulator are used in single-phase (Split Phase system L1-N-L2). The EMS of the storage system measured exchanged power with the grid and control battery charging/discharging power so as to reduce electricity purchase. Since the battery output and PV output is merged on DC side, this configuration is called DC-coupled system (or DC coupled hybrid system).

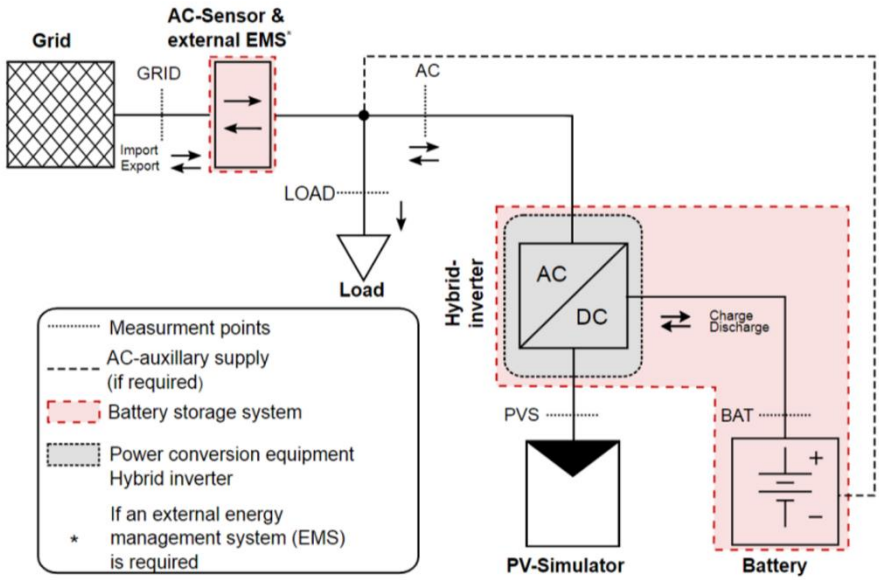

Figure 6: Set-up of test bed [9]

4.3.2 Battery Control

The PV-battery hybrid system has 4 control modes; (1)Peak Cut Mode, (2)Max Power Export Mode, (3)Economy Mode and (4)Home Backup Mode. The tested mode In this test is (3)Economy mode, in which the battery is controlled to reduce electricity purchases. When the load is larger than PVS output, the battery covers the difference by discharging unless all stored energy is discharged. And when the load is smaller than the PVS output, the excess is charged to the battery until the SOC reaches maximum value.

4.4 Data Management and Processing

Current and voltage is measured at 5 points as shown in Figure 6; GRID, LOAD, AC, PVS and BAT. Active power is computed from measured data and used for efficiency computation.

5 Results and Conclusions

5.1 Efficiency testing results

5.1.1 Rated power measurement

Before the actual efficiency measurement, the rated power is determined to confirm detailed spec of the device. The results are shown below.

Nominal power of PV2AC: 2486 W
Nominal power of PV2BAT: 1627 W
Nominal power of BAT2AC: 2019 W

5.1.2 Conversion Efficiency

a. PV2AC

Table 2 and Figure 7 show the static MPPT efficiency defined as (1) which means ratio of the energy drawn from the test object to the theoretical energy provided by the PV simulator at the Maximum Power Point (MPP) [9]. The energy is integrated over the measurement period t_M.

$$\eta_{MPPT} = \frac{\int_0^{t_M} P_{PVS,DC}(t)dt}{\int_0^{t_M} P_{PVS,MPP}(t)dt} \quad (1)$$

The efficiency was measured at 8 power levels for 3 MPP voltage levels, 235V(min), 380V(nom), 440(max). The PV output is changed stepwise, and the holding time of each step is 180s. Integration time for energy computation is at least 140s of each step to exclude transient behaviour. The result of the additional test done at low AC voltage (232V) is also shown in the table and the figure. MPPT efficiency was over 98% in almost all cases but the efficiency is reduced when MPP voltage is at its nominal value and the power level is high. This is because the MPP power had been set incorrectly at the PV simulator to a higher value than the nominal value of the inverter. Therefore, this value is not reliable and has to be excluded. If the unreliable data is excluded, it is found that there is no influence of AC voltage change on MPPT efficiency.

Table 2 Static MPPT efficiency in conversion efficiency test of PV2AC

AC voltage	MPP voltage	Power level for nominal power of PV2AC							
		5%	10%	20%	25%	30%	50%	75%	100%
Nominal (240V)	nom	99.0	99.8	99.9	99.9	99.9	99.9	99.9	87.6
	min	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
	max	99.6	99.7	99.6	99.9	99.9	99.9	99.9	99.8
Low (232V)	nom	99.3	99.7	99.9	99.9	99.9	99.9	99.9	95.3
	min	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
	max	99.6	99.8	99.8	99.9	99.9	99.9	99.9	98.9

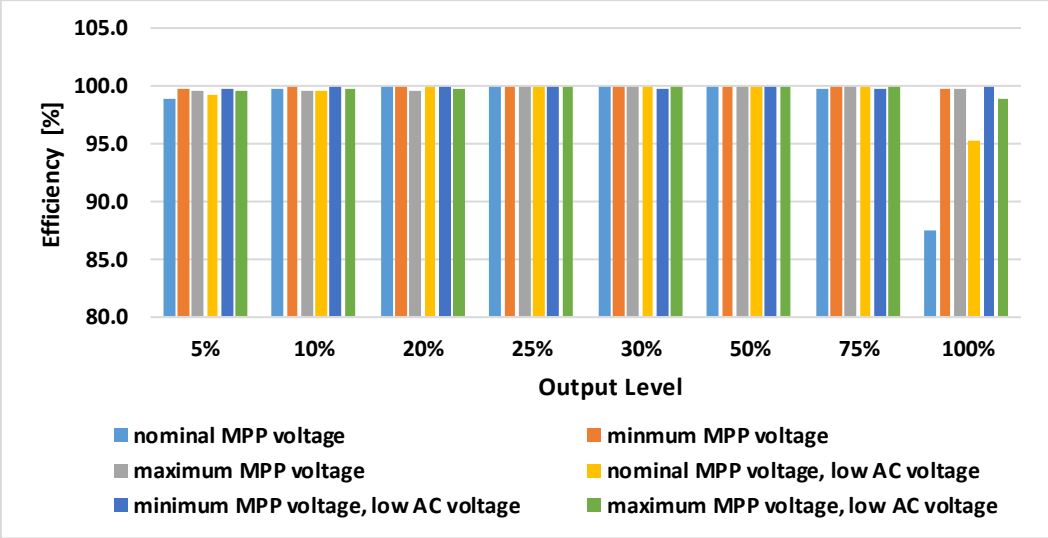

Figure 7 Static MPPT efficiency in conversion efficiency test of PV2AC

Efficiency of the converter is described as (2). Because the battery is fully charged in this test, the battery does not charge/discharge ideally. But actually, a small amount of power flows from/to battery, and so the battery output is considered in the efficiency computation.

$$\eta_{PV2AC,conv} = \frac{\int_0^{t_M} P_{AC(Export)}(t)dt}{\int_0^{t_M}\left[P_{PVS,DC}(t) - P_{BAT(Charging)}(t) + P_{BAT(Discharging)}(t)\right]dt} \quad (2)$$

Table 3 and figure 8 show the results of the efficiency computation. Efficiency is decreased as the power level decreases. At each power level, efficiency tends to be the highest when MPP voltage is set to nominal value. When AC voltage is set to minimum, the efficiency decreases especially at low power levels.

Table 3 Converter efficiency in conversion efficiency test of PV2AC

AC voltage	MPP voltage	Power level for nominal power of PV2AC							
		5%	10%	20%	25%	30%	50%	75%	100%
Nominal (240V)	nom	61.7	80.8	90.0	91.5	92.6	94.5	95.4	95.5
	min	56.4	78.0	88.3	90.1	91.4	93.6	94.6	94.9
	max	55.2	78.3	88.4	90.1	91.5	93.8	95.0	95.4
Low (232V)	nom	43.5	60.9	81.0	84.5	87.3	91.8	93.9	94.6
	min	40.2	61.4	80.9	84.3	87.1	91.5	93.5	94.1
	max	44.8	61.1	80.5	84.0	86.9	91.6	93.6	94.4

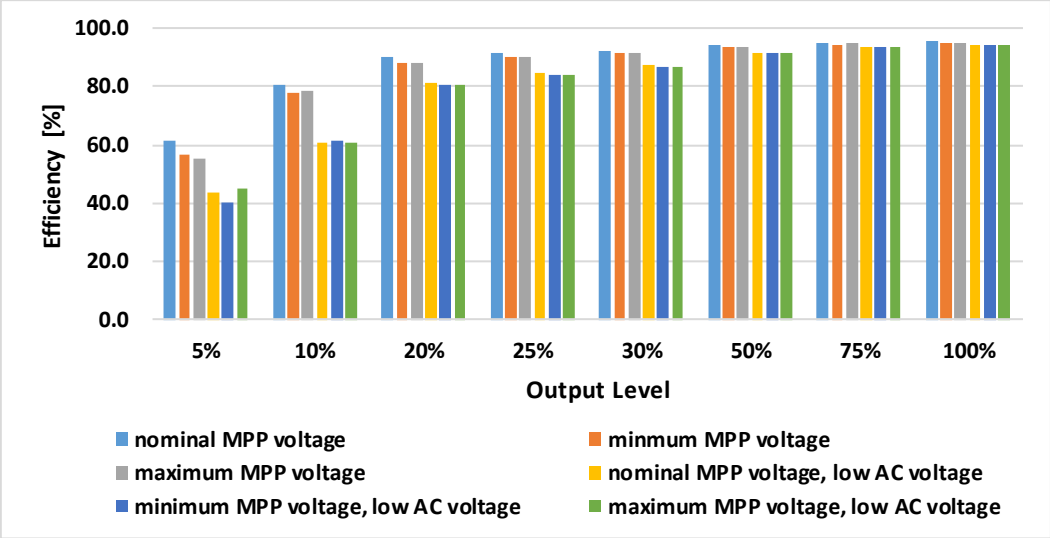

Figure 8 Converter efficiency in conversion efficiency test of PV2AC

Total efficiency of PV2AC is computed from MPPT efficiency and converter efficiency as shown in (3). The results are shown in Table 4 and figure 9. Since MPPT efficiency is so high, the characteristic of the total efficiency is almost same as converter efficiency.

$$\eta_{PV2AC,t} = \eta_{PV2AC,conv} \cdot \eta_{MPPT} \tag{4}$$

Table 4 Total efficiency in conversion efficiency test of PV2AC

AC voltage	MPP voltage	Power level for nominal power of PV2AC							
		5%	10%	20%	25%	30%	50%	75%	100%
Nominal (240V)	nom	61.0	80.6	89.9	91.4	92.5	94.4	95.3	83.6
	min	56.3	77.9	88.2	90.0	91.4	93.6	94.5	94.8
	max	55.0	78.1	88.0	90.0	91.4	93.8	94.9	95.2
Low (232V)	nom	44.6	61.0	80.3	83.9	86.8	91.5	93.6	93.4
	min	40.1	61.4	80.8	84.3	87.0	91.5	93.3	94.1
	max	43.2	60.7	81.0	84.4	87.3	91.8	93.8	90.2

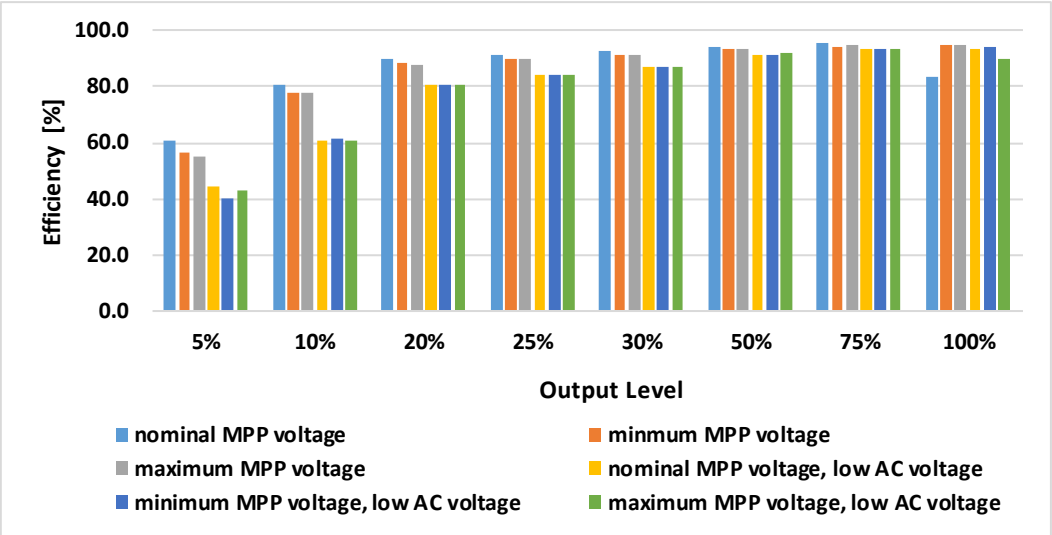

Figure 9 Total efficiency in conversion efficiency test of PV2AC

At last, the measured efficiency is compared with the result in AIST. Table 5 and figure 10 show the converter efficiency measured in AIT and AIST. The difference tends to increase as power level decreases. This is because the PVS at AIST has a low accuracy at low power output levels and tend to output higher power than the setting value as shown in Figure 11 while AIT PV simulator has high accuracy even in low output level as shown in Figure 12. This is because AIST PVS has a large capacity of 300kW and resolution is low in the range of 100 watts.

Table 5 Comparison of converter efficiency under PV2AC condition between AIT and AIST

	Power level for nominal power of PV2AC							
	5%	**10%**	**20%**	**25%**	**30%**	**50%**	**75%**	**100%**
AIT	61.7	80.8	90.0	91.5	92.6	94.5	95.4	95.5
AIST	71.2	89.5	91.0	94.1	94.4	97.6	94.5	95.1
Difference	-9.5	-8.7	-1.1	-2.6	-1.8	-3.1	0.9	0.4

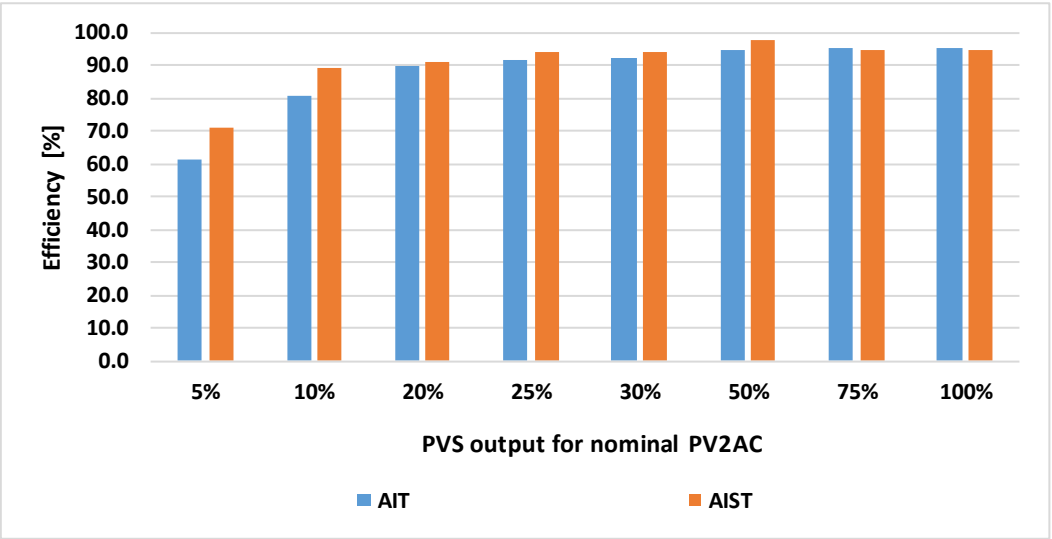

Figure 10 Comparison of converter efficiency under PV2AC condition between AIT and AIST

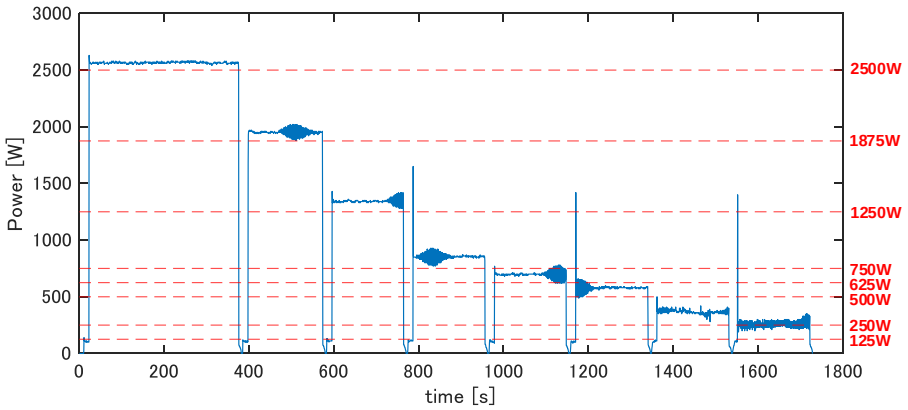

Figure 11 PVS output in conversion efficiency test of PV2AC in AIST

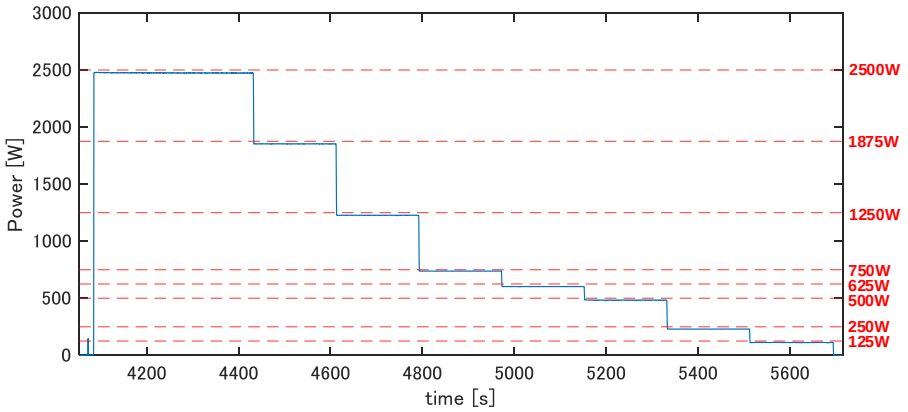

Figure 12 PVS output in conversion efficiency test of PV2AC in AIT

b. PV2BAT

Table 6 and figure 13 show the static MPPT efficiency. Although the efficiency slightly decreases as the PVS output decreases, the efficiency is always over 98.0%.

Table 6 Static MPPT efficiency in conversion efficiency test of PV2BAT

MPP Voltage	**Power level for nominal power of PV2BAT**							
	5%	**10%**	**20%**	**25%**	**30%**	**50%**	**75%**	**100%**
nominal	98.3	98.9	99.9	99.9	99.9	99.9	99.9	99.9
minimum	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
maximum	99.6	99.7	99.5	99.8	99.6	99.9	99.9	99.9

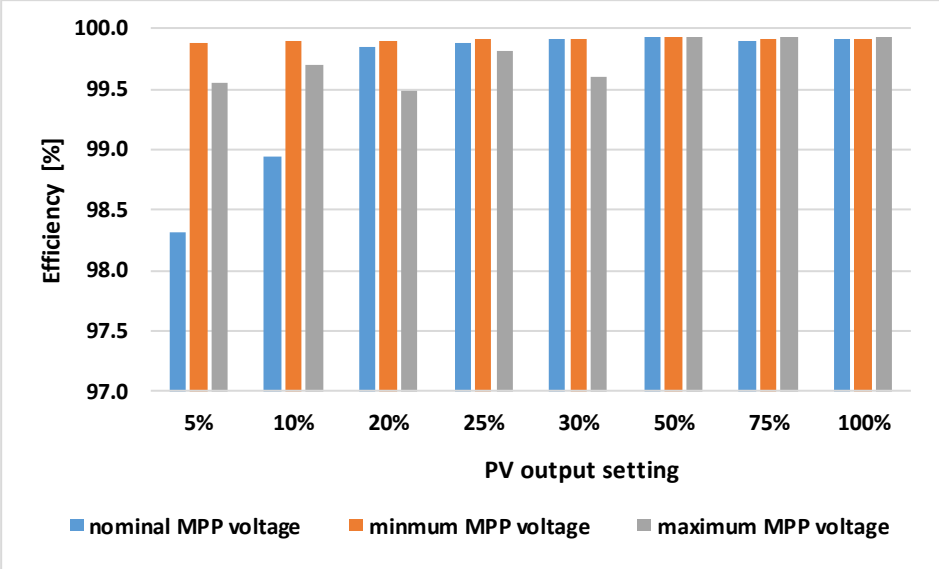

Figure 13 Static MPPT efficiency in conversion efficiency test of PV2BAT

The converter efficiency is computed according to (5), and total efficiency of PV2BAT is computed according to (6). As same as the computation of efficiency of PV2AC, power flow at AC node is considered in the converter efficiency though power is not appeared at AC node ideally. Table 7 and Figure 14 show the total efficiency of PV2BAT. The efficiency at low power levels was very small because power flow of PV2BAT includes 2 DC/DC converters.

$$\eta_{PV2BAT,conv} = \frac{\int_0^{t_M} P_{BAT(Charging)}(t)dt}{\int_0^{t_M}\left[P_{PVS,DC}(t) - P_{AC(Export)}(t) + P_{AC(import)}(t)\right]dt} \tag{5}$$

$$\eta_{PV2BAT,t} = \eta_{PV2BAT,conv} \cdot \eta_{MPPT} \tag{6}$$

Table 7 Total efficiency of conversion efficiency test of PV2ABAT

MPP Voltage	Power level for nominal power of PV2BAT							
	5%	10%	20%	25%	30%	50%	75%	100%
nominal	6.4	53.8	76.8	80.5	83.3	88.3	90.5	91.4
minimum	14.8	55.9	77.2	80.4	83.0	88.0	90.2	91.0
maximum	2.0	52.6	75.8	79.7	82.7	88.0	90.3	91.3

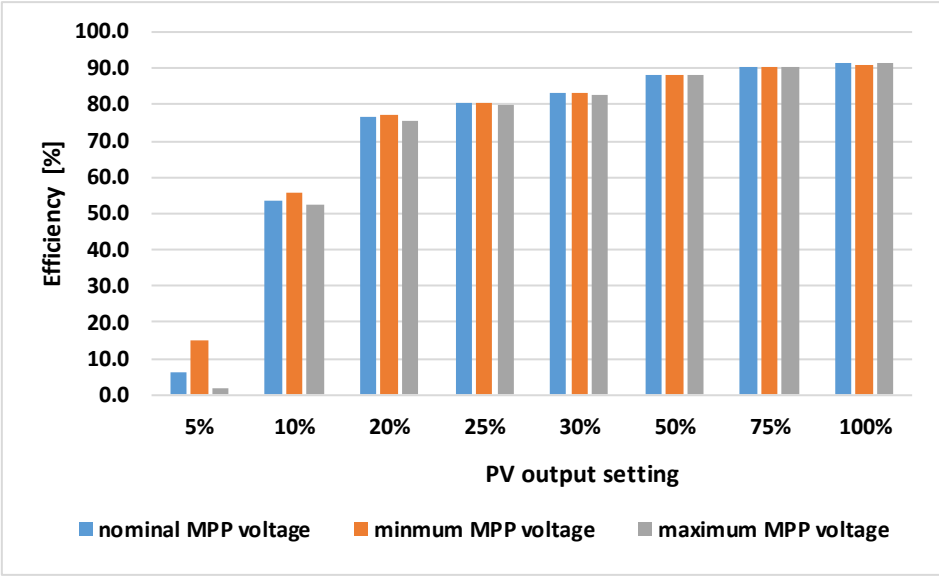

Figure 14 Total efficiency of conversion efficiency test of PV2ABAT

Comparison of the PV2BAT converter efficiency under nominal MPP voltage setting is shown in table 8 and Figure 15. In all cases other than lowest power level, the efficiency measured in AIT was larger. we will search the reason in future work.

Table 8 Comparison of converter efficiency under PV2BAT condition between AIT and AIST

	Power level for nominal power of PV2BAT							
	5%	**10%**	**20%**	**25%**	**30%**	**50%**	**75%**	**100%**
AIT	6.4	53.8	76.8	80.5	83.3	88.3	90.5	91.4
AIST	14.8	55.9	77.2	80.4	83.0	88.0	90.2	91.0

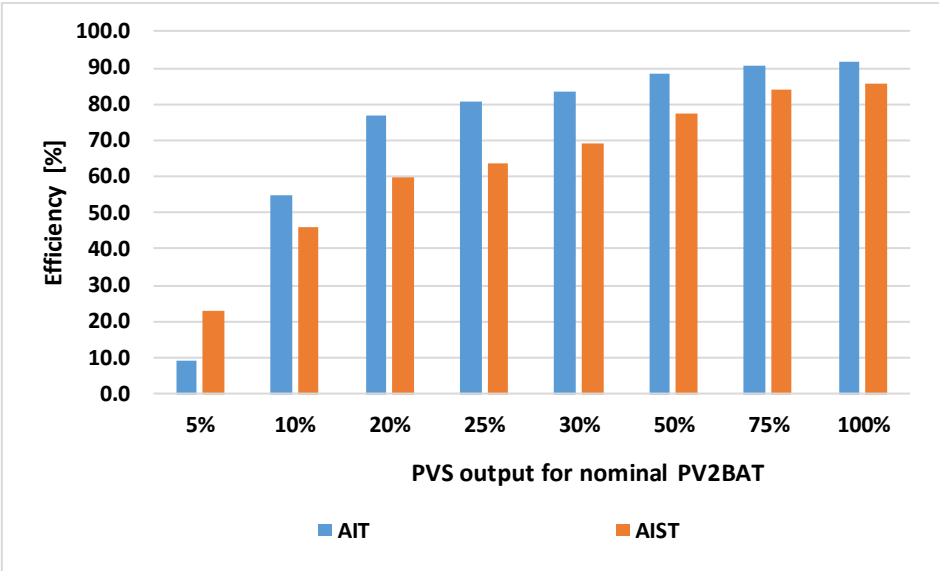

Figure 15 Comparison of converter efficiency under PV2BAT condition between AIT and AIST

c. BAT2AC

The conversion efficiency of BAT2AC was computed according to (7) and the results are shown in Table 9 and Figure 16 with the result of AIST. The test was carried out 6 times in AIT and the table and figure show the average value. Differently from the former tests PV2AC and PV2BAT, the efficiencies are close between AIT and AIST. One of the reason is that low accuracy of PVS output in low output level does not affect to the result in AIST because the PVS is not used in the test for BAT2AC. However, the accuracy of current transducers are different and it seems to cause the difference, the current transducer in AIST had lower accuracy compared with AIT one.

$$\eta_{BAT2AC} = \frac{\int_0^{t_M} P_{AC(Export)}(t)dt}{\int_0^{t_M} P_{BAT(Discharging)}(t)dt} \tag{7}$$

Table 9 Conversion efficiency of BAT2AC

	Power level for nominal power of BAT2AC							
	5%	**10%**	**20%**	**25%**	**30%**	**50%**	**75%**	**100%**
AIT	64.0	76.2	84.8	86.7	87.9	90.3	91.1	91.2
AIST	72.1	79.6	85.6	86.5	88.0	89.8	90.3	90.4

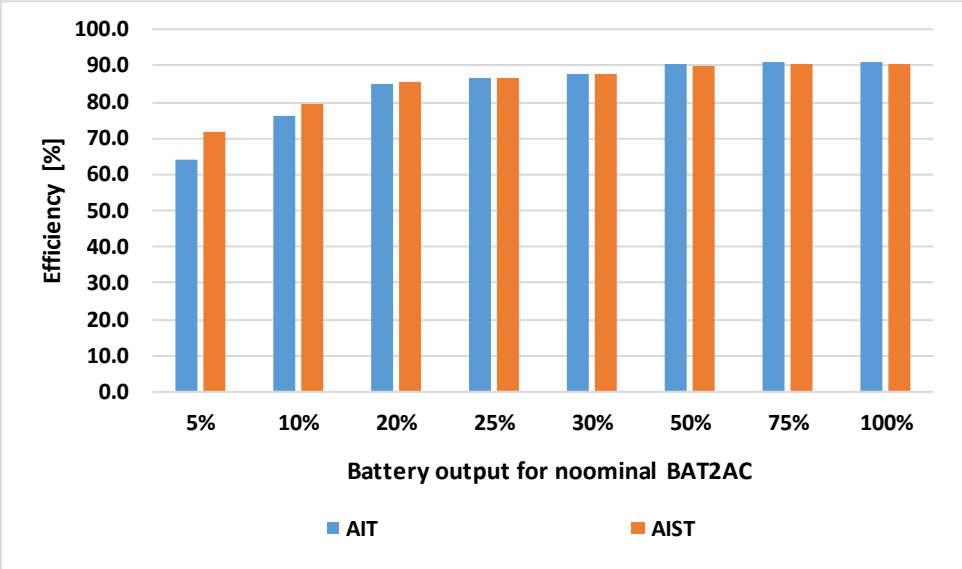

Figure 16 Conversion efficiency of BAT2AC

5.1.3 Control Deviation

a. Dynamic control deviation test

Figure 17 shows the result of dynamic control deviation test. The load profile has 14 power step and it is iterated 10 times. The figure shows the results of 2nd cycle. Holding time is set to 10s and sampling time is 100ms. The inverter reacted to load changes rapidly and overshoot was found when the battery decreases charging power or increases discharging power. Table 10 shows dead time and settling time measurement results. Because the inverter has very fast responsivity, dead time was equals to sampling time in maximum. In order to catch the transient behaviour, sampling time should be set smaller. The efficiency guideline should include information for sampling time setting for very fast reacting systems.

Figure 18 shows the result of the AIST test, where sampling time was set to 50ms. Reaction of battery to load change was almost same between both test. Figure 19, Figure 20 shows the battery response in transition from step 7 to step 8. As shown here, dead time is not changed even if sampling time is changed to 50ms from 100ms.

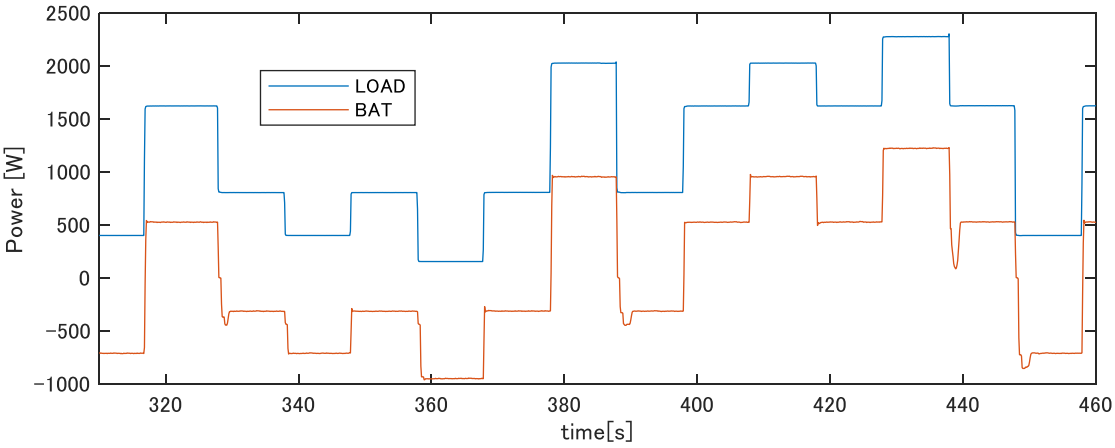

Figure 17 Dynamic control deviation test in AIT

Table 10 Dead time and settling time

	td_mean	td_max	td_min	ts_mean	ts_max	ts_min
step_1	0.05	0.10	0.00	1.61	1.70	1.50
step_2	0.07	0.10	0.00	0.72	0.90	0.50
step_3	0.06	0.10	0.00	0.22	0.30	0.10
step_4	0.07	0.10	0.00	0.75	0.90	0.60
step_5	0.08	0.10	0.00	0.23	0.30	0.10
step_6	0.07	0.10	0.00	0.29	0.30	0.20
step_7	0.04	0.10	0.00	2.22	2.30	2.20
step_8	0.07	0.10	0.00	0.23	0.30	0.20
step_9	0.08	0.10	0.00	0.21	0.30	0.10
step_10	0.08	0.10	0.00	0.24	0.30	0.20
step_11	0.07	0.10	0.00	0.20	0.30	0.10
step_12	0.06	0.10	0.00	1.64	1.70	1.50
step_13	0.04	0.10	0.00	2.27	2.30	2.20
step_14	0.06	0.10	0.00	0.31	0.40	0.30

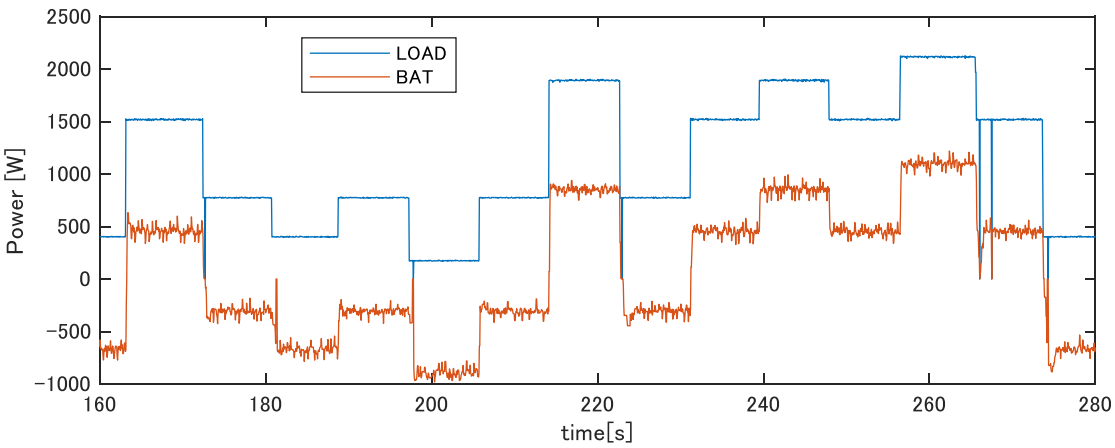

Figure 18 Dynamic control deviation test in AIST

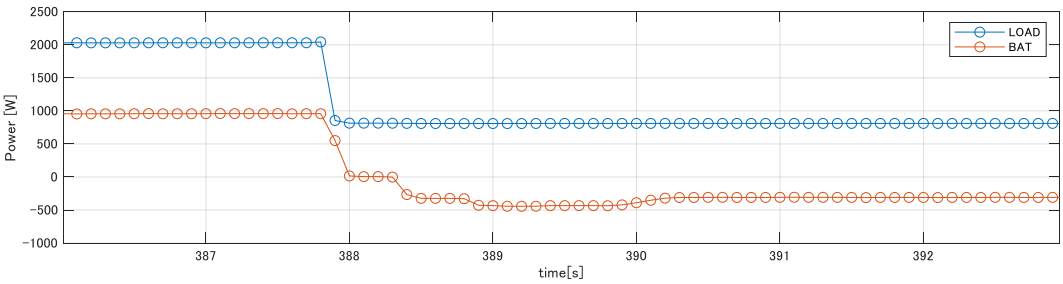

Figure 19 Dynamic control deviation test in AIT: Transition from step 7 to step 8

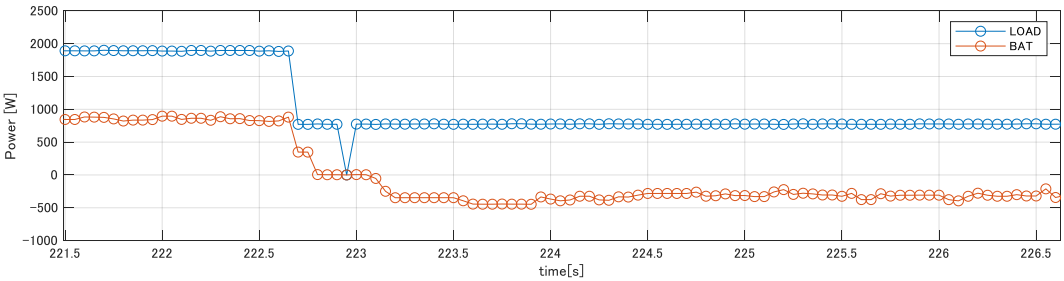

Figure 20 Dynamic control deviation test in AIST: Transition from step 7 to step 8

b. Stationary control deviation test

The profile of electrical load was changed so that holding time of each step increases to 160s and it is iterated 10 times. 14 power steps are categorized into 6 groups(E1, E2, E3, L1, L2, L3) depending on battery output level. In E1, battery discharge large amount of power, and in L3, battery charges large amount of power. Table 11 shows average power flow state in each category. Power flow to the grid was always less than 1.0W and it is found that EMS manages battery output so as to reduce exchanged power with grid in high accuracy. On the other hand, in the test in AIST, about 10W exchange was always seen as shown in table 12. It is considered that the difference comes from power noise made by the PV simulator.

Table 11 Measurement result of stationary control deviation in AIT

	E1	E2	E3	L1	L2	L3
PVS/LOAD	0.5	0.6	0.8	1.5	3.0	7.6
PVS	1210.9	1210.7	1210.9	1210.8	1211.0	1210.9
LOAD	2279.5	2033.2	1562.7	811.5	406.7	159.4
BAT	1229.1	964.1	512.5	-306.4	-703.8	-944.1
Grid,import	0.2	0.2	0.9	0.3	0.3	0.2
Grid,export	0.2	0.2	0.2	0.1	0.1	0.3

Table 12 Measurement result of stationary control deviation in AIST

	E1	E2	E3	L1	L2	L3
PVS/LOAD	0.5	0.6	0.8	1.5	2.8	6.6
PVS	1137.0	1143.2	1140.0	1147.1	1143.0	1146.5
LOAD	2116.9	1892.6	1519.5	774.5	402.2	174.0
BAT	1102.3	858.0	459.9	-304.6	-670.3	-892.9
Grid,import	10.9	10.2	11.0	9.8	9.1	11.3
Grid,export	8.6	8.3	8.7	11.8	10.9	11.7

5.1.4 Power conversion efficiency in mixed power flow condition

Testing points are shown in Figure 21, where testing points in conversion efficiency test of PV2AC, PV2BAT and BAT2AC. The operation points where battery charges from the grid are excluded. There are 140 testing points and so SOC is changed largely during test. In order to reduce the SOC change and testing time, holding time is set to 120s which is shorter than that in conversion efficiency test(180s). And the order of testing point is also arranged so that SOC change becomes small. Figure 22 shows estimated time variation of SOC. Reduction of holding time is effective for decrease SOC change. And changing order of testing operation point also reduces SOC change.

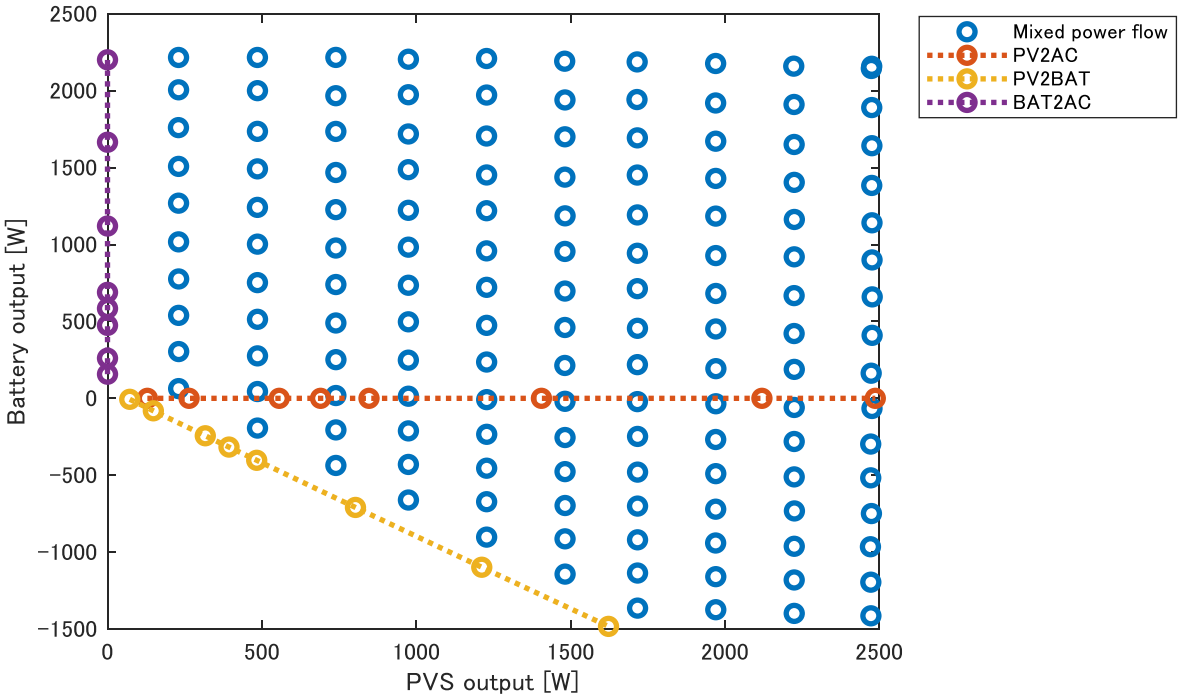

Figure 21 Testing points in conversion efficiency test in mixed power flow condition

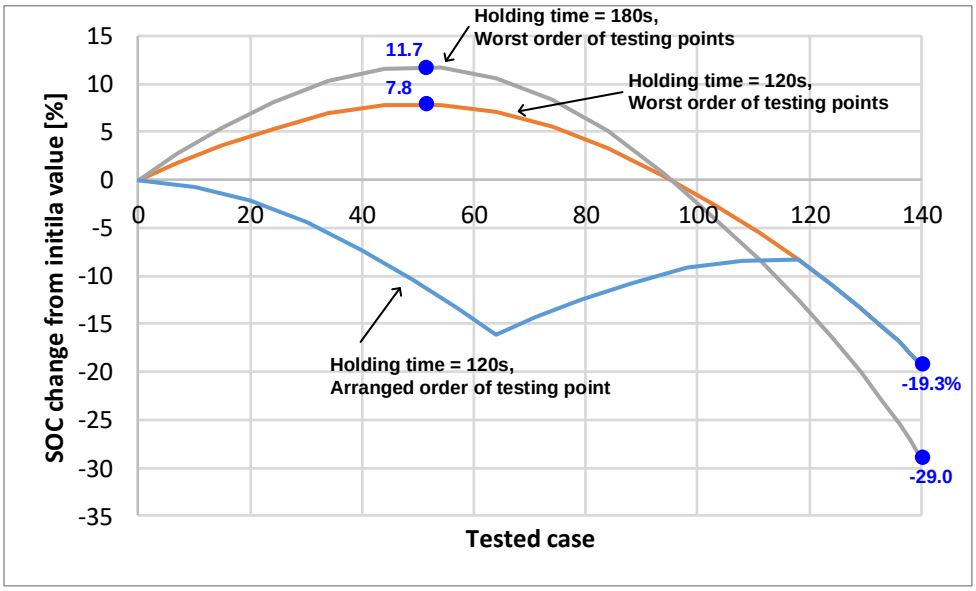

Figure 22 Estimated variation of SOC during test

Figure 23 shows time variation of power during the testing. Since the TABUCHI inverter has fast responsivity, the power flow reaches steady state for the change of the load and the PVS output. The data for 60s in steady state is used for efficiency computation. After 1550s, there is difference between the load power and the inverter AC output but it is not covered by the power from the grid. The AC output data is not measured correctly because the limit of the measuring range was exceeded. For example, although amplitude of AC current reaches 27.7A when the load is set to maximum value 4500W, the measuring range of AC current is set to ±20A during this test. In the tests described in the guideline, such a large current would not flow but this test increased the PVS output and battery discharging to maximum level and the large current flows in the circuit. For a future test it is very important to set the right measurement range on the measurement equipment. Unfortunately, the mistake was only observed during the analyses, after the DuT was already packed to ship it back to Japan. As the AC power is an important data for computation of conversion efficiency a workaround is done to still be able to analyse this test. It is done by calculating the AC power from the difference between the load power and the power from the grid. Smaller inaccuracies may occur due to losses in the cables, which increase the uncertainty but a first analyses of this test of mixed power flows is still possible with this solution.

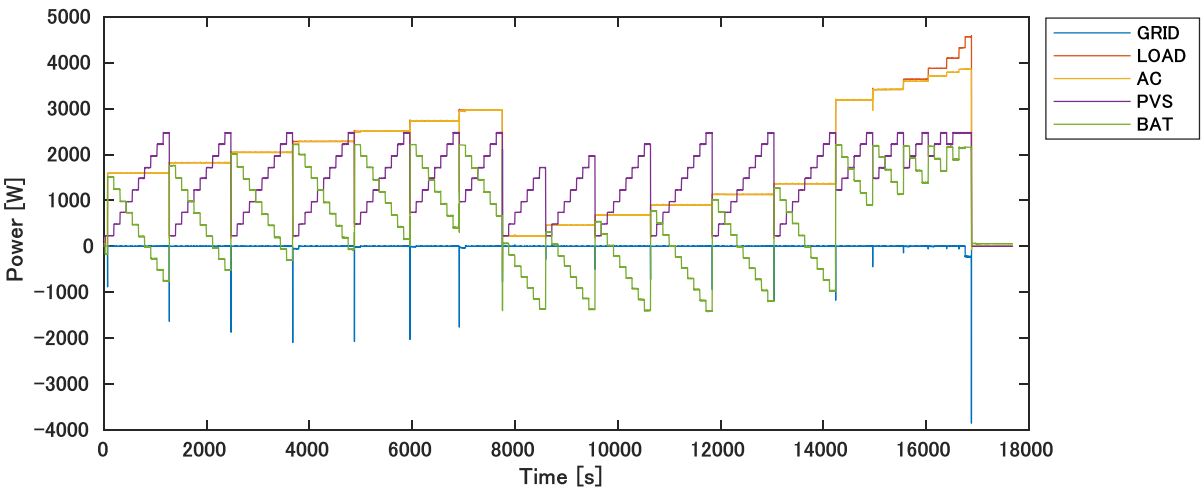

Figure 23 Time variation of power during test

Figure 24 shows the converter efficiency under mixed power flow condition. Figure 25 also shows the efficiencies in narrower scaling to make the difference of efficiency easy to see. The Efficiency can be defined as (8) and (9). When the battery charges power, the PVS output is input of the inverter and the charging power is output of the inverter as well as AC output, and the efficiency is described as (8). Otherwise, the efficiency is derived as (9) in same way. However, as described above, the data of the inverter AC output measurement data is not sufficiently reliable due to a wrong setting of the measurement range. Thus the computation formula is modified as (10) and (11). The AC output power is replaced by the difference of the load power and exchanged power with the grid. The calculated values are shown in section 9.3. From the result, when the PVS output was maximum and the battery neither charged nor discharged, the efficiency was maximum. As the PVS output decreased or the battery charging/discharging increased, the efficiency decreased.

$$\eta_{mixed,charging} = \frac{\int_0^{t_M}[P_{AC(Export)}(t) + P_{BAT(Charging)}(t)]dt}{\int_0^{t_M} P_{PVS,DC}(t)dt} \quad \left(P_{BAT} < 0(charging)\right) \qquad (8)$$

$$\eta_{mixed,discharging} = \frac{\int_0^{t_M} P_{AC(Export)}(t)dt}{\int_0^{t_M}\left[P_{PVS,DC}(t) + P_{BAT(Discharging)}(t)\right]dt} \quad \left(P_{BAT} \geq 0(discharging)\right) \qquad (9)$$

$$\eta_{mixed,charging} = \frac{\int_0^{t_M}[P_{LOAD}(t) - P_{GRID(Import)}(t) + P_{BAT(Charging)}(t)]dt}{\int_0^{t_M} P_{PVS,DC}(t)dt} \qquad (P_{BAT} < 0) \qquad (10)$$

$$\eta_{mixed,discharging} = \frac{\int_0^{t_M}[P_{LOAD}(t) - P_{GRID(Import)}(t)]dt}{\int_0^{t_M}\left[P_{PVS,DC}(t) + P_{BAT(Discharging)}(t)\right]dt} \qquad (P_{BAT} \geq 0) \qquad (11)$$

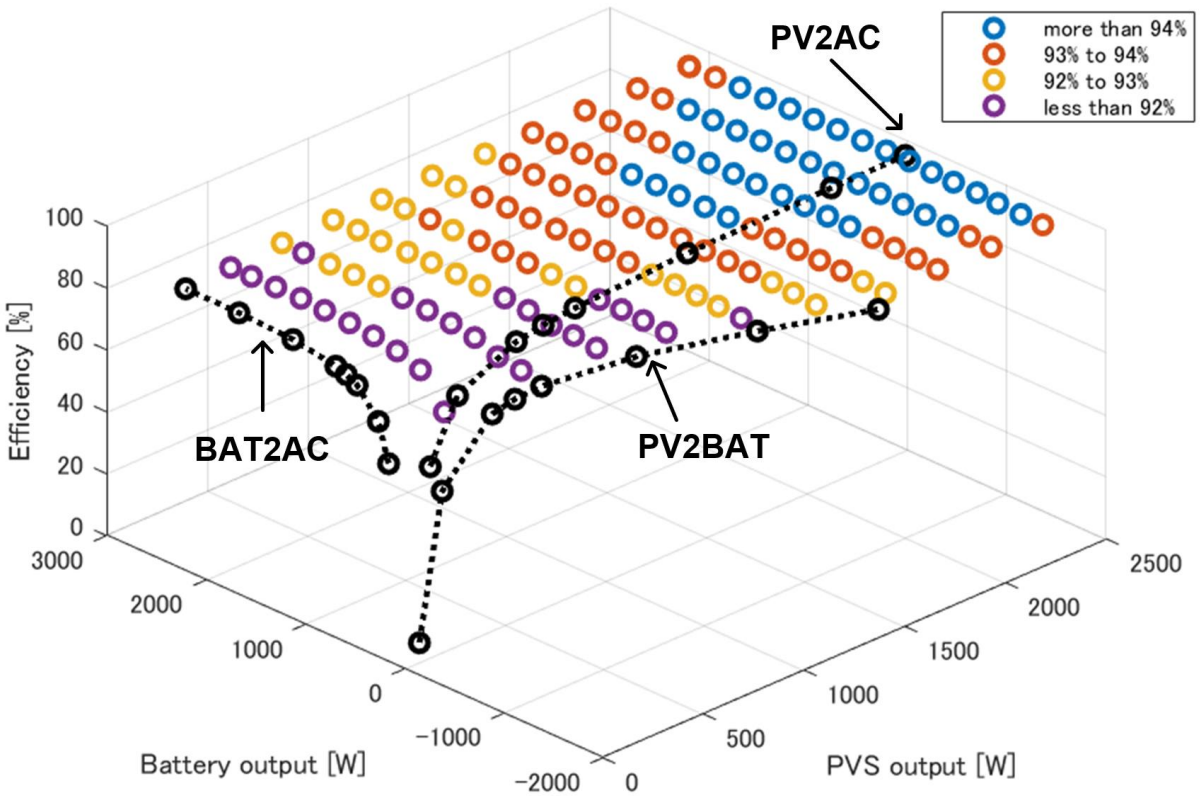

Figure 24 Conversion efficiency in mixed power flow condition

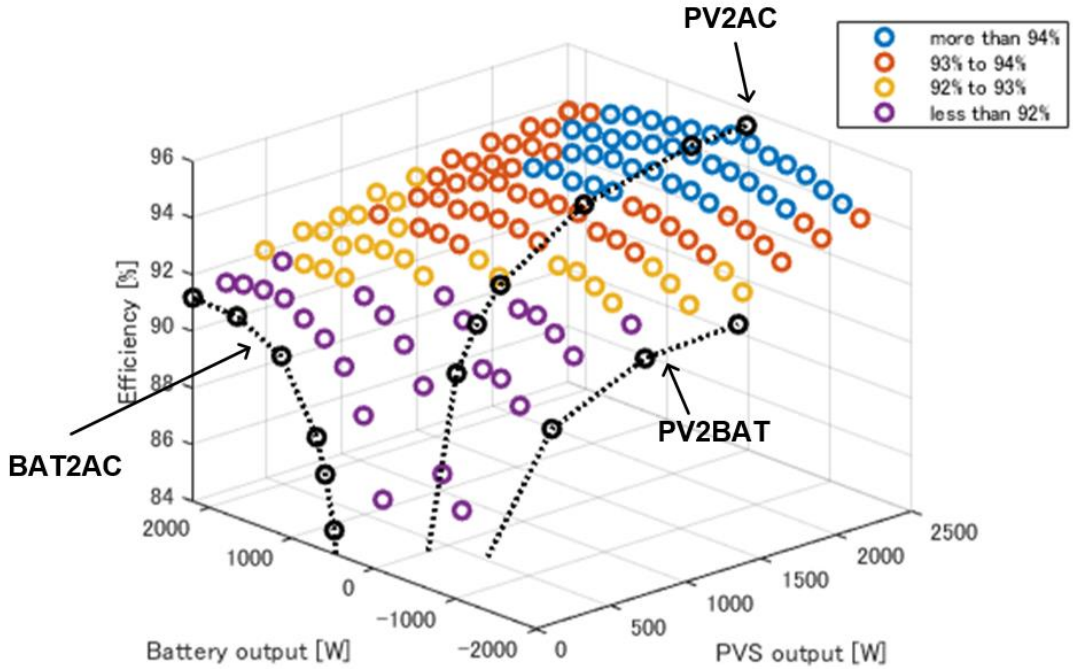

Figure 25 Conversion efficiency in mixed power flow condition (narrower scaling)

5.2 Uncertainty Computation

In this project, the results of AIT are compared with that of AIST based on uncertainty on the efficiency measuring. As a first step, uncertainty in AIST is computed. This section explains the measurement environment in AIST and explains elements which should be considered in computation of uncertainty. In the end, computation results and influence of the uncertainty on accuracy of efficiency measurement are described.

The uncertainty of the efficiency measurement means how much the measured efficiency is dispersed. The elements giving influence on the uncertainty are;

- Accuracy of measurement devices
- Dispersion of measured quantity

The former is a characteristic of the measuring device. It means that the measured data is different from the actual value within the accuracy. The latter means the dispersion of the actual quantity, which is caused by power noise injected by power sources such as grid simulator, PV simulator and electrical load, etc. These devices make power noise at a certain level even if the output setting is constant because of resolution of power level and switching action in those devices. And variation of external environment such as temperature can also be a cause of the dispersion.

Because different environment has different uncertainty, comparison of efficiency measured in different environment needs to be done considering the uncertainty. On the other hand, the difference of the measuring result does not come only from the uncertainty difference. Difference of hardware set-up, understanding of test engineer of the testing procedure also causes the difference of testing results. The testing guideline should be developed so that such differences other than uncertainty difference are reduced as possible to improve reproducibility.

Regarding to tests at AIT and AIST, DuTs are not identical while those are the same model, and so

the result difference includes individual difference. And the set-up is also different. The test at AIST does not use neutral line in AC system but it is used in AIT because of different specifications of the grid simulator. It also may cause differences in the result.

5.2.1 Testing set up in AIST including measurement devices

Figure 25 shows the measurement set-up of AIST. Voltage and current at GRID, LOAD and BAT node are measured by current transformers (CT) and voltage transformers (VT) and are the input to the power analyzer(B). Power analyzer(A) is used for measurement of the PV node. A shunt resistor is used for measuring the current at the PV node.

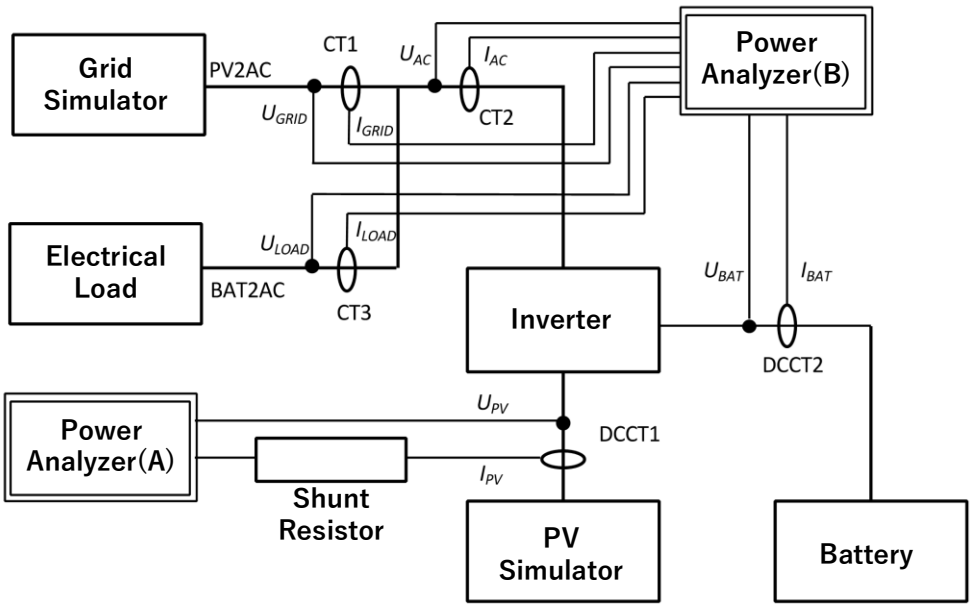

Figure 26 Set up of measurement system in AIST

5.2.2 Elements considered in uncertainty computation

The element which is considered in the efficiency computation is different depending on the kind of conversion efficiency (PV2AC, BAT2AC, PV2BAT …). This section explains the considered elements in detail for each efficiency conversion path.

a. PV2AC

From equation (1) and (2), total conversion efficiency $\eta_{PV2AC,t}$ is described as (12).

$$\eta_{PV2AC,t} = \frac{\int_0^{t_M} P_{AC(Export)}(t)dt}{\int_0^{t_M} P_{PVS,MPP}(t)dt} \frac{1}{1 - \frac{\int_0^{t_M}\left[P_{BAT(Charging)}(t) - P_{BAT(Discharging)}(t)\right]dt}{\int_0^{t_M} P_{PVS,DC}(t)dt}} \quad (12)$$

If the battery output is very small, measurement uncertainty of PV output does not affect to the uncertainty of the total efficiency. Based on (12), elements of uncertainty are listed below.

(a-1) Uncertainty of average value of maximum PVS output $u(P_{\mathrm{PVS,MPP}})$

$u(P_{\mathrm{PVS,MPP}})_1$ Uncertainty of PVS output against PV characteristic setting
Evidence: uncertainty associated with calibration of PVS output voltage

$u(P_{\mathrm{PVS,MPP}})_2$ Following capability of PV simulator to MPPT function of inverter
Evidence: (a) Measuring result of PVS and MPPT action (Resolution of measurement at PVS node), (b) Resolution of PVS output setting

(a-2) Uncertainty associated with average power of PVS output $u(P_{PVS,DC})$

$u(P_{\mathrm{PVS,DC}})_1$ Dispersion of measurement data
Evidence: Standard deviation of measurement data

$u(P_{\mathrm{PVS,DC}})_2$ Accuracy of measuring device and uncertainty associated with calibration
Evidence: Calibration proof and spec sheet

(a-3) Uncertainty of average AC power injected to the grid $u(P_{AC})$

$u(P_{\mathrm{AC}})_1$ Dispersion of measurement data
Evidence: Standard deviation of measurement data

$u(P_{\mathrm{AC}})_2$ Accuracy of measuring device and uncertainty associated with calibration
Evidence: Calibration proof and spec sheet

(a-4) Uncertainty of average battery output of $\Delta P_{BAT}\left(= P_{BAT(Discharging)} - P_{BAT(Charging)}\right)$ $u(\Delta P_{\mathrm{BAT}})$、

$u(\Delta P_{\mathrm{BAT}})_1$ Dispersion of measurement data
Evidence: Standard deviation of measurement data

$u(\Delta P_{\mathrm{BAT}})_2$ Accuracy of measuring device and uncertainty associated with calibration
Evidence: Calibration proof and spec sheet

Those uncertainties of power measurement are converted to uncertainty of efficiency based on sensitivity coefficient derived from (12). And combined standard uncertainty is computed from those uncertainties. Finally, extended uncertainty is computed as double value of the combined standard uncertainty. The extended uncertainty means 2σ value of gaussian distribution of measured efficiency.

b. PV2BAT
The efficiency of PV2BAT is derived as (13) from (1) and (5).

$$\eta_{PV2BAT,t} = \frac{\int_0^{t_M} P_{BAT(Charging)}(t)dt}{\int_0^{t_M} P_{PVS,MPP}(t)dt} \frac{1}{1 - \frac{\int_0^{t_M}\left[P_{AC(Export)}(t) - P_{AC(import)}(t)\right]dt}{\int_0^{t_M} P_{PVS,DC}(t)dt}} \tag{11}$$

As same as the case of PV2AC, uncertainty of PVS output $P_{PVS,DC}$ does not affect to measurement uncertainty of the efficiency if undesired power flow at AC node is small enough. The elements associating the uncertainty are listed below.

(b-1) Uncertainty of maximum PVS output $u(P_{PVS,MPP})$: This is same as (a-1).

(b-2) Uncertainty of measured PVS output $u(P_{PVS,DC})$: This is same as (a-2).

(b-3) Uncertainty of measured AC power injected to the grid $u(P_{AC})$: This is same as (a-3)

(b-4) Uncertainty of measured battery output $u(P_{BAT})$

$u(P_{\mathrm{BAT(Charging)}})_1$ Dispersion of measured data
Evidence: Standard deviation of measured data

$u(P_{\mathrm{BAT(Charging)}})_2$ Accuracy of measurement device and calibration uncertainty
Evidence: Calibration proof and spec sheet

c. BAT2AC

The elements associating uncertainty of efficiency is listed below.

(c-1) Uncertainty of discharging power of battery $u\left(P_{BAT(Discharging)}\right)$

$u(P_{\mathrm{BAT(Discharging)}})_1$ Dispersion of measurement data
Evidence: Standard deviation of measurement data

$u(P_{\mathrm{BAT(Discharging)}})_2$ Accuracy of measuring device and calibration uncertainty
Evidence: Calibration proof and spec sheet

(c-2) Uncertainty of exporting power to load $u\left(P_{AC(Export)}\right)$

$u(P_{\mathrm{AC}(Export)})_1$ Dispersion of measurement data
Evidence: Standard deviation of measurement data

$u(P_{\mathrm{AC}(Export)})_2$ Accuracy of measuring device and calibration uncertainty
Evidence: Calibration proof and spec sheet

5.2.3 Computation results of uncertainty in AIST testing environment

Uncertainty of efficiency measurement is computed based on the elements described above. Here, accuracy described in the spec sheet is used as calibration uncertainty. In computation of standard uncertainty of each element, distribution of measurement data is regarded as Gaussian one and dispersion of accuracy is regarded to follow rectangular distribution.

Table 14, table 15, and table 16 show the uncertainty of efficiency measurement of PV2AC, PV2BAT, and BAT2AC, respectively. When the output of PV and battery is large, uncertainty is small. It means that conversion efficiency can be measured correctly at high power levels, On the other hand, at low power level, uncertainty is quite large and exceeds 10% in some cases. This is because sensitivity tends to be large as power level decreases while dispersion of measurement data and calibration uncertainty is not so different between tested power levels.

As a future works, uncertainty in AIT environment is computed and comparison with the uncertainty in AIST is carried out. And we try to develop a methodology for comparison of efficiency measured according to the guideline considering the difference of uncertainty between different testing environments.

Table 13 Uncertainty of efficiency measurement of PV2AC power flow

Testing condition			Uncertainty			
Power(PV)		U_MPP	Combined standard uncertainty		Extended uncertainty	
Level	[W]	[V]	u(ηPV2AC)		U(ηPV2AC)	
1	2500	380	0.4%	Gaussian	0.8%	Gaussian

1	2500	235	0.4%	Gaussian	0.8%	Gaussian
1	2500	440	0.4%	Gaussian	0.9%	Gaussian
0.75	1875	380	0.5%	Gaussian	1.0%	Gaussian
0.75	1875	235	0.5%	Gaussian	0.9%	Gaussian
0.75	1875	440	0.5%	Gaussian	1.0%	Gaussian
0.5	1250	380	0.6%	Gaussian	1.2%	Gaussian
0.5	1250	235	0.6%	Gaussian	1.1%	Gaussian
0.5	1250	440	0.6%	Gaussian	1.3%	Gaussian
0.3	750	380	0.9%	Gaussian	1.8%	Gaussian
0.3	750	235	0.8%	Gaussian	1.6%	Gaussian
0.3	750	440	1.0%	Gaussian	1.9%	Gaussian
0.25	625	380	1.1%	Gaussian	2.1%	Gaussian
0.25	625	235	0.9%	Gaussian	1.9%	Gaussian
0.25	625	440	1.1%	Gaussian	2.2%	Gaussian
0.2	500	380	1.3%	Gaussian	2.5%	Gaussian
0.2	500	235	1.1%	Gaussian	2.2%	Gaussian
0.2	500	440	1.3%	Gaussian	2.7%	Gaussian
0.1	250	380	2.5%	Gaussian	4.9%	Gaussian
0.1	250	235	2.1%	Gaussian	4.3%	Gaussian
0.1	250	440	2.6%	Gaussian	5.3%	Gaussian
0.05	125	380	4.7%	Gaussian	9.5%	Gaussian
0.05	125	235	4.3%	Gaussian	8.5%	Gaussian
0.05	125	440	5.0%	Gaussian	10.0%	Gaussian

Table 14 Uncertainty of efficiency measurement of PV2BAT power flow

Testing condition			**Uncertainty**			
Power(PV)		**U_MPP**	**Combined standard uncertainty**		**Extended uncertainty**	
Level	**[W]**	**[V]**	**u(ηPV2BAT)**		**U(ηPV2BAT)**	
1	1500	380	0.5%	Gaussian	1.1%	Gaussian
1	1500	235	0.5%	Gaussian	1.0%	Gaussian
1	1500	440	0.6%	Gaussian	1.1%	Gaussian
0.75	1125	380	0.7%	Gaussian	1.4%	Gaussian
0.75	1125	235	0.6%	Gaussian	1.2%	Gaussian
0.75	1125	440	0.7%	Gaussian	1.4%	Gaussian
0.5	750	380	0.9%	Gaussian	1.8%	Gaussian
0.5	750	235	0.8%	Gaussian	1.6%	Gaussian
0.5	750	440	1.0%	Gaussian	1.9%	Gaussian
0.3	450	380	1.3%	Gaussian	2.7%	Gaussian
0.3	450	235	1.1%	Gaussian	2.3%	Gaussian
0.3	450	440	1.4%	Gaussian	2.9%	Gaussian
0.25	375	380	1.7%	Gaussian	3.4%	Gaussian
0.25	375	235	1.5%	Gaussian	2.9%	Gaussian
0.25	375	440	1.8%	Gaussian	3.6%	Gaussian
0.2	300	380	2.2%	Gaussian	4.3%	Gaussian
0.2	300	235	1.9%	Gaussian	3.8%	Gaussian
0.2	300	440	2.3%	Gaussian	4.6%	Gaussian
0.1	150	380	3.9%	Gaussian	7.9%	Gaussian
0.1	150	235	3.3%	Gaussian	6.6%	Gaussian
0.1	150	440	4.2%	Gaussian	8.5%	Gaussian
0.05	75	380	6.5%	Gaussian	12.9%	Gaussian
0.05	75	235	5.2%	Gaussian	10.4%	Gaussian
0.05	75	440	7.1%	Gaussian	14.1%	Gaussian

Table 15 Uncertainty of efficiency measurement of BAT2AC power flow

Testing Condition		Uncertainty			
Power(BAT)		Combined standard uncertainty		Extended uncertainty	
Level	[W]	u(ηBAT2AC)		U(ηBAT2AC)	
1	2200	0.4%	Gaussian	0.8%	Gaussian
0.75	1650	0.4%	Gaussian	0.8%	Gaussian
0.5	1100	0.5%	Gaussian	1.0%	Gaussian
0.3	660	0.7%	Gaussian	1.4%	Gaussian
0.25	550	0.9%	Gaussian	1.7%	Gaussian
0.2	440	0.9%	Gaussian	1.8%	Gaussian
0.1	220	1.6%	Gaussian	3.2%	Gaussian
0.05	110	2.9%	Gaussian	5.7%	Gaussian

5.3 Conclusion

The efficiency measurement of PV-battery system is becoming important as PV owners installs battery system to use PV generation for self-consumption. This project evaluates the influence of difference of testing environment on efficiency measurement result through round-robin testing and uncertainty computation. In the Transnational Access program, the efficiency test was carried out at AIT, and the result was compared with the test results of AIST, where the same inverter model is used. The uncertainty of efficiency measurement is computed for testing environment in AIST.

In the efficiency test, energy conversion efficiency is measured under 3 power flow conditions and battery controller performance is verified from the aspect of dynamic behaviour for the load and PV output change and control error in steady state. MPPT efficiency was always almost 100% although it decreased to about 98% for low output levels. Conversion efficiency was over 90% when large power is inputted and efficiency decreased as converting power decreased. Especially, the efficiency of PV2BAT, in which battery charged from PV, is affected significantly by converting power, and it decreased under 10% in minimum power level.

There was some difference between the results of AIT and AIST. The difference includes the influence of the difference of testing environment, especially the low accuracy of the AIST PVS output for low output levels is expected to affect the result. AIST will try to improve the accuracy until the next test carried out and the influence of the accuracy of PVS output should also be investigated in uncertainty analysis.

The uncertainty in AIST testing environment is computed according to accuracy information described in the spec sheets of the measurement equipment. It is found that uncertainty of the efficiency is quite large under small amount of power flow condition because the sensitivity of the efficiency to the power change is quite high in such condition. As next steps, uncertainty in AIST is computed again based on calibration proof, and the computation is carried out for AIT test environment for comparison of the uncertainty.

6 Open Issues and Suggestions for Improvements

6.1 Sampling time setting

Since the tested system has very fast responsivity, sampling time was needed to be set to smaller values than 200 ms to measure the dynamic behaviour in control deviation test better. Some guidance of sampling time setting should be included in the testing guideline.

6.2 Accuracy of power source

In preliminary testing in AIST, low accuracy of the PVS output is observed and it causes large difference of results among AIT and AIST. This is because the PVS in AIST has large capacity and low resolution in the range of 100 watts. The testing guideline should include the requirement of the accuracy of power source not only PVS but grid simulator and electrical load.

6.3 Requirement for AC voltage variation

As shown in the report, AC voltage variation influence on the conversion efficiency especially in case low power flow condition but the guideline does not give any requirement of AC voltage variation. It doesn't matter when grid simulator is used in the testing but the influence become severe if the inverter is connected to the bulk power system.

6.4 Measurement accuracy

To limit the measurement unsecurity for the efficiency result, future standards must define minimum requirements for the uncertainty of voltage- and current measurement equipment. It seems also not enough to do an uncertainty analyses for the nominal value of the measurement range only because if the nominal value is much higher than the measured value the accuracy at low power might be significantly higher than expected. Furthermore, also calibration of the measurement equipment on a regular basis seems very important to guarantee a certain accuracy.

6.5 Influence of cabling

The voltage at the battery and AC connection point of the inverter must be measured closest as possible to the inverter terminals to reduce the influence of cable losses to the efficiency. This is not described in the efficiency guideline and should be mentioned. Sunn<

7 Dissemination Planning

- A joint paper will be presented at a related international conference in 2020.
- Key findings and remaining issues will be shared with The German Energy Storage Association and DKE/AK 371.0.9 through AIT connection.
- This activities and results will disseminated to IEC standard members and Japanese domestic committee e.g. IEC TC82 Solar photovoltaic energy systems, TC120 Electrical Energy Storage (EES) Systems.

8 References

[1] Johannes Weniger, Joseph Bergner, Tjarko Tjaden, Volker Quaschning, “ECONOMICS OF RESIDENTIAL PV BATTERY SYSTEMS IN THE SELF-CONSUMPTION AGE,” 29th European Photovoltaic Solar Energy Conference and Exhibition, 2014.

[2] IEA,” Tracking Clean Energy Progress: Energy Storage,” June 2019 *https://www.iea.org/tcep/energyintegration/energystorage/*

[3] Johannes Weniger, Tjarko Tjaden, Volker Quaschning, “Sizing of residential PV battery systems,” proceedings of 8th International Renewable Energy Storage Conference and Exhibition(IRES 2013), Vol. 46 (2014), pp. 78–87

[4] Johannes Weniger, Tjarko Tjaden, Joseph Bergner, Volker Quaschning, “EMERGING PERFORMANCE ISSUES OF PHOTOVOLTAIC BATTERY SYSTEMS,” 32nd European Photovoltaic Solar Energy Conference and Exhibition 2016

[5] IEC 62933-2-1:2017. Electrical energy storage (EES) systems - Part 2-1: Unit parameters and testing methods - General specification

[6] IEC 61683:1999. Photovoltaic systems - Power conditioners - Procedure for measuring efficiency

[7] Johannes Weniger, Selina Maier, Lena Kranz, Nico Orth, Nico Böhme, Volker Quaschning, “Energy Storage Inspection 2018,” 2018 *https://pvspeicher.htw-berlin.de/wp-content/uploads/HTW-Berlin-Energy-Storage-Inspection-2018.pdf*

[8] BVES and BSW-Solar,” Efficiency guideline for PV storage systems 2.0,” pp.1-55, 2019 April

[9] 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

[10] Despeghel, J., Tant, J., & Driesen, J. (2019). Loss Model for Improved Efficiency Characterization of DC Coupled PV-Battery System Converters. IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, 1, 4740–4745.

9 Annex

9.1 List of Figures

9.2 List of Tables

9.3 Results of conversion efficiency test in mixed power flow condition

9.3.1 Test case No.1 to No. 40

Table 16 Results of conversion efficiency measuring in mixed power flow (testing point No. 1 to No.40)

No.	P_GRID [W]	P_LOAD [W]	P_AC(ex) [W]	P_BAT(chr) [W]	P_BAT(dis) [W]	P_PVS [W]	Efficiency [%]
1	0.6	1590.4	1591.5	0.0	1508.1	230.2	91.5
2	0.5	1590.7	1591.8	0.0	1241.5	485.7	92.1
3	0.5	1590.4	1591.5	0.0	977.4	739.7	92.7
4	0.5	1590.4	1591.4	0.0	735.2	974.8	93.0
5	0.5	1590.6	1591.6	0.0	474.5	1228.2	93.4
6	0.6	1590.5	1591.6	0.0	213.8	1481.6	93.9
7	0.7	1590.5	1591.7	21.5	0.0	1716.6	93.9
8	0.6	1590.4	1591.6	267.7	0.0	1970.3	94.3
9	0.7	1590.5	1591.7	510.8	0.0	2224.6	94.5
10	0.7	1590.4	1591.7	749.1	0.0	2474.8	94.6
11	0.5	1821.7	1822.8	0.0	1760.2	229.9	91.6
12	0.5	1822.3	1823.4	0.0	1492.0	485.7	92.2
13	0.4	1822.7	1823.7	0.0	1226.9	739.7	92.7
14	0.4	1823.0	1824.0	0.0	982.8	974.7	93.2
15	0.4	1823.2	1824.2	0.0	721.7	1228.2	93.5
16	0.3	1823.2	1824.1	0.0	460.6	1481.8	93.9
17	0.4	1823.4	1824.3	0.0	219.1	1716.6	94.2
18	0.4	1823.5	1824.5	35.3	0.0	1970.8	94.3
19	0.4	1823.5	1824.5	280.6	0.0	2224.6	94.6
20	0.5	1823.6	1824.7	517.0	0.0	2472.6	94.7
21	0.5	2045.4	2046.6	0.0	2006.1	230.2	91.5
22	0.3	2045.3	2046.2	0.0	1735.7	485.7	92.1
23	0.3	2045.4	2046.3	0.0	1468.5	739.8	92.6
24	0.3	2045.3	2046.2	0.0	1222.5	974.7	93.1
25	0.3	2045.2	2046.1	0.0	958.8	1228.0	93.5
26	0.2	2045.3	2046.2	0.0	697.4	1482.0	93.9
27	0.2	2045.3	2046.2	0.0	455.3	1716.8	94.2
28	0.2	2045.3	2046.2	0.0	192.8	1970.9	94.5
29	0.3	2045.2	2046.1	59.4	0.0	2224.7	94.6
30	0.3	2045.3	2046.2	297.4	0.0	2472.5	94.8
31	-49.6	2283.6	2234.7	0.0	2216.2	230.1	91.3
32	0.4	2284.1	2285.2	0.0	2000.4	485.8	91.9
33	0.1	2284.1	2284.9	0.0	1735.3	739.8	92.3
34	0.3	2284.2	2285.2	0.0	1486.8	974.6	92.8
35	0.3	2284.2	2285.1	0.0	1219.9	1228.1	93.3
36	0.3	2284.4	2285.3	0.0	955.1	1481.8	93.8
37	0.3	2284.6	2285.5	0.0	713.0	1716.5	94.0
38	0.3	2284.6	2285.5	0.0	451.0	1970.6	94.4
39	0.3	2284.5	2285.5	0.0	188.2	2224.9	94.7
40	0.4	2284.5	2285.6	66.1	0.0	2476.6	94.9

9.3.2 Test case No.41 to No. 80

Table 17 Results of conversion efficiency measuring in mixed power flow (testing point No. 41 to No.80)

No.	P_GRID [W]	P_LOAD [W]	P_AC(ex) [W]	P_BAT(chr) [W]	P_BAT(dis) [W]	P_PVS [W]	Efficiency [%]
41	-18.6	2505.4	2487.5	0.0	2216.3	485.7	92.0
42	0.7	2505.3	2506.7	0.0	1967.7	739.8	92.6
43	0.5	2505.2	2506.3	0.0	1718.8	974.7	93.0
44	0.6	2505.2	2506.5	0.0	1452.3	1228.1	93.5
45	0.4	2505.1	2506.2	0.0	1186.4	1482.3	93.9
46	0.5	2505.0	2506.1	0.0	943.2	1716.6	94.2
47	0.3	2505.0	2505.9	0.0	681.6	1970.8	94.5
48	0.3	2505.1	2506.1	0.0	421.2	2224.3	94.7
49	0.5	2505.2	2506.3	0.0	163.3	2474.0	95.0
50	-5.8	2734.2	2729.0	0.0	2216.7	739.8	92.3
51	0.6	2734.1	2735.3	0.0	1974.1	974.7	92.7
52	0.4	2734.3	2735.4	0.0	1705.6	1228.0	93.2
53	0.3	2734.2	2735.2	0.0	1438.3	1481.7	93.6
54	0.4	2734.1	2735.2	0.0	1192.3	1716.7	94.0
55	0.2	2734.2	2735.1	0.0	928.2	1970.7	94.3
56	0.3	2734.3	2735.3	0.0	667.9	2224.3	94.5
57	0.3	2734.2	2735.2	0.0	409.5	2477.0	94.7
58	-29.4	2968.2	2939.5	0.0	2204.9	974.7	92.4
59	0.5	2968.7	2969.9	0.0	1972.0	1228.2	92.8
60	0.3	2968.9	2969.9	0.0	1700.4	1481.9	93.3
61	0.3	2968.8	2969.8	0.0	1451.8	1716.4	93.7
62	0.2	2969.0	2969.9	0.0	1184.7	1970.5	94.1
63	0.4	2968.8	2969.9	0.0	919.9	2224.7	94.4
64	0.3	2968.9	2969.9	0.0	659.5	2477.3	94.7
65	0.3	221.6	222.0	0.0	63.1	230.5	75.6
66	0.3	221.6	222.0	193.4	0.0	486.0	85.4
67	0.3	221.6	222.0	436.4	0.0	739.8	89.0
68	0.3	221.6	222.0	661.3	0.0	974.9	90.6
69	0.3	221.6	222.0	902.5	0.0	1228.2	91.5
70	0.3	221.6	222.0	1142.9	0.0	1482.4	92.1
71	0.3	221.6	222.0	1364.1	0.0	1717.1	92.4
72	0.5	457.8	458.5	0.0	304.1	230.6	85.7
73	0.5	457.8	458.6	0.0	44.2	485.8	86.5
74	0.5	457.8	458.6	205.3	0.0	739.9	89.7
75	0.6	457.9	458.6	429.9	0.0	974.8	91.1
76	0.6	457.9	458.7	672.2	0.0	1228.2	92.1
77	0.6	457.9	458.6	913.6	0.0	1482.2	92.6
78	0.6	457.9	458.6	1136.0	0.0	1717.1	92.9
79	0.5	457.8	458.6	1374.5	0.0	1970.6	93.0
80	0.7	680.0	681.0	0.0	539.3	230.4	88.4

9.3.3 Test case No.81 to No. 120

Table 18 Results of conversion efficiency measuring in mixed power flow (testing point No. 81 to No.120)

No.	P_GRID [W]	P_LOAD [W]	P_AC(ex) [W]	P_BAT(chr) [W]	P_BAT(dis) [W]	P_PVS [W]	Efficiency [%]
81	0.6	680.0	680.9	0.0	276.0	485.9	89.3
82	0.6	680.0	680.9	0.0	18.2	739.8	89.8
83	0.6	680.0	680.9	211.8	0.0	974.9	91.5
84	0.6	680.0	680.9	454.4	0.0	1228.3	92.4
85	0.6	680.0	680.9	696.9	0.0	1482.4	92.9
86	0.6	680.0	680.9	920.0	0.0	1717.1	93.2
87	0.6	680.0	680.9	1159.5	0.0	1970.6	93.4
88	0.5	680.0	680.8	1398.4	0.0	2224.7	93.4
89	0.6	904.4	905.4	0.0	776.2	230.5	89.9
90	0.6	904.5	905.4	0.0	513.7	485.9	90.5
91	0.6	904.3	905.2	0.0	251.5	739.9	91.3
92	0.5	904.3	905.2	0.0	13.7	974.9	91.5
93	0.5	904.3	905.1	234.0	0.0	1228.5	92.7
94	0.6	904.3	905.2	476.6	0.0	1482.2	93.2
95	0.6	904.3	905.2	700.7	0.0	1717.1	93.5
96	0.5	904.3	905.2	940.7	0.0	1970.1	93.7
97	0.5	904.3	905.2	1181.0	0.0	2224.6	93.8
98	0.5	904.3	905.1	1414.0	0.0	2473.1	93.8
99	0.6	1130.3	1131.3	0.0	1017.4	230.2	90.6
100	0.5	1130.2	1131.2	0.0	752.4	485.8	91.3
101	0.5	1129.2	1130.1	0.0	489.9	739.8	91.9
102	0.5	1129.3	1130.2	0.0	248.1	974.6	92.4
103	0.5	1129.2	1130.2	8.5	0.0	1228.4	92.7
104	0.5	1129.2	1130.1	254.9	0.0	1482.2	93.4
105	0.6	1129.3	1130.3	479.8	0.0	1717.2	93.7
106	0.5	1129.3	1130.3	720.9	0.0	1970.3	93.9
107	0.5	1129.3	1130.2	962.0	0.0	2224.7	94.0
108	0.6	1129.3	1130.3	1195.5	0.0	2472.8	94.0
109	0.4	1364.9	1365.8	0.0	1268.9	230.2	91.1
110	0.5	1365.0	1365.9	0.0	1002.7	485.8	91.7
111	0.8	1365.1	1366.3	0.0	740.0	739.8	92.3
112	0.4	1364.9	1365.8	0.0	497.4	974.8	92.7
113	0.3	1365.0	1365.8	0.0	236.1	1228.2	93.2
114	0.4	1365.0	1365.9	19.5	0.0	1482.2	93.4
115	0.4	1365.0	1365.9	247.7	0.0	1717.2	93.9
116	0.5	1365.0	1365.9	489.7	0.0	1970.6	94.1
117	0.5	1365.0	1366.0	732.2	0.0	2225.3	94.3
118	0.5	1365.0	1365.9	965.0	0.0	2471.6	94.3
119	0.5	3190.9	3192.1	0.0	2209.5	1227.9	92.8
120	0.5	3191.1	3192.2	0.0	1940.1	1481.9	93.3

9.3.4 Test case No.121 to No. 140

Table 19 Results of conversion efficiency measuring in mixed power flow (testing point No. 121 to No.140)

No.	P_GRID [W]	P_LOAD [W]	P_AC(ex) [W]	P_BAT(chr) [W]	P_BAT(dis) [W]	P_PVS [W]	Efficiency [%]
121	0.4	3191.4	3192.4	0.0	1693.5	1716.5	93.6
122	0.3	3191.4	3192.3	0.0	1429.8	1970.5	93.9
123	0.4	3191.5	3192.5	0.0	1163.0	2225.0	94.2
124	0.2	3191.6	3192.4	0.0	899.8	2476.7	94.5
125	0.5	3415.1	3416.2	0.0	2192.0	1481.1	93.0
126	0.6	3415.9	3417.1	0.0	1942.8	1715.3	93.4
127	0.4	3416.4	3417.4	0.0	1671.8	1970.4	93.8
128	0.4	3416.8	3417.8	0.0	1404.1	2224.7	94.2
129	0.4	3417.3	3418.2	0.0	1141.3	2476.6	94.5
130	-2.6	3642.1	3593.9	0.0	2187.4	1715.9	93.2
131	0.6	3642.2	3595.8	0.0	1920.3	1970.1	93.6
132	0.5	3642.4	3595.6	0.0	1650.6	2224.4	94.0
133	0.5	3642.2	3595.5	0.0	1384.2	2475.8	94.4
134	-2.9	3877.2	3709.7	0.0	2177.2	1970.1	93.4
135	0.6	3877.4	3711.2	0.0	1910.6	2224.1	93.8
136	0.5	3876.8	3710.8	0.0	1642.5	2476.2	94.1
137	0.5	4100.1	3792.2	0.0	2159.8	2223.1	93.6
138	0.7	4100.3	3792.5	0.0	1890.6	2475.8	93.9
139	0.8	4328.1	3857.0	0.0	2144.8	2474.6	93.7
140	-223.0	4564.0	3858.4	0.0	2159.0	2475.7	93.7