Explanation of the PV System Survey Sheet

We design the survey format to collect failure data of PV systems for various climate zones. The goal of the survey is to evaluate the possible different impact of the failures for various climate zones and give recommendations for test methods depending on the climate zone. The survey data may be used for further statistical evaluation.

To fill in new data into the survey sheet (Fig. 1) you have to load the survey sheet into the excel program and choose the worksheet "PV_system_survey". It is important to agree with the two notifications for "enable editing" and "enable macros" if they pop up. Scroll to the upper left corner of the worksheet if you are not already there. Click the button "New form" to generate a new input mask. A new mask appears and the focus automatically jumps to the new mask with a name "PV_system_survey (X)" where X stand for a number. Now you can start to input your data. If you want to delete a table you can press the button "Delete form" then the current visible table will be deleted. If you want to duplicate a table, e.g. your next input is very similar to one which is already in the database, then navigate to the table to be copied and click on "Copy form". This generates a new mask with exact the same data. Now you can edit this form as you like.

The **System ID** is a category that enables the contributor to identify the source of its own data input and avoids double input of the same data. The System ID should not enable other people to identify the source of the data. Furthermore, the System ID can be used to address questions from the TASK13 team to the contributor of the data set. The System ID will be exchanged in the public version of the database with an arbitrary number. If the current input is extracted from a scientific publication, the System ID has to be used to fill in the reference of the paper in the IEEE format style. The source of the data must be specified in the category **Source of data**.

The version number in the upper right corner of the survey excel sheet has to be specified if you have questions to the TASK13 team on the survey excel sheet. In the following we give examples how to fill in the survey format. Please note that only the cells highlighted in green are provided for editing.

New form | Copy form | Delete form | Survey version: 11 August 2016

PV system basics — Goal of this survey | How to start ? | Other questions

System ID:		PV module type		
Source of data		Inverter type		
Country		Mounting system type		
Climate zone		Grounding of substructure & module frames/conductor		
Special stress		Other system component		
Kind of system		Nominal system power	[kWp]	
Orientation		Date of system start	[MM/YYYY]	
Inclination		Date of failure documented here	[MM/YYYY]	
Comment if a field is orange				

Integral data

Total system power loss [%]	Following failure specifications are based on investigated percentage of					
	Inverter [%]	Cable and interconnector [%]	PV module [%]	Mounting [%]	Other [%]	Comment

Failure specification for 0 **% of the system**

Failed system part	Failure 1 specification	Power loss 1 [%]	Failure 2 specification	Power loss 2 [%]	Safety failure 1	Safety failure 2
Inverter	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Cable and interconnector	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
PV module	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Mounting	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Other system component	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Comment if a field is orange						

Fig. 1: The survey is implemented in a Microsoft Excel worksheet. For each PV system five separate failure specifications are available. For most of the input fields a preselection is available.

a) Simple standard roof top system

To input a simple standard roof top system, simply go through the fields and choose from the drop down lists your input. For a typical roof top system choose in the category **Kind of system** the item *Rooftop commercial*. In the category **Orientation** choose one system orientation which is closest to or the mean of the system orientation. There is one special item for *west/east* orientated systems. Roof top systems with various orientations which differ from each other more than ±22.5° must be divided into two systems. For each orientation a table has to be filled in. The inclination of the photovoltaic modules must be filled in the category **Inclination**. Choose the closest inclination item. For systems with various inclinations of the photovoltaic modules for each inclination a table has to be filled in if the inclination angle varies more than ±10°.

b) Large system with components of various types

For large systems with components of various types for each part of the system with one equal set of system components one failure survey should be filled in. If one type of failure causes a variety of power losses, the failure should be split up into several parts. E.g. there are 10% of the total amount of PV modules with PID failure. Five percent points have a power loss of]3%-10%] 3 percent points]10%-20%] and two percent points]20%-30%]. In this case the PV failure survey should be filled in as shown in Fig. 2. If all of these PID modules have an additional failure the failure may be added as failure 2. However it is not possible to include various distributions of different failures. **Therefore, it is recommended to focus on the failures with the highest impact to the power loss.**

Integral data

Total system power loss [%]	Following failure specifications are based on investigated percentage of					
	Inverter [%]	Cable and interconnector [%]	PV module [%]	Mounting [%]	Other [%]	Comment
2				100		

Failure specification for 5 **% of the system**

Failed system part	Failure 1 specification	Power loss 1 [%]	Failure 2 specification	Power loss 2 [%]	Safety failure 1	Safety failure 2
Inverter	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Cable and interconnector	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
PV module	Potential indu	]3%-10%]	Discolouring c	No detectable loss	No failure	No failure
Mounting	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Other system component	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Comment if a field is orange						

Failure specification for 3 **% of the system**

Failed system part	Failure 1 specification	Power loss 1 [%]	Failure 2 specification	Power loss 2 [%]	Safety failure 1	Safety failure 2
Inverter	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Cable and interconnector	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
PV module	Potential indu	]10%-20%]	Discolouring c	No detectable loss	No failure	No failure
Mounting	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Other system component	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Comment if a field is orange						

Failure specification for 2 **% of the system**

Failed system part	Failure 1 specification	Power loss 1 [%]	Failure 2 specification	Power loss 2 [%]	Safety failure 1	Safety failure 2
Inverter	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Cable and interconnector	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
PV module	Potential indu	]20%-30%]	Discolouring c	No detectable loss	No failure	No failure
Mounting	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Other system component	No failure	No detectable loss	No failure	No detectable loss	No failure	No failure
Comment if a field is orange						

Fig. 2: Splitting of a PID failure distribution into ranges of power loss. Additional failure can be easily added if they affect all the PID affected modules. If the PV-modules or the System has mixed failure modes one should focus on the most relevant failure concerning the power loss.

If only 1 % of the total amount of modules is examined in a large system consider that in the section "Failure specification for X % of the system" the failure specification if relative to the total nominal power of the system and not relative to the examined part of the system. For example if from the 1 % of examined PV modules 10 % have a specific failure then you have to put in: "Failure specification for 0.1 % of the system".

c) Input a bunch of PV modules of a PV system

If you have just information about of a bunch of PV modules been installed in a PV system, you can also use the survey sheet to input the data. Fill in as much fields of the system basics as possible. However you must at least fill in the fields System ID, Source of data, Climate zone, PV module type, Nominal system power, Date of system start, Date of failure documented here. If you cannot give that input you should not use the data as input.

d) Input of failures

A requirement for filling in a failure is a power loss of the PV system or a safety failure. Try to select failures as accurately as possible. To support the selection of failures several examples of failures are given in the appendix. Precisely specified failures should be preferred to failure classes which describe the failure more generally. For each failure a power loss has to be specified which is caused by the failure. Two safety failures can be filled in which result from the specified failures. Safety failures are failures that may harm a person near the PV system. A safety failure can occur even without a power loss.

If a failure occurs in a part of the PV system that is not given in the list of "failed system part", then select an option for **Other system component** in the "PV system basic" section. The available other system components are listed in Tab. 1. In this case a failure for this system part can be specify in section "failed system part" named "Other system component".

Tab. 1: Description of other PV system components

Power transformer	Transformers are used to increase or decrease the alternating voltage level of the PV system to match the voltage of the electricity network [1].
Main DC cable	This type of cable connects the combiner box to the inverter.
Main AC cable	This type of cable connects the inverter to the transformer or to the external grid.
Battery	Batteries are used in energy storage systems.
Optimizer DC/DC	A DC/DC optimizer is a converter which is connected by installers to each PV module or embedded by module manufacturers, replacing the traditional solar junction box. An optimizer is used to increase energy output from PV systems by constantly tracking the maximum power point (MPPT) of each module individually [2].
Optimizer DC/AC	A DC/AC optimizer converts the current directly to voltage and frequency of the end-user grid.
Other electrical/electronic parts	E.g. monitoring devices.
Other mechanical parts	E.g. tracking system.

e) Input of special system characteristics

There are a lot special systems which may differ from standard systems. Some of these systems can be covered by the survey sheet and some not. Tab. 2 shows some special cases and gives suggestions how to fill the special characteristics into the survey format.

Tab. 2: Examples to input special system characteristics. Field names of the survey sheet are written in bold letters, choice options are written in italic letters.

Specialty	Choose in category	Item
Any kind of tracked system	**Kind of system** **Orientation**	*Tracked system commercial* or *Tracked test system* *Tracked*
Special location near the cost (10 km)	**Special stress**	*Island, coastal region (10 km)*
The system must be very anonymous	**Country**	*unknown*
Visual change, but no power loss and no safety failure	do not input	-
Climate zone	**Climate zone**	Please choose the related climate zone according to the Koeppen and Geiger classification, see link. Alternatively, an Excel sheet is provided that gives you the climate zone on basis of your geo coordinates.
If I choose in a **power loss** column the item *]0%-3%]* the cell gets orange		The measurement technique is normally not that precise that one can state a power loss of 3% or less. If you want to state a power loss of 3% or less please add into the **comment** row how you assured the power loss of 3% or less.

If you choose in one category the item *other* the field will turn orange and you should specify the input in the **Comment** field of the correspondent section of the survey. Fill in the name of the field where you choose *other* and add your information in the following format:

Category: information

If you have multiple categories with the item *other* in one section you can add multiple comments into the **Comment** field by separating them by semicolon, e.g.:

Comment: Kind of system: Modules are integrated into noise protection wall; PV module type: Bifacial monocrystalline Si

However we encourage the user to select one of the existing categories even if they do not fit exactly. For the former example you could also choose the following:

Kind of system: *Facade/roof integrated commercial*

PV module: *type monocrystalline Si*

Appendix - Failures of PV systems

The listed examples help you to fill in the data with the correct type of failure. The first examples, from ”external fire” to “unknown”, can be applied to almost every component of the PV system.

Fig. 3: Inverters are burned due to fire [8].

Failure due to external fire: External fire caused by e.g. a house fire can damage PV components. Fig. 3 shows an example for burned inverters due to a house fire.

Failure due to internal fire: Internal fire due to a malfunction of a system component. Fig. 4 shows an example for a burned combiner box.

Theft/vandalism: Modules/components/cables are stolen or vandalized.

No Failure: Choose this option when no failure occurred.

Other: Choose this option when the failure is not selectable and add a comment in the corresponding comment field of the section.

Unknown: Choose this option when the cause of the failure is unknown.

Fig. 4: A combiner box is destroyed due to fire [11]

<u>Inverter</u>

Complete failure: A complete failure of the inverter occurs due one or more malfunctions of single components of the inverter. One example for a complete failure is overheating due to a soiled air filter, see Fig. 5**:** and Fig. 6 [3]. A total performance loss of the inverter is an indicator for a total failure, if all other parts of the system working properly.

Fig. 5: A soiled air filter causes overheating 1 [3].

Fig. 6: A soiled air filter causes overheating 2 [3].

Fig. 7: Inverter failure due to an exploded insulated-gate bipolar transistor [4].

Partial failure: In general, the inverter operates properly, but at a specific date a partial/total power loss is observed or the inverter does not work at its specified efficiency. This failure can occur due to a hot ambient temperature at summer days or due to a poor programming/software of the inverters control unit. This failure also has to be chosen if the inverter has problems with MPP tracking at changing weather conditions [5]. A difference between the specified/typical energy yield and the actual yield is an indication for this failure. The annual energy yield loss has to be written in the field “Total system power loss”.

Interconnect failure: The interconnection between cables and inverter components are corroded or worn out (e.g. Fig. 8). You can detect the failure by visual inspection.

Fig. 7: Corroded interconnection, Image taken from Ref. [12].

PV module

An overview of typical PV module failures can be found in the ”Review of Failures of Photovoltaic Modules” [6] (the document can be accessed from here).

Some defects occur during the processing of the solar cells, the manufacturing of the solar panel, during the installation or during the operation of the PV system. There are two failure that typically occur during the operation in the field:

a) Light induced degradation (LID) and light induced degradation at elevated temperatures (LeTID)
b) Potential induced degradation (PID) that can be further classified in sub-groups: (i) shunting, (ii) polarization and (iii) corrosion.

The LID effect is caused by the formation of a chemical complex that involves boron and oxygen [7]. The LID effect strongly related to the boron concentration of the typically used p-type wafers and is not present in n-type based solar panels. The LeTID effect is also harming the performance of the silicon wafer material. By using the electroluminescence (EL) techniques [8], it is possible to distinguish the LeTID degradation effect from others due to its specific pattern in the EL image of solar module, an example is shown in Fig. 8.

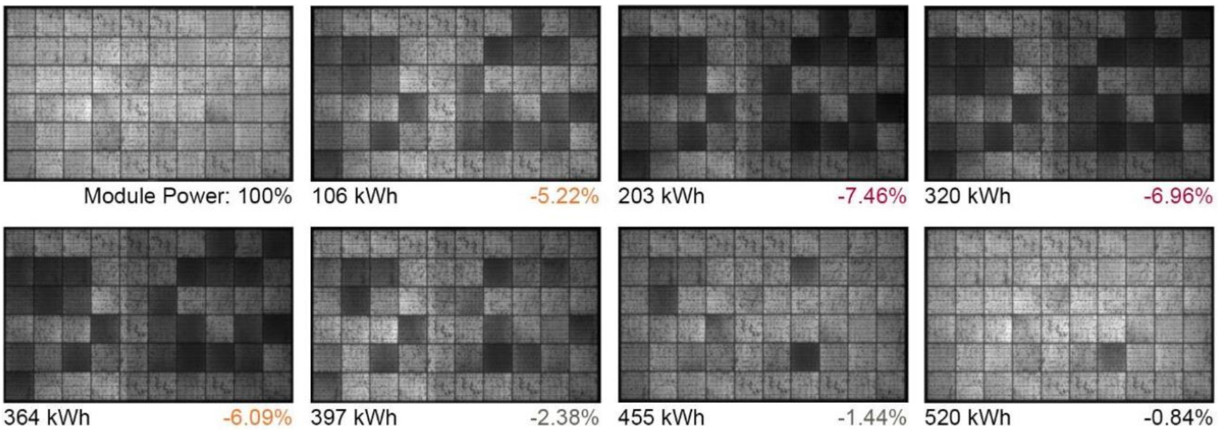

Fig. 8. Electroluminescence images (bright contrast refers to high electrical power) and measured output power at STC conditions of (left upper image) non-treated solar module and (other images) solar modules that suffer from light induced degradation at elevated temperatures (LeTID) with corresponding relative power loss [9].

The PID effect is also visible in EL images and shows a typical pattern with harmed solar cells often located at the edges of the solar module (Fig. 9).

Fig. 9: Electroluminescence images (bright contrast refers to high electrical power) of PID affected solar module. Image taken from Ref. [10].

Mounting

System design failure: This failure occurs due to nonconformity of the system to national or international guidelines, the generally recognized rules of technology or the state of the art.
For example, the PV system is not designed to withstand the load of wind and snow which are typical for the plant site (e.g. Fig. 10) or the plant site is shaded by trees or buildings (e.g. Fig. 11). If the PV system is exposed to a corrosion promoting environment (e.g. Fig. 12) without considering the use of corrosion resistant materials, this failure must be chosen as well. This failure has to selected, if two requirements are fulfilled. First, the plant design does not fulfill the standards for the typical load of the plants environment, for example regional snow load. Second, a failure occurred.

Fig. 10: Destroyed system after high wind load [18].

Fig. 11: Shading due to poor design [3].

Fig. 12: Corrosion due to salt water [17].

Overload of structure: Even though the system is designed to withstand the typical environmental conditions, an extreme weather event, untypically for the plant site, causes a failure in the substructure/ mounting system (e.g. Fig. 13, Fig. 14, Fig. 15). This failure must be chosen if the system design fits with the required specification of wind load and snow load for the plant site and an extreme weather condition exceeds the typical environmental conditions of the plant and causes a failure.

Fig. 13: Mounting system collapsed due to high wind load [13].

Fig. 14: Cracks due to mechanical stress [14].

Fig. 15: Structural subsidence due to snow load [15].

Material failure: Parts of the mounting structure brake down due to material failure. A material failure has to be chosen if the component does not withstand the load which it is designed for (e.g. Fig. 16, Fig. 17). Bendings, cracks and fractures of screws, brackets, clamps and rails can be detected by visual inspection.

Fig. 16: Screw canal bends due to mechanical stress [19].

Fig. 17: Bracket fractured due to mechanical stress [19].

Indentation/damage of the roof: This particular case shows no failure and no safety issue of the PV system itself. Therefore neither a power loss nor a safety failure can be specified. The weight of the PV system and the ballast is causing the mounting system to sink into the roof system, creating a localized low spot for water to accumulate (e.g. Fig. 18). Continued thermal cycling can cause roof membrane failure and a subsequent water leak. Poor mounting practices, such as affixing roof hooks directly to roof shingles, can cause roof leaks, and will void manufacturer's material and system warrantees [7]. An example for a crack in a roof shingle is given in Fig. 19. To determine the failure you have to investigate the roof and look out for wet/low spots around the roof mount array or cracks in in the roof shingle. If it is possible for you to specify the financial costs (e.g. repair costs of the roof) in American dollars (USD), enter the value in the comment field. If this is not the case, do not consider this failure.

Fig. 18: Localized low spot for water [7].

Fig. 19: Roof shingle has contact to roof tile [16].

Clamp detachment/improperly installed: An improperly installed end clamp compromises the integrity of this mounting system and the ability of the module to stay in place during high winds (e.g. Fig. 19) [7]. The most common mistake in module clamping, is their improper installation that can lead to damage of the module and sometimes to its detachment from the mounting structure (e.g. Fig. 21). To determine the failure you have to visually inspect the end brackets and the mounting practice on the roof.

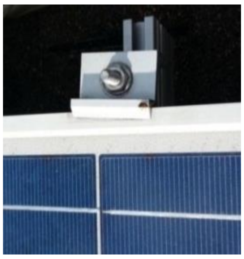

Fig. 20: Improperly installed end brackets [7]

Fig. 21: Wrong combination of clamps and modules are used [3].

Interconnection

Connector does not fit: This failure occurs due to the fact that connectors of two different manufactures or even different types are used, shown in Fig. 22 and Fig. 23, which lead to a increased contanct resistance and a leaky connection of the connectors [3], [8], [9]. Fig. 24 describes correct and incorrect crimped cables. These failures can be identified by visual inspection. At humid weather mismatching connectors can lead to a partial failure of the inverter. In this case the resulting yield loss has to be specified for the “Connector does not fit” and not for the inverter.

Fig. 22: Different type of connectors 1 [8].

Fig. 23: Different type of connectors 2 [3].

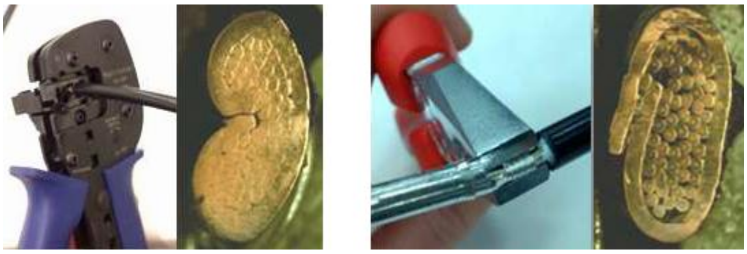

Fig. 24: : Left images show correct crimping, right images shows incorrect crimping [8].

Connector corroded: This failure contains all types of corroded connectors (see Fig. 25) due to e.g. oxidation, penetrating moisture and varying temperatures. The use of connectors of two different types as explained in the failure description “Connector does not fit” increases the effect of corrosion. You can detect the failure by visible inspection.

Fig. 25: Corroded connectors [20].

Defect combiner box: Single strings are combined in combiner boxes. For instance not properly addressing thermal expansion of conductors inside raceways causes damage at box fittings [10]. An example for a defect combiner box is given in Fig. 26. Another example of a defect combiner box due to improper wire torquing is shown in Fig. 27. Blank wires, a lack of insulation or discolored parts of the terminal block can be found by visual inspection.

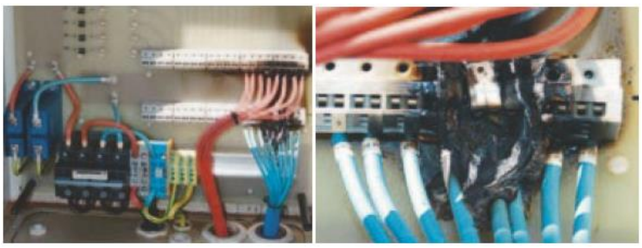

Fig. 26: Burned terminal block of the combiner box [21].

Fig. 27: Improper wire torquing causes a fire [10].

Defect/triggered string fuse: Fuses protect conductors and other equipment against overcurrent. A string fuse protects the PV modules against reverse current. An example of a triggered string fuse is given in Fig. 28. The fuse triggered due to a faulty connection between fuse and fuse holder [4]. A discolored fuse is an indication for a defect/triggered fuse.

Fig. 28: Triggered string fuse [4].

Animal bite/other animal issues: An example for an animal bite is given in Fig. 29. The failure can be determined by visual inspection. Very often an additional partial failure of the inverter occurs when the cable isolation is insufficient. In this case the resulting yield loss has to be specified for the "Animal bite/other animal issue" and not for the inverter.

Fig. 29: Damage of cable due to rodent bite [22]

Isolation failure: Degradation of insulation of cables due to mechanical stress/corrosion (e.g. Fig. 30, Fig. 31) Sometimes the bare wire is visible, whereas partly degradation is found more frequently.
The failure can be determined by visual inspection. Very often an additional partial failure of the inverter occurs when the cable isolation is insufficient. In this case the resulting yield loss has to be specified for the "Isolation failure" and not for the inverter.

Fig. 30: Mechanical degraded cable insulation [23].

Fig. 31: Degraded cable insulation due to corrosion and mechanical stress [24].

Wrong interconnection: This failure describes a wrong interconnection of PV system components e.g. due to connection of wires/cables with reversed polarity.

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