Alfred Kärcher GmbH & Co. KG

iSolar800 Cleaning System

Cleaning Action and Handling

DLG Test Report 6103 F

FOKUS TEST
10/12 Cleaning Action and Handling

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DLG e.V.
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Evaluation in summary form

Test Criteria/Test Result	Rating*
Cleaning Action	
– **Laboratory Test:** Good cleaning effects, depending on parameters	+/++
– **Practical Test:** Visually very good effects, the level of actual improvement in performance depends on the particular PV installation, the season and irradiation	+
Handling	
– Mechanically, no damage was detected	○
– Considerable time savings compared to manual cleaning	+
– With a telescopic length of up to ca. 8 m in a straight line, good control of brushes possible	N.E.
Safety	
– Safety measures are to be observed during roof access from above (e.g. harness) or from below (e.g. cherry picker)	○
– Detailed operating instructions provided	○
– Reviewed by DPLF (German Centre for the Testing and Certification of Agricultural and Forestry Technology)	N.E.
Insulation Test and Insulation Resistance in Wet Conditions	
– Normative requirements are fulfilled. Despite a partial deterioration in the insulation resistance, a 'high' to 'very high' level is retained.	N.E.

* Range of evaluations: ++/+/○/–/–– (○ = standard)/N.R. = no result

Test Result

The iSolar800 photovoltaic (PV) cleaning system has passed the DLG FokusTest for Cleaning Action and Handling.

Based on this test result, the system is in principle suitable for the cleaning of PV installations, preferably in agricultural areas.

Principal Technical Data (Manufacturer's information)

Design

Cleaning Brushes

Solar cleaning system consisting of two contra-rotating brushes mounted on ball bearings which are propelled by the water jet of a high-pressure washer, with flexible brass angle joint.

Telescopic Rods

In order to use the cleaning system, a telescopic rod is required. Depending on the design, this is made out of a glass and carbon fibre mixture or full carbon. It is available in different overall lengths.

High-Pressure Washer

The cleaning system is operated by a high-pressure washer which must be supplied by the user.

iSolar800 Cleaning Brushes

Working Width	800 mm
Weight	7 kg
Flow Rate	700 – 1000 l/h / 1000 – 1300 l/h
Connection	M18 x 1,5IG

Telescopic Rods

	iSolar TL 7 H	ISolar TL 10 H	iSolar TL 10 C	iSolar TL 14 C
Weight	3.5 kg	4.0 kg	3.7 kg	5 kg
Length	1.8 m–7.2 m	2.4 m–10.2 m	2.4 m–10.2 m	2.4 m–14 m
Connection	M18x1.5AG/M22x1.5AG	M18x1.5AG/M22x1.5AG	M18x1.5AG/M22x1.5AG	M18x1.5AG/M22x1.5AG
Material	Glass and Carbon Fibre Mixture	Glass and Carbon Fibre Mixture	Full Carbon	Full Carbon

High Pressure Washer

Type	HDS 8/18-4 C
Power Rating	6.0 kW
Flow Rate Water	300 – 800 l/h
Working Pressure Water	30 – 180 bar
Maximum Operating Pressure	215 bar
Burner Capacity	61 kW
Fuel	Extra-light heating oil or diesel
Length x Width x Height	1060 mm x 650 mm x 920 mm
Weight	126.1 kg

Test Criterion "Cleaning Action"

The test criterion "Cleaning Action" for DLG-FokusTest's "Cleaning systems for PV modules" was investigated in a laboratory as well as a practical setting.

I. LABORATORY TEST

Test conditions and performance of the test

The laboratory test is intended to demonstrate the suitability of the system for cleaning photovoltaic (PV) modules. For this purpose, 10 structurally identical, standard photovoltaic modules were used by the testers and coated with standardised pollution. After a period of exposure and drying, two modules were cleaned using identical cleaning parameters, i.e. five different cleaning variations such as cleaning temperatures or the addition of cleaning agents could be evaluated.

For the evaluation of the cleaning action of the PV modules, the following individual tests were carried out based on or in accordance with international norms:

- Determining electrical capacity under standard test conditions (10.2*) with a Class A solar simulator
- Gloss level of front glass**
- Insulation test (10.3*)
- Insulation test in wet conditions (10.15*)
- Visual test (10.1*)

In the first stage, the gloss levels, performance values and insulation resistance of a new, unused module were recorded and an initial visual test carried out. The documented values were used as reference and benchmark values during the test.

Image 2:
Module cleaning during laboratory test

Subsequently, a pre-determined staining of the PV modules was carried out with a DLG standard pollutant for the external areas of a shed or stable. This polluting process was based on EN ISO 15883-5. In addition, knowledge of the composition of dust from the exhaust air of stables was taken into account. In this way, a high practical relevance can be achieved. The pollutant was applied to the 10 modules uniformly and opaquely and, depending on the testing approach, was dried over 5 to 7 days.

In this polluted condition, the second performance measurement and visual test of the modules were carried out. This determines the actual level of pollution. In these conditions, a measurement of the gloss level was not possible.

The pairs of modules were then each cleaned according to the manufacturer's instructions as follows:

- With cold tap water (ca. 20 °dH and 10 °C)
- With warm tap water (ca. 20 °dH and ca. 60 °C)
- With cold tap water and cleaning agent (1 % concentration)
- With warm tap water and cleaning agent (1 % concentration)
- With soft water (ca. 0 °dH and 10 °C)

Comment:

Based on the results of this test, the manufacturer prepared guidelines on the maximum water temperature. According to the manufacturer, the maximum temperature for long-term use must be reduced to 40 °C in order to guarantee the fatigue limit of the brushes.

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* Test step in accordance with IEC 61215 "Crystalline silicon terrestrial photovoltaic (PV) modules – design qualification and type approval"

** Based on DIN EN ISO 7668 "Anodizing of aluminium and its alloys – measurement of specular reflectance and specular gloss of anodic oxidation coatings at angles of 20 degrees, 45 degrees, 60 degrees or 85 degrees"

As with the practical cleaning, cleaning in the laboratory test was carried out for exactly 60 seconds.

The module was cleaned for 30 seconds from top to bottom on the left-hand side. For the other 30 seconds, the module was cleaned on the right-hand side from bottom to top (See Image 2).

The switchover took place without putting down or turning off the cleaning system.

A telescopic rod with a length of 2 m was used during cleaning (maximum length of rod 7.2 m).

After the module was completely dried, a third performance measurement as well as visual test was carried out. The gloss level and both insulation resistance levels were subsequently investigated again.

On the basis of the measurements recorded and their analysis, an evaluation of the system's cleaning action was made.

For the purposes of a comparable visual examination, after the cleaning process a structurally identical reference module was available to the testers.

Change in performance through cleaning

On average, the laboratory-based pollution caused a reduction in performance of 14.9 %. This loss of performance reflects the actual loss incurred by a heavily polluted roof at an agricultural facility.

In order to determine the performance ability in weaker irradiation conditions, measurements in irradiance intensity of 800 W/m² as well as 200 W/m² were carried out in addition to the standard test conditions (STC: solar radiation 1000 W/m², module temperature 25 °C, spectrum AM 1.5). For the evaluation of the cleaning action, only values below STC were assessed.

Tables 1 and 2 show how much of the performance loss caused by the pollution in each cleaning parameter can be offset by the cleaning system (cleaning action).

The results of the cleaning action in the tables below only partly illustrate the results that can be achieved in practice. A lower value in the cleaning action does not mean that cleaning is functioning poorly but that cleaning time must be increased. This could be demonstrated in a second series of tests (Table 2).

Gloss Level

The gloss level of the front glass of the PV modules was measured before cleaning (i.e. the modules were new and unused) and after cleaning.

The measurement was carried out in accordance with EN ISO 2813 and DIN 67530 using a glossmeter at test angles of 20°, 60° and 85°.

For the purposes of clarity, in this report only the gloss level at 60° will be discussed (see Image 3).

The respective gloss level is the average of 9 measuring points on a module. As has been confirmed in validation measurements, this measurement variable can only be repeated satisfactorily with a deviation of ca. 1 %.

Table 1:
Cleaning action with different parameters (Test Series 1)

Water Temperature	Cleaning Time	Cleaning Agent	Soft Water	Performance Measurement	Cleaning Action
10 °C	1 minute	No	No	STC1*	31 %
10 °C	1 minute	1 %	No	STC*	35 %
10 °C	1 minute	No	Yes	STC*	46 %
60 °C	1 minute	No	No	STC*	94 %
60 °C	1 minute	1 %	No	STC*	100 %

Table 2:
Cleaning action with different parameters (Test Series 2)

Water Temperature	Cleaning Time	Cleaning Agent	Soft Water	Performance Measurement	Cleaning Action
10 °C	1 minute	No	No	STC*	46 %
10 °C	1 minute	0.25 %	No	STC*	57 %
10 °C	2 minutes	No	No	STC*	96 %

* STC = Standard Test Conditions (see page 5)

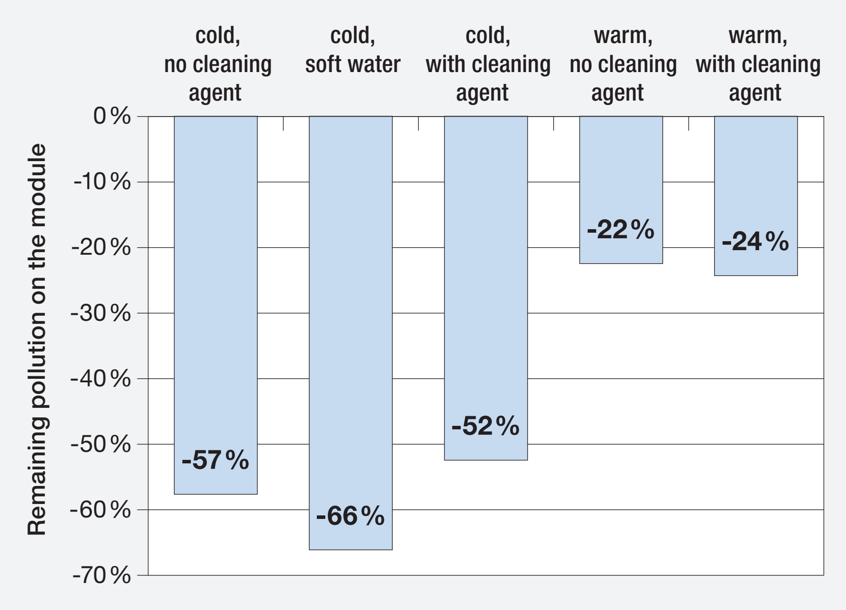

Image 3:
Change in gloss level after cleaning – the bigger the value, the bigger the remaining pollution

of both installation parts measured again for 24 hours. The differences should confirm the cleaning action attained in the laboratory test.

In order to evaluate the cleanliness of the module surface, the gloss levels of the front glass of the polluted and cleaned modules were compared with each other as in the laboratory test.

The first farm was a pig and dairy farm in the district of Böblingen with a quarry located nearby. The PV installation there consists of framed crystalline PV modules. The second farm was a poultry farm in the district of Darmstadt-Dieburg. In close proximity to the farm was a maize drying facility. On this farm, frameless thin-film PV modules had been installed.

Insulation test in wet and dry conditions

For the insulation test in wet and dry conditions, the requirements of IEC 61215* (no disruptive discharge, no surface crack, insulation resistance of at least 40 MΩm²) were fulfilled.

In dry conditions, resistance values of between 804 MΩm² and 1672 MΩm² were measured in new, unused modules. In wet conditions, values of between 104 MΩm² and 267 MΩm² were measured. After cleaning, the insulation resistance values did not change compared to the start values.

The constancy of the insulation resistance values shows that the modules are not damaged by a one-off cleaning process.

II. PRACTICAL TEST

Test conditions and performance of the test

For the practical testing of the cleaning performance, two farms were selected in order to clean PV installations under practical conditions.

In so doing, the energy generated in one day by the module strings was measured directly in front of a solar inverter. Afterwards, each string was cleaned and the energy

Generated Energy and Performance

Farm 1

Farm 1 had a relatively clean roof compared to Farm 2. This is because the last cleaning had only taken place 4 weeks previously and there had been high rainfall levels before the testing period.

At the time of testing at this installation, there was only a small amount of sunshine available for the total length of testing. Tables 3 and 4 show the impact of cleaning with the iSolar800. Both the improve-

Table 3:
Farm 1 – Comparison of peak performance

Peak Performance (W)	String 1	String 2	Difference between String 2 and String 1
Before Cleaning	2022.33	2054.20	+1.58 %
After Cleaning	1878.38	1918.90	+2.16 %
Impact of Cleaning	+0.58 %		

Table 4:
Farm 1 – Comparison of output

Output (Wh)	String 1	String 2	Difference between String 2 and String 1
Before Cleaning	1863.13	1897.76	+1.86 %
After Cleaning	3062.17	3132.75	+2.31 %
Impact of Cleaning	+0.45 %		

* IEC 61215 "Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval"

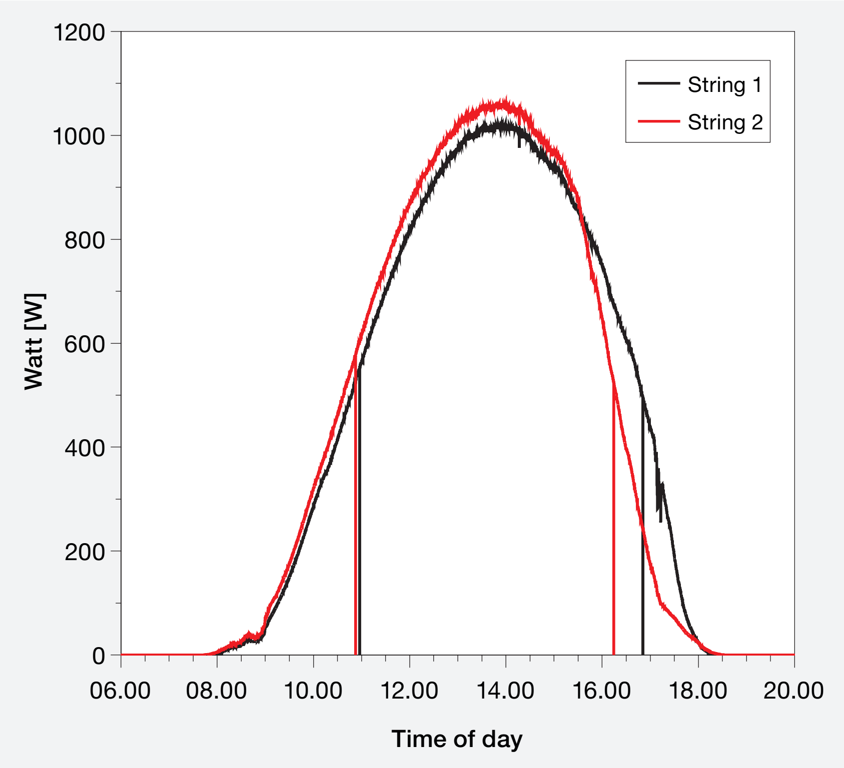

Image 4:
Comparison of performance cycle in one day of Strings 1 and 2 at Farm 2

ment in peak performance and gain in output were recorded at approximately 0.5 %. Even before cleaning, String 2 was performing better than String 1.

With cleaning, the performance and output of String 2 further improved. In the foreground of Image 5, the cleaned modules (lower row) are visible. All rows located higher were not cleaned.

Optically, clear differences in the gloss can be seen.

Farm 2

Only the results from the time period are representative of the comparative assessment because:

- Before 9.15 am there was little direct sunlight available
- After 3.15 pm there was shading on String 2 (see Image 4)

At Farm 2 there was a considerably dirtier roof.

Image 5:
Comparison between cleaned modules (lower row) and uncleaned modules (upper rows)

At the time of testing, there was an almost permanently high solar radiation for this time of year.

Tables 5 to 7 show the impact of cleaning with the cleaning system. Both the improvement in peak performance and gain in output were recorded at over 7 %. Before cleaning, the output from String 2 was approximately 2.5 % less than the output from String 1. With cleaning, the performance and output from String 2 improved so much that it achieved higher values than String 1. As a result, String 2 achieved an almost 8 % increase in output and an approximately 7 % increase in peak performance.

In the foreground of Image 6 the cleaned modules are visible (the 5 visible lower rows). All rows located higher were not cleaned.

Optically, massive differences in the gloss can be seen which were

Table 5:
Comparison of peak performance

Peak Performance (W)	String 1	String 2	Difference between String 2 and String 1
Before Cleaning	1182.14	1142.78	-3.33 %
After Cleaning	1022.55	1061.45	+3.80 %
Impact of Cleaning	+7.13 %		

Table 6:
Comparison of output

Output (Wh)	String 1	String 2	Difference between String 2 and String 1
Before Cleaning	4448.58	4202.11	-5.54 %
After Cleaning	5771.19	5848.89	-1.33 %
Impact of Cleaning	+4.21 %		

Table 7:
Comparison of output from 9.15 am to 3.15 pm

Output (Wh)	String 1	String 2	Difference between String 2 and String 1
Before Cleaning	3310.69	3233.75	-2.32 %
After Cleaning	4383.53	4629.81	+5.62 %
Impact of Cleaning	+7.94 %		

Image 6:
Comparison between cleaned modules (lower rows) and uncleaned modules (upper rows) at Farm 2

also confirmed in the measurement of the gloss level (see section on gloss level).

Comments on the impact of and differences between farms

In principle it should be noted that the practice tests are based on snapshots. Therefore, no conclusions can be reached on whether a measurement taken over the course of a single day applies to the additional output for an entire year. The value can be higher as well as lower as a result of a number of influencing factors, e.g. temperature, position of the sun, weather, etc. The testing proved with certainty that the cleaning of heavily polluted PV installations can be considered a sensible approach. The level of pollution at which cleaning should be carried out should depend on an efficiency analysis.

The level of pollution found at Farm 1 was not very strong with the result that only a slight improvement in the relevant values could be achieved (compare page 5). At Farm 2, the differences before and after cleaning were more obvious (compare page 7).

The values measured cannot be automatically applied to other PV installations.

Gloss Level

As in the laboratory test, in the practical test the gloss levels of the polluted and cleaned front glass pieces were also measured directly on the roof with a glossmeter. At both farms, the gloss level increased after cleaning. This confirms the visual impressions.

At Farm 1 the gloss level increased from 37 GU to 53 GU.

At Farm 2 the gloss level before cleaning was 66 GU. After cleaning it increased to 99 GU.

The absolute values vary because of the different types of glass and do not make inferences about the cleaning quality. However, in both practical tests, a clear improvement in the gloss was identified. Therefore in relative terms, the data demonstrate a good cleaning performance.

Test Criterion "Handling"

Test conditions and performance of the test

At both farms, in addition to the performance effects, the practical application in relation to the system's functional reliability and occupational and operational safety was evaluated. In addition, two possible approaches could also be compared. Firstly, the cleaning can be carried out from the crest of the building roof with the operator secured with a harness and the modules cleaned from top to bottom (see Image 8). Alternatively, the modules can be cleaned from bottom to top with the operator working in a cherry picker at the level of the eaves (see Image 7).

Functional reliability and operational safety

During use in the test, the cleaning system did not malfunction. Similarly, no occurrence of deterioration was detected.

However, during the course of use, a discolouring of the brushes did occur. At this point, the manufacturer responded and the white brushes were replaced with black brushes.

Because of the easy handling, there was no incorrect operation of the cleaning system during the test. It should be noted here that the persons conducting the test had received instructions from the manufacturer and also received operating instructions during the testing. Such instructions are recommended for an operator of the system.

The results of the functional reliability and operational safety tests relate to the evaluation of the pilot batch of the cleaning system. They do not apply to further developed cleaning systems of the same type.

Only the testing period was examined. An evaluation for long-term use is therefore not possible.

User friendliness and recommendations for use

In principle, the cleaning system can be well handled. Using both a

Image 7:
Cherry picker occupied by two people for cleaning upwards.

cherry picker at the level of the eaves as well as standing on the roof, the cleaning can be controlled very well and leads to good results.

However, it should be noted that cleaning requires a certain exertion of strength. This increases significantly depending on the length of the telescopic rod. For this reason it is recommended to clean at a length of up to approximately 8 m and to only work with a longer rod in exceptional cases. Observations made during the practical test have showed that brushes with a rod length of 14 m no longer lie flat on the modules due to sagging. During the course of the testing, the manufacturer dealt with this problem. A new design was introduced with the flexible angle joint for the telescopic rod located centrally between the two rotating brushes. In order to reduce the exertion of strength and to guarantee better handling, cleaning should only be carried out in a straight line, i.e. with the telescopic rod running parallel to the roof verge and the operator standing directly behind the rod.

It is advisable to carry out the cleaning with two people. In this way, one person can use the cleaning device while the other is responsible for supporting hand movements, e.g. operating the cherry picker, handling the hoses or operating the high pressure washer (compare Images 7 and 8). Working in a pair eases the cleaning process and increases safety.

Similarly, it should be noted that there is an increased danger of sliding while cleaning on the roof crest due to water splashing. To prevent this, suitable footwear should be worn and a secure footing established.

In addition, before the start of any cleaning work, the roof pitch must be taken into consideration. The practical tests showed that cleaning on the roof crest while standing is possible with a roof pitch of up to 40°. However, the cleaning becomes considerably more difficult with an increasing roof pitch and hides a higher potential risk. The roof pitch must be factored into any decision on how the cleaning will be carried out.

A very important point which must normally be borne in mind when cleaning PV modules is the difference in temperature between the modules and the water. This difference cannot be too big as otherwise it could lead to very high tension in the glass surface and in a worst case to a crack in the glass. Such irreparable damage must be avoided at all costs. Generally, cleaning should take place only in the mornings or evenings and/or in cloudy weather as at these times the module temperature is at its lowest. Another option is to adapt the water temperature to the module temperature. However in doing so, the manufacturer's maximum temperature of 40 °C should be adhered to.

Note: A PV module can reach temperatures of up to 80 °C during use.

Image 8:
Two people on roof cleaning downwards.

Overview of practical tests

	Pig Farm: Barn Roof/Horse Stable	Pig Farm: Machinery Shed Roof	Poultry Farm: Stable
Cleaning Parameters*	**Farm 1**	**Farm 1**	**Farm 2**
Temperature			
	Cold	Cold	30 °C
Cleaning agents			
	No	0.25 %	No
Water			
	Soft Water	Soft Water	Soft Water
Water flow			
	Ø ca. 13.8 l/min up to 14.5 l/min		Ø ca. 14 l/min
Pressure (high pressure washer)			
	ca. 50 bar		ca. 50 bar
Energy requirements (high pressure washer)			
	ca. 0.8 kW		
Period of time since last cleaning of modules			
	4 weeks	4 weeks	Never cleaned
Pollution level			
	Faint layer of dirt visible	Faint layer of dirt visible; scattered bird droppings	Clearly visible (maize drying facility located nearby)
Duration of cleaning**			
	7.25 min/10 modules = 34 s/m²	11.5 min/21 modules = 26 s/m²	1.25 min/6 modules (frameless) = 17 s/m²
Use of cleaning agents			
		2 l solution of: 1 l concentrate + 3 l water for 21 modules (80 cm x 120 cm)	
Roof access			
	Cherry Picker	Harness	Cherry Picker
Telescopic rod used			
	7 m	14 m	10 m

* Single-phase cleaning with no coarse pre-cleaning or rinsing

** The duration of cleaning and the work rate is very dependent on the operator's experience. With further practice, the work rate can be increased.

Work Rate

At Farm 1 all installed units were manually cleaned with sheepskin on a regular basis. For this, 15 man days were needed for a total module surface of 2000 m², including set-up time. This equates to 3.6 min/m² or 133 m² per day.

With a calculated work rate of 2 x 0.5 min/m² with the cleaning system, at Farm 1 only 4.2 man days (without set-up time) would be necessary in order to clean the entire module surface area. This equates to 480 m² per day. Taking into consideration the set-up time, with the help of the cleaning system approximately two-thirds of the time originally required can be saved.

According to the manufacturer a work rate of 100–300 m² per hour can be achieved. The work rate is dependent on the following factors:

- Direction of work (according to the manufacturer: standing on the roof working downwards ca. 200–300 m² per hour, in a cherry picker working upwards ca. 100–150 m² per hour)
- Level of expertise of operator
- Degree of pollution
- Accessibility of modules (set-up times)
- Working length of telescopic rods

Occupational Safety

The Kärcher solar cleaning system iSolar800 was reviewed by the German Centre for the Testing and Certification of Agricultural and Forestry Technology (DPLF). From an occupational safety perspective there are no objections against the use of the system.

Test

The focus test included a test of the cleaning performance of a cleaning system for PV modules under laboratory conditions and in a practical test at two farms.

Based on the available results the iSolar800 meets the requirements of the test criterion "Cleaning Action and Handling" (rating "○" or better) for the award of the DLG-FokusTest seal of approval.

Other criteria were not tested.

Performance of the tests

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