

Testing Report
Arc Fault Circuit Interrupter (AFCI) Protection
of
United International University (UIU)
Location: United City, Madani Avenue, Badda, Dhaka, Dhaka 1212,
Bangladesh.

Tested product:

Inverter Model: SUN2000-50KTL-M3

Tested By:
Huawei Technologies Co., Ltd.
Testing Date: 16 October 2024

1. Background

1.1 Introduction

Electricity is the most valuable type of energy consumed by humanity in an uninterrupted rhythm because most applications require electricity in different forms, e.g. heating, cooling, cooking, cell phone use. All these basic daily needs require different energy quantities, summing up a certain amount of electricity. At the moment, everything related to technology is also related to electricity, as it acts as a driving force for every new technological innovation that exists.

The installation of photovoltaic systems has been increased rapidly during the recent years, as technology continues to evolve and the performance ratio of these systems increases accordingly. As PV installations have increased and take place in a variety of environments, such as large agricultural fields (for utility scenarios), as well as C&I rooftops and residential rooftops, safety issues should be even more seriously considered. Arc faults can easily represent a cause of fire in PV inverters, in PV systems and consequently in the house where the PV system is installed. This has harmful effects on the environment and also on humans.

1.1 Fire Danger from Distributed PV System

This century is characterized by the increased installation of Renewable Energy Sources in any form, mainly of Photovoltaic and Wind Parks. The size of such installations varies from a few kW up to MWs. Thousands of such investments are already in operation and even more are planned for the near future. All this dispersed or distributed power production through PV and wind systems is opening a new era in the electric power networks. Smart grids are being installed and tested utilizing dispersed resources.

Rooftop PV systems are usually divided into residential (kW size) and industrial/commercial (kW-MW size) ones. Risk is a concept that is determined by the probability of occurrence and the severity of loss. Independently from the rooftop size and the kW of the PV system, many representative cases of fire incidents have been noted around the world. The wide wiring range, possible inverter faults, high current-carrying cables, loose electrical connections may be causes of an arc phenomenon that can lead to a fire. The problem is multiplied because the place of installation is above resident or working people. Nevertheless, the lost energy

because of such a severe fault is significant due to the increased difficulty and extended time of restoration of the whole system.

More specifically, PV systems are composed of electrical components, so they are at risk of the traditional fire ignition types that are usually associated with electrical systems. Within internal PV systems, the following are the most common primary ignition scenarios:

- Incorrect or poor mechanical installation can cause DC arc faults and overheating.
- PV components of poor-quality result in DC arc faults and overheating.
- Overheating and DC arc faults caused by age or deterioration of PV components, resulting in spontaneous igniting.
- Hot spot effects that cause localized overheating.
- Product failure or system component defect that causes localized overheating.

The causes of fire in PV systems can be classified into DC arc fault and localized overheating of PV components. In comparison to AC arcing, DC arcs are more dangerous because the voltage continues to remain after the arcing is established.

As a result, it is important to investigate the possible causes of fire hazard of both new and old PV modules, as well as other PV components.

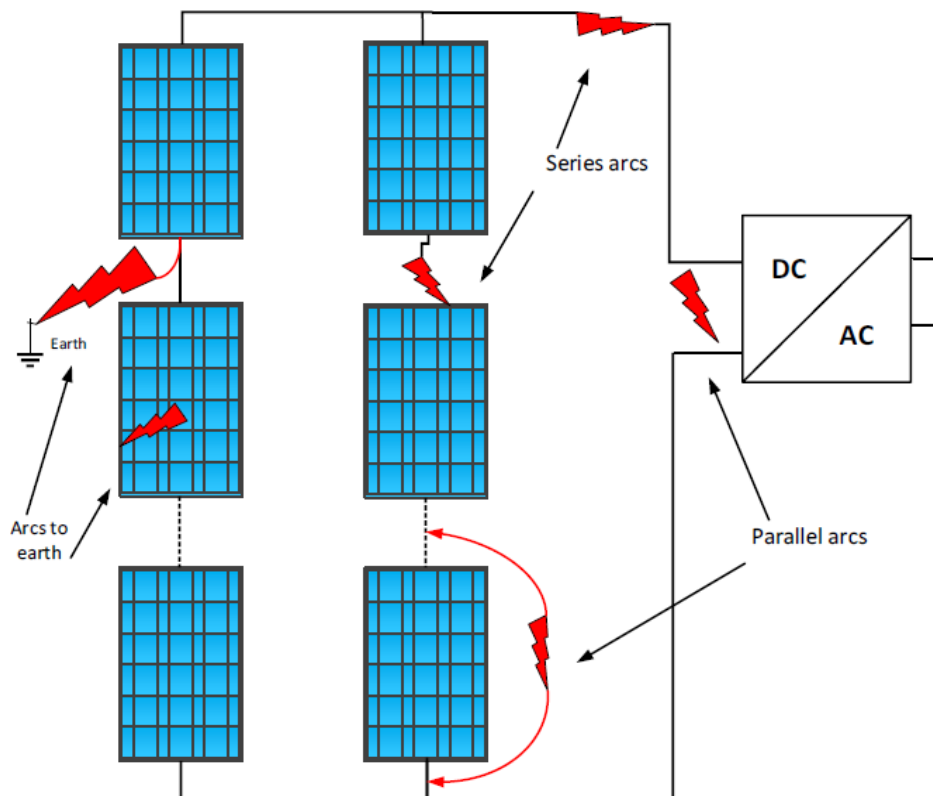
Major event and components	Failure type grouping		
	UK	Germany	Australia
S01: Ignition caused by PV module	PV modules	Module, Junction box, Cell connector	Exterior roof/Solar panel
S02: Ignition caused by isolator	DC isolators	DC switch, AC switch	Isolator
S03: Ignition caused by inverter	Inverters	Inverter electronics, Inverter, Transformer, AC distribution	Inverter/Switchboard/Overload
S04: Ignition caused by combiner box and fuse	DC combiner box	DC fuse, Generator junction box, AC fuse	N/A
S05: Ignition caused by cable	DC cables	DC cables	N/A
S06: Ignition caused by connector	DC connectors	Crimping, DC terminal, AC terminal, DC plug, AC plug	N/A
S07: Unidentified or unrelated source of ignition	Unidentified components	N/A	Batteries, Exterior Other, In-House, Other, Deficiency/Failure Electrical, Unknown

In conclusion, together with the PV modules, the number of connectors is proportional with the capacity of the PV system, and it is assumed that the quantity of PV modules and connectors are significantly higher than the quantity of isolators and inverters, which indicate a higher failure rate of the two last-mentioned components despite the similar failure frequency.

2. Technical Description

2.1 ARC Faults in PV System

There are three main types of arcs, which are Series arcs, Parallel arcs and arc to earth. The most frequent arcs in these installations are series arcs, which are mostly brought on by poor cable connections. A partial short circuit between two neighboring wires or circuits with varying potentials might result in parallel arcs. Inadequate insulation of the system to the earth leads to arcs to the earth. Arcs to ground and series arcs are more likely to occur in PV systems than parallel arcs because the wire is double insulated, a fact which reduces the chance of a parallel arc.



Several accidents involving fire hazards have been reported in recent years, but most of these accidents are caused by a lack of knowledge about different types of failures in photovoltaic systems. Photovoltaic systems installed today do not have built-in self-contained protection against fire, personal injury and death due to DC electrical failure. Arc flashes and fires pose the biggest threat to personnel safety in a PV system.

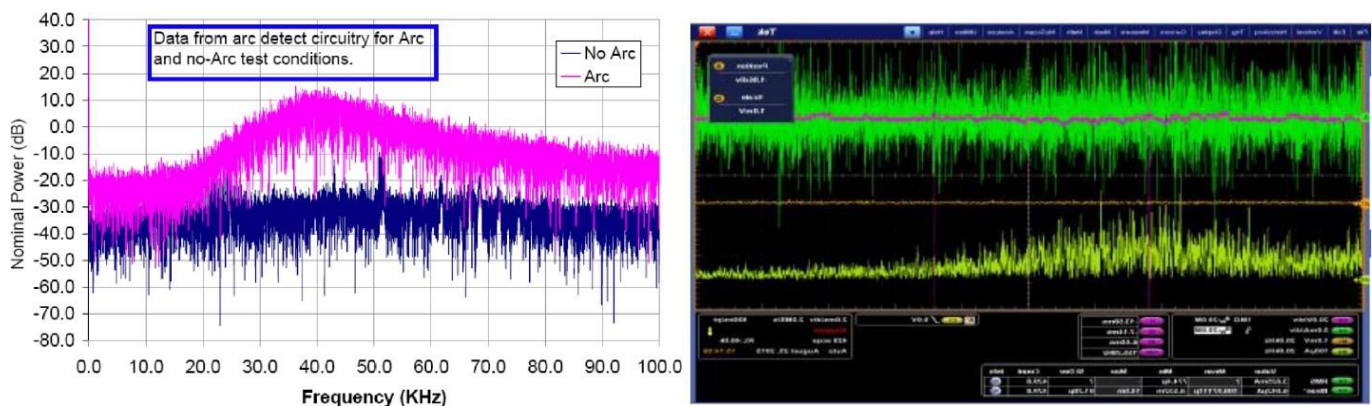


2.2 Technical Features of Huawei AFCI Function

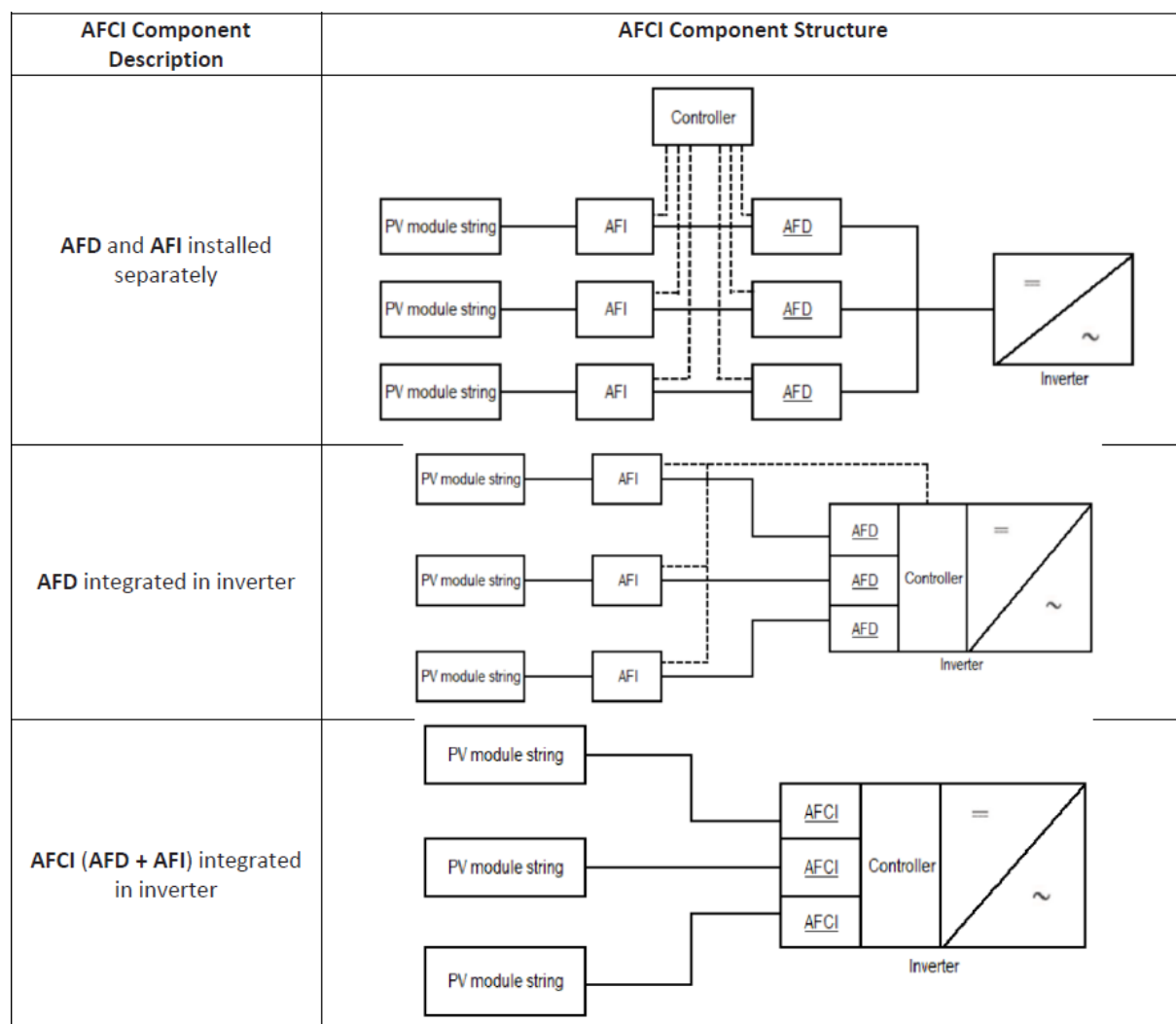
The AFCI (Arc Fault Circuit interrupter) is a device that interrupts a circuit when it detects an arc. This can prevent an intense fire from spreading. The arc is characterized by a white high frequency noise signal with frequencies between 10 kHz and 100 kHz. AFCI can detect an arc by monitoring its signal and the noise it produces. There have been developed mature technologies for the detection of AC arcs, which make the detection process easy. There are several methods to detect an arc like acoustic physical characteristics, waveform characteristic, harmonic analysis, and frequency domain. However, detecting DC arcs is more difficult than AC arcs. The waveform of the DC arc is similar to the normal status, with only the amplitude of it being different. This results in difficulties detecting arcs in frequency or energy bands,

which can cause instability and a lack of efficiency in detecting them. Regarding the noise adaptability, the thresholds that are set and the detection algorithm are mainly based on human experience. If the environmental noise spectrum is close to the arc noise spectrum, it can be difficult to distinguish the arc, resulting in missed detections or false alarms which can cause tripping by interrupting the operation of the system, affecting the energy generation data. Regarding the adaptability of the scenarios, in commercial and industrial scenarios the cable length of the PV system can exceed 200 m and the maximum MPPT current 26 A. The main problem is that the longer cable length may affect the ability to effectively detect arc faults. Therefore, the main difficulty is to accurately detect the actual arc fault without causing false alarms.

Achieving this goal is not trivial, and often the AFCI function has been disabled by the owner/installer to avoid unnecessary trips due to false alarms, but at the same time, the likelihood of an actual arc fault occurring increases, as do the potential hazards.



In most cases of PV installations, the mechanism of AFCI is consisted of three different forms: The Arc Fault Detector (AFD) and Arc Fault Interrupter (AFI) which are installed separately as external devices, the Arc Fault Detector (AFD) which is integrated in the inverter, and the AFCI (AFD + AFI) integrated in the inverter



Huawei's AFCI can overcome the problem of complex algorithms trying to accurately detect the features of the DC arc with AI and deep learning technology based on neural network algorithm. It has the ability to rapidly calculate, process and iterate massive data that helps to effectively distinguish characteristic signals with similar waveforms.

With the AI and deep learning function, the AFCI also is able to continuously learn unknown spectrums, leading to effectively improve the noise adaptability of the device. These features have helped in order to effectively distinguish the DC arc from these two characteristics which in traditional methods many times lead to false alarms.

I.2 Inverter Specification

Here in this test SUN2000-50KTL-M3 inverter has been used. Inverter datasheet attached bellow:

SUN2000-50KTL-M3 Technical Specification

Technical Specification	SUN2000-50KTL-M3
Efficiency	
Max. Efficiency	98.5%
European Efficiency	98.0%
Input	
Max. Input Voltage ¹	1,100 V
Max. Current per MPPT	30 A
Max. Current per Input	20 A
Max. Short Circuit Current per MPPT	40 A
Start Voltage	200 V
MPPT Operating Voltage Range ²	200 V ~ 1,000 V
Rated Input Voltage	600 V
Number of Inputs	8
Number of MPP Trackers	4
Output	
Rated AC Active Power	50,000 W
Max. AC Apparent Power	55,000 VA
Max. AC Active Power (cosφ=1)	55,000 W
Rated Output Voltage	400 Vac / 480 Vac, 3W+ (N) + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Rated Output Current	72.2 A @ 400Vac, 60.1 A @ 480Vac
Max. Output Current	79.8 A @ 400Vac, 66.5 A @ 480Vac
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	<3%
Protection	
Input-side Disconnection Device	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
Residual Current Monitoring Unit	Yes
Arc Fault Protection	Yes
Ripple Resistor Control	Yes
Integrated PID Recovery ³	Yes
Communication	
Display	LED Indicators, Bluetooth + APP
RS485	Yes
Smart Dongle	WLAN/Ethernet via Smart Dongle-WLAN-FE (Optional) 4G / 3G / 2G via Smart Dongle-4G (Optional)
Monitoring BUS (MBUS)	Yes (Isolation Transformer required)
Optimizer Compatibility	
DC MBUS Compatible Optimizer	MERC-1100/1300W-P
General Data	
Dimensions (W x H x D)	640 x 530 x 270 mm (25.2 x 20.9 x 10.6 inch)
Weight (with mounting plate)	49 kg (108.1 lb)
Operating Temperature Range	-25°C ~ 60°C (-13°F ~ 140°F)
Cooling Method	Smart Air Cooling
Max. Operating Altitude	4,000 m (13,123 ft.)
Relative Humidity	0% RH ~ 100% RH
DC Connector	Amphenol HH4
AC Connector	Waterproof Connector + OT/DT Terminal
Protection Degree	IP 66
Topology	Transformerless
Nighttime Power Consumption	≤ 5.5W
Standard Compliance (more available upon request)	
Safety	EN 62109-1/-2, IEC 62109-1/-2, EN 50530, IEC 62116, IEC 60068, IEC 61683
Grid Connection Standards	IEC 61727, VDE-AR-N4105, VDE 0126-1-1, BDEW, G59/3, UTE C 15-712-1, CEI 0-16, CEI 0-21, RD 661, RD 1699, P.O. 12.3, RD 413, EN-50438-Turkey, EN-50438-Ireland, C10/11, MEA, Resolution No.7, NRS 097-2-1, DEWA

¹ The maximum input voltage is the upper limit of the DC voltage. Any higher input DC voltage would probably damage inverter.

² Any DC input voltage beyond the operating voltage range may result in inverter improper operating.

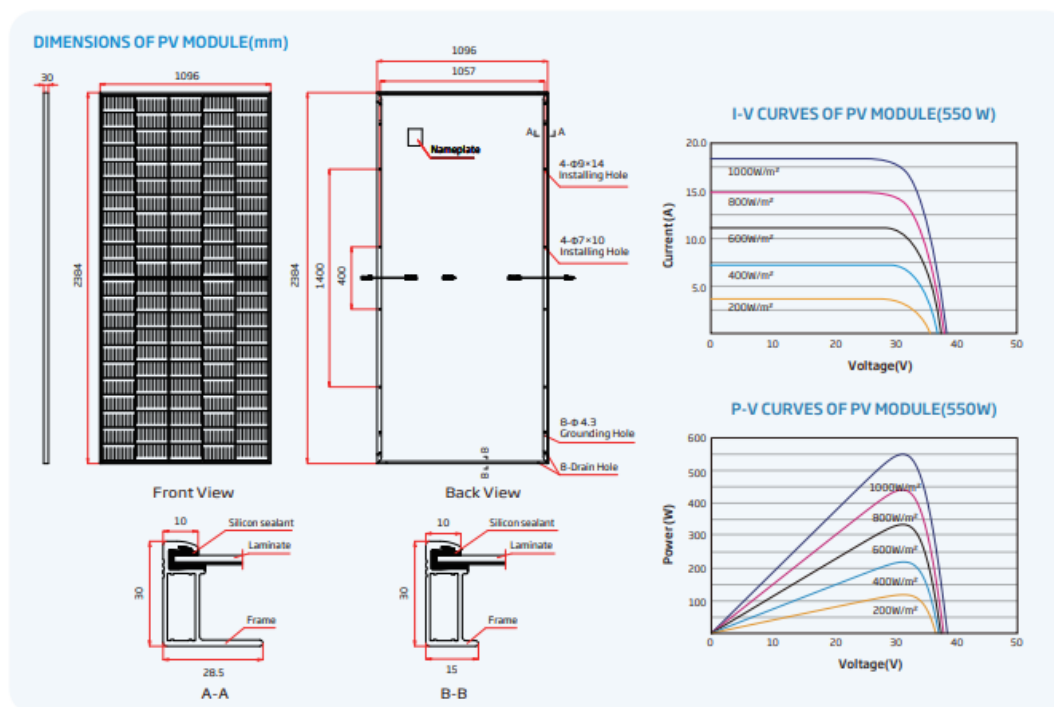
³ SUN2000-30-50KTL-M3 raises potential between PV- and ground to above zero through integrated PID recovery function to recover module degradation from PID. Supported module types include: P-type (mono, poly), N-type (nPERC, HJT)

⁴ 50KTL Platform only supports CAI Optimizer(MERC-1100/1300W-P). The current version does not support this function and it can be upgraded to optimizer version via new inverter software version(Dec 30th, 2022)

Refer to HTTP://solar.huawei.com/

I.3 Panel Specification

Here used Trina solar TSM-550DE19 panel. Panel datasheet attached bellow:



ELECTRICAL DATA (STC)

Peak Power Watts- P_{max} (Wp)*	540	545	550	555	560
Power Tolerance- P_{max} (W)			0 ~ +5		
Maximum Power Voltage- V_{mp} (V)	31.2	31.4	31.6	31.8	32.0
Maximum Power Current- I_{mp} (A)	17.33	17.37	17.40	17.45	17.49
Open Circuit Voltage- V_{oc} (V)	37.5	37.7	37.9	38.1	38.3
Short Circuit Current- I_{sc} (A)	18.41	18.47	18.52	18.56	18.60
Module Efficiency η_m (%)	20.7	20.9	21.0	21.2	21.4

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5. *Measuring tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power- P_{max} (Wp)	409	413	417	420	424
Maximum Power Voltage- V_{mp} (V)	29.0	29.2	29.3	29.5	29.7
Maximum Power Current- I_{mp} (A)	14.10	14.15	14.19	14.23	14.26
Open Circuit Voltage- V_{oc} (V)	35.3	35.5	35.7	35.9	36.1
Short Circuit Current- I_{sc} (A)	14.84	14.88	14.92	14.96	14.99

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline
No. of cells	110 cells
Module Dimensions	2384×1096×30 mm (93.86×43.15×1.18 inches)
Weight	28.3 kg (62.39 lb)
Glass	3.2 mm (0.13 inches), High Transmission, Tempered Glass
Encapsulant material	EVA/POE
Backsheet	White
Frame	30mm(1.18 inches) Anodized Aluminium Alloy
J-Box	IP68 rated
Cables	Photovoltaic Technology Cable 4.0 mm ² (0.006 inches ²) Portrait: 350/290 mm(13.78/11.02 inches) Length can be customized
Connector	MC4 EV02 / TS4 Plus / TS4*

*Please refer to regional datasheet for specified connector.

TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	43°C (±2°C)
Temperature Coefficient of P_{max}	-0.34%/°C
Temperature Coefficient of V_{oc}	-0.25%/°C
Temperature Coefficient of I_{sc}	0.04%/°C

MAXIMUM RATINGS

Operational Temperature	-40° ~ +85°C
Maximum System Voltage	1500V DC (IEC)
Max Series Fuse Rating	30A

WARRANTY

12 year Product Workmanship Warranty
25 year Power Warranty
2% first year degradation
0.55% Annual Power Attenuation

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 36pieces
Modules per 40' container: 720 pieces



CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

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Version number: TSM_EN_2023_A

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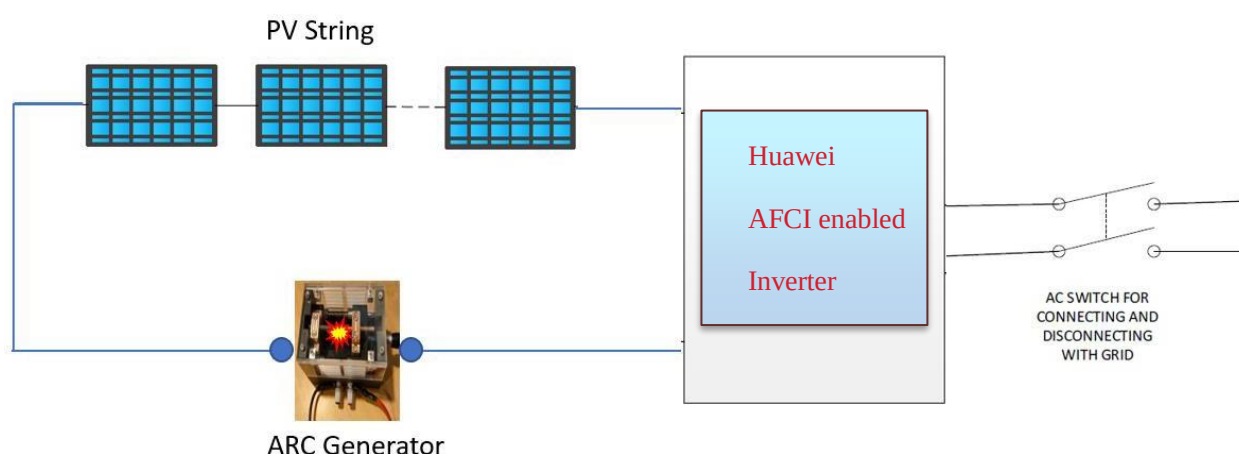
2. Onsite AFCI Test

2.1 Test Site Details

Testing Date	16 th October 2024
Location	United City, Madani Avenue, Badda, Dhaka 1212, Bangladesh
Customers Company	United International University (UIU)
Team	1. Zaidullah Zubiar 2. MD Nazmul Sadik 3. Md Mahmudul Hasan
Site Name	United International University (UIU)
Point of Connection	Inverter end and Panel end
DC Capacity	20.35 kWp
AC Capacity	50 KW
Inverter Model	SUN2000-50KTL-M3
Quantity of Inverter	01
No. of Strings / Inverter (SUN2000-50KTL-M3)	2 strings per inverter. One string 18 Panels & another sting 19 panels connected.
Monitoring System	Fusion Solar APP

I.1 Test Method

The on-site testing was carried out to verify inverter detection and interruption of electric series DC arc in PV array circuit. While inverter AFCI is evaluated by R&D and certification test lab in accordance to UL 1699B and IEC 63027, this on-site testing is to validate if the inverter has the correct capability of detecting and extinguishing DC arc fault upon installation as the AFCI effectiveness ultimately depends on installation condition as well. Other parameters such as tripping time and arc energy measurement are excluded from this exercise.



Arc generator was placed between the PV modules and test distance is given below:

Description	Cable Length
Near the Inverter	1 m
Cable length from PV Module to PV Module	180m-190m

Arc generator was placed between the PV modules and test distance is given below:

I.2 Test Instrument and Test person

- Arc generator with PV connector input (see below photo).
- External PV cable with PV connectors to connect DC array and PV inverter to arc generator.
- Smartphone with Huawei Fusion Solar APP that has access and control the Huawei inverter.



Our service specialist ensures testing procedure maintain its standard during this testing.



Figure: On-site AFCl testing by Huawei Service Engineer

2.2 Test Procedure and Results

AFCI disabled test

- Use Fusion Solar App to disable AFCI function.
- Turn off the inverter in accordance to user manual.
- Disconnect DC connector from DC+ from inverter.
- Connect the DC+ input array to arc generator at AFCI 1 (DC+) position and to the inverter string input by using External PV cable.
- Make sure that the arc generator electrodes are closed to form a complete circuit.
- Turn on the inverter in accordance to user manual and wait until the PV system is operating normally.
- Slowly separate the arc generator electrode to create DC arc fault condition.

Test outcome:

- DC arc happened continuously within the arc generator.
- Inverter did not trip and no DC arc fault warning was received in Fusion Solar App.

AFCI Enabled Test

- Check in Fusion Solar App that AFCI function is enabled.
- Repeat Step 2 to 7 in Section AFCI disabled procedure.

Test outcome:

- Inverter detected DC arc, AFCI function was triggered, and the inverter tripped automatically. DC arc was extinguished due to open circuit.
- Inverter display LED lighting showed warning blinking indication and subsequently switched off.
- FusionSolar App received DC arc fault alarm.
- From SmartLogger monitoring system we also got the Arc fault alarm



Figure: Arc generating from the Arc generator and inverter alarm LED blinking

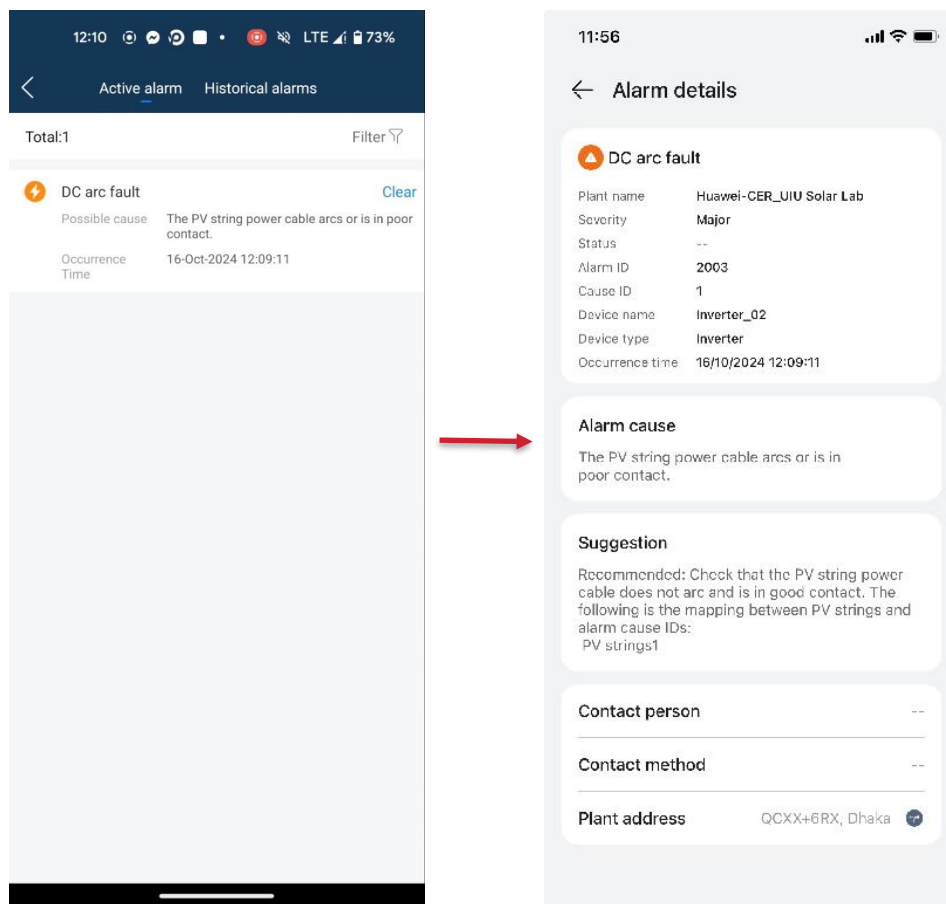


Figure: DC arc fault alarm from FusionSolar management system

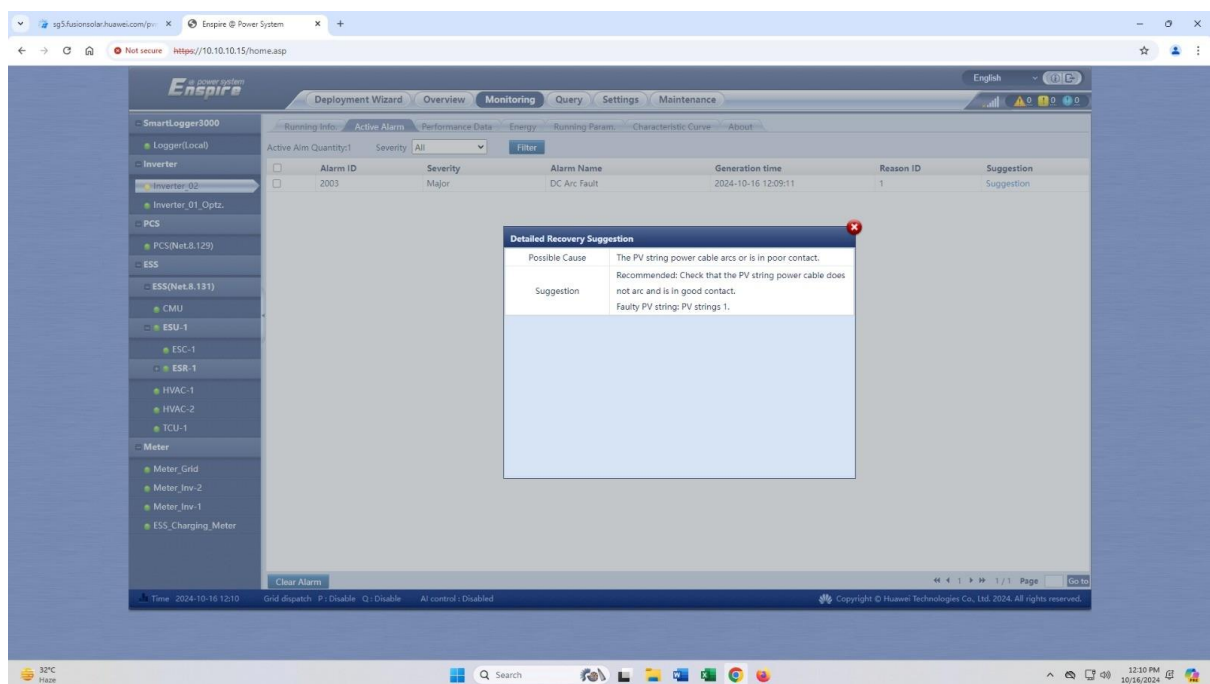


Figure: DC arc fault alarm from SmartLogger management system

3. Conclusion

DC arc fault condition was created at PV array to simulate poor contact arcing condition. Huawei inverter SUN2000-50KTL-M3 (AFCI function enabled) successfully detected the DC arc fault and automatically tripped to extinguish the arc. Inverter physical display showed alarm warning and Fusion Solar app received DC arc fault alarm.

Performance requirements of IEC 63027 and Huawei AFCI performance test & verification results are tabled below:

Performance requirements of IEC 63027 AFCI performance test & verification results are tabled below:

Item	IEC 63027	Huawei SUN2000-50KTL-M3	Compliance
Arc type	Series arc	Series arc	Comply
Cable length	140 meters	Tested at 190 meters <i>(Actual detection capability up to 200 meter)</i>	Comply
Protection threshold	Arc duration < 2.5s	Arc duration < 2.5s <i>(self-learning capability; faster tripping subsequently)</i>	Comply
Fault clearing	1. When the protection device needs to reset for the second time, the automatic reset waiting time should be at least 10 minutes. 2. If the protection device automatically has reset 5 times in a day, the next reset must be performed manually.	1. Automatic reset waiting time was about 15 minutes after DC arc fault. 2. After 5 times of automatic reset (in a day), the next reset must be performed manually.	Comply