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# Arc-Fault Unwanted Tripping Survey with UL 1699B-Listed Products

Jay Johnson[1], Kenneth M. Armijo[1], Modi Avrutsky[2], Daniel Eizips[2], Sergey Kondrashov[2]

[1]Sandia National Laboratories, Albuquerque, NM, 87185, USA
[2]Tigo Energy, Los Gatos, CA, 95032, USA

***Abstract* — Since adoption of the 2011 *National Electrical Code®*, many photovoltaic (PV) direct current (DC) arc-fault circuit interrupters (AFCIs) and arc-fault detectors (AFDs) have been introduced into the PV market. To meet the *Code* requirements, these products must be listed to Underwriters Laboratories (UL) 1699B Outline of Investigation. The UL 1699B test sequence was designed to ensure basic arc-fault detection capabilities with resistance to unwanted tripping; however, field experiences with AFCI/AFD devices have shown mixed results. In this investigation, independent laboratory tests were performed with UL-listed, UL-recognized, and prototype AFCI/AFDs to reveal any limitations with state-of-the-art arc-fault detection products. By running AFCIs and stand-alone AFDs through realistic tests beyond the UL 1699B requirements, many products were found to be sensitive to unwanted tripping or were ineffective at detecting harmful arc-fault events. Based on these findings, additional experiments are encouraged for inclusion in the AFCI/AFD design process and the certification standard to improve products entering the market.**

***Index Terms* — photovoltaic systems, arc-fault detection, unwanted tripping, AFD, AFCI, safety**

## I. Introduction

Arc-faults in PV systems have been linked to dozens of PV fires around the world [1-4]. These PV electrical fires are the result of high temperature plasmas produced as current passes across separated and/or damaged conductors [5-6]. In response, the 2011 *National Electrical Code®* [7] Section 690.11—requiring listed PV arc-fault circuit interrupters on PV installations—was created to reduce the likelihood of an electrical fire. In order for PV inverter, smart combiner box, and original equipment manufacturer (OEM) products to become listed, the device must undergo a sequence of tests defined in UL 1699B to verify its safety, ability to detect arc-faults, and ensure a basic level of unwanted tripping.

In September 2013, the UL 1699B [8-9] standards technical panel (STP) held a meeting at Northbrook, IL to revise the Outline of Investigation and move the draft toward an American National Standards Institute (ANSI) certification standard. A number of limitations were identified at the meeting and six task groups were formed to address specific issues, including arc-fault generation methods (see [5, 10]), use of PV simulators, and unwanted tripping. The unwanted tripping task group was composed of a dozen individuals from government, PV manufacturers, and authorities having jurisdiction (AHJs). The task group first collaborated to identify situations where unwanted tripping occurred in the field. They then attempted to design realistic, repeatable, and inexpensive experiments could be added to UL 1699B to represent these scenarios which would improve the quality of products entering the market and reduce the number of unwanted tripping issues.

The list of unwanted tripping situations created by this working group is shown in Table 1. In general, each unwanted tripping situation case has a respective arc-fault event which created conditions similar to those generated by real arcs on the DC system. Since many AFCI devices operate by detecting high frequency (HF) noise generated by the arcing event [11-13], and/or rapid changes in the current-voltage characteristics, AFCI/AFDs may malfunction when:

1. Electromagnetic Interference (EMI) causes incompatibility between devices because inductive, capacitive, or radiative coupling produces unexpected noise in the DC subsystem.
2. Rapid changes in array or inverter operation cause current or voltage steps or transients.
3. Additional power electronics devices on the system (e.g., DC/DC converters) produce unexpected switching noise and may cause unwanted tripping due to conductive coupling [14].
4. Especially for transformerless (TL), galvanically non-isolated PV inverters, noise from the AC-side of the system can couple with the DC-side and lead to unwanted tripping [15].
5. AFCIs are installed on unexpected PV system configurations that saturate the core of the current transducer on the AFCI and render it blind to arc-faults.

Due to the range of potential unwanted tripping scenarios, it was challenging for the task group to establish a concise set of tests which encompassed all unwanted tripping cases. The task group successfully adding tests to the proposed UL standard which addressed cases 1-2 in Table 1; however in the cases of EMI coupling (cases 3-5 in Table 1), unwanted tripping is highly dependent on the type of arc-fault detection algorithm, trip thresholds, and installation topology, so these were not added to the UL 1699B draft. One option discussed for addressing coupling issues was to test AFCIs by injecting prerecorded PV system noise signatures [16-17] or to inject a spectrum frequency sweep to verify the devices are resilient to different inputs. In the end, the consensus of the UL task group was to allow AFCI manufacturers to continue to address these problems individually because those experiments were not technology agnostic.

TABLE I

UNWANTED TRIPPING SITUATIONS IDENTIFIED BY THE UL 1699B TASK GROUP

| Unwanted Tripping Situation | Evidence |
|---|---|
| 1. Downward power step change from, e.g., disconnecting a portion of the array or shading. | Manufacturer experienced tripping when a portion of the array was disconnected. Sandia witnessed unwanted tripping when PV simulator irradiance is stepped down and when switching between the simulator and real PV. |
| 2. Upward power or current step change, e.g., turning on the PV system mid-day. | Manufacturer has seen high frequency noise when PV systems are energized in the middle of the day. |
| 3. Capacitive coupling (in conduit) from dissimilar PV inverters caused unwanted tripping. | Manufacturer discovered this problem and developed a new AFCI algorithm to address the issue. |
| 4. Unwanted tripping due to conducted DC/DC converter noise on the PV system. | Sandia has seen this with prototype AFCIs [14]. |
| 5. AC noise propagating to the DC system for transformerless inverters. | University of Berne reported problems with elevators injecting noise on the AC side and causing DC tripping [15]. A manufacturer stated a PV system on a parking garage would trip when the lights energized. |
| 6. Single-string AFCI used on combined strings caused tripping, likely from a saturated current transducer (CT). | Manufacturer noted that certain devices did not function up to their current rating. |

In addition to technical challenges, there are also financial implications for testing. Certification experiments become more expensive to manufacturers as the number and duration of tests increases, so there is no incentive for the STP to added unproven, unnecessary, or unrealistic barriers to the market. Therefore, only a directed subset of operating conditions can be recreated in the UL 1699B certification process, and manufacturers are left responsible to expand to a wider range of AFCI/AFD unwanted tripping experiments.

In this investigation, Sandia National Laboratories and Tigo Energy collaborated to evaluate AFCI/AFD products with experiments of realistic PV environments beyond those in the UL 1699B certification protocol. This anonymous survey reveals limitations of products on the market and informs the STP of additional tests that could be added to the protocol in the future.

## II. PRODUCT EVALUATIONS

A variety of arc-fault unwanted tripping tests were performed on 10 products. An anonymized list of the products that were tested—including PV inverters, stand-alone AFCI devices, and one smart combiner box—is provided in Table 2. The experiments were conducted at the Tigo Energy research laboratory in Los Gatos, CA. Tigo Energy developed this test lab in 2012-2013 for arc-fault detector evaluations, funded partly with a DOE SunShot grant to develop an AFCI product [18]. There were three types of tests:

1. Arc-fault detection tests in which an arc-fault was generated either by the steel wool or pull-apart method (see [5]) to evaluate the ability of the AFCI/AFD to detect an arc-fault.
2. Masking tests in which the circuit was configured to disguise or hide the arc-fault from the detector.
3. Unwanted tripping tests in which different realistic, non-fault scenarios where created to deceive the detector algorithms into prematurely tripping.

Initially, arc tests were performed to verify the AFCI/AFD was enabled and functioning correctly. Then the masking and unwanted tripping tests were performed. The following sections describe the tests in more detail.

### A. Arc-Fault Tests

Arc-fault experiments were performed using the test configurations in Figs. 1 and 2 without the inductors and capacitors. The stand-alone AFD products did not contain interrupting devices (IDs) so they were connected in series in the DC test circuit while each of the inverter-integral AFCIs was evaluated. The AFCI in the combiner box was removed from the enclosure and disconnected from the ID for the experiments. To perform arc-fault tests in a controlled environment, a TDK Lambda GEN 600-08 power supply, with a 6 or 12 Ω resistor was used to simulate a PV supply. During the high-irradiance periods of the day, or in the case of AFCIs that tripped on the power supply, real PV power was used using two strings of Sanyo HIT-N225A01 modules with Tigo Optimizers shown in Fig. 2. The arc-fault current was measured with an Agilent 1146A probe and the voltage was measured with an Agilent N2791A differential probe connected to an Agilent DSO-X 2024A oscilloscope. The conducted RF noise on the DC system was separately monitored with an Anritsu MS2034B Spectrum Analyzer and Solar Electronics Co. Type 6741-1 PF current probe. In this paper, the high frequency spectral content is converted from power (dBmW) measured by the Anritsu to current (dBμA)—including a 3 dBμA probe attenuation correction.

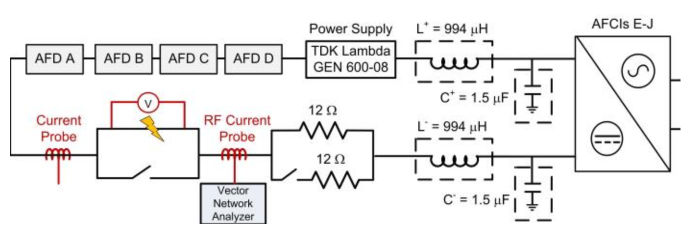


Fig. 1. Arc-fault test circuit using a power supply.

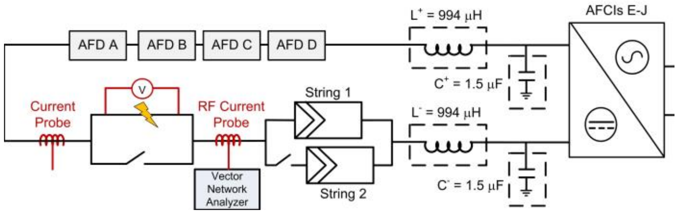


Fig. 2. Arc-fault test circuit using rooftop PV.

UL 1699B was originally written to test detectors with 300, 500, 650, and 900 W arcs using the steel wool method in order to harmonize testing with the AC AFCI test standard, UL 1699. Based on Sandia research [5, 10] the addition of a 100 W test using the pull-apart method was added to the draft Outline of Investigation in November 2014. To verify the AFCI/AFD products were functioning correctly, 100-200 W and 300 W arcs were created on the DC system. Both of these arc power levels are capable of causing PV fires [6] and should be detected—though only 300 W arcs are currently used in the listing/recognition process. Unfortunately, two stand-alone detectors and three inverter based detectors did not detect at least one arc-fault as shown in Table 2. Inverter I was found to detect only 33% of the 300 W arc-faults using the UL 1699B test standard despite being a listed AFCI product in the market. In the case of Inverter I, many of the unwanted tripping tests were not performed because the AFCI sensitivity was believed to be set too high to experience unwanted tripping.

B. Arc-Fault Masking with Inductance/Capacitance

The masking tests were conducted with 300 W arc-faults on test configurations in either Fig. 1 or Fig. 2 with the $L^+$, $L^-$, $C^+$, or $C^-$ parasitic impedance installed sequentially. The inductor was installed between the PV output circuit, while the inverter and the capacitor were connected from the positive or negative PV output circuit to the inverter chassis ground. Multiple inductance and capacitance values were tested, but all devices were tested with a 994 µH series inductor and a 1.5 µF capacitor to ground. It should be noted that the current draft of UL 1699B includes a masking test with line impedance created with 200 ft of wire arranged with four 180 degree bends of six-inch radius. The inductor in these tests was also created from hundreds of feet of PV wire but, in this case, tightly wrapped into an air inductor with approximately a 10 inch radius. Depending on the installation, high inductance scenarios are certainly possible if there is coiled PV wire. The capacitance to ground was designed to replicate the array capacitance. This property can vary significantly with module technology and design. SMA estimated the parasitic capacitance of wet silicon PV arrays to be 60-110 nF per kW and wet thin film arrays to be 100-160 nF per kW [20]. Therefore, a wet 9.4 kW thin film array could produce 1.5 µF to ground and potentially render the arc-fault protection system ineffective.

The masking test results showed six of the seven tested products were susceptible to masking arc-faults when series inductance or capacitance to ground was added to the PV system, shown in Table 2. Since these detectors rely on high frequency noise or di/dt (current transients), the series inductance and capacitance filters out high frequency noise on the DC system and conceals the arc. It is recommended that manufacturers characterize any AFCI/AFD vulnerabilities to these parasitics and specify operating inductance and capacitance limits for their respective products.

C. Unwanted Tripping with Inductance/Capacitance

One of the surprising findings of this study was that one of the listed AFCI's tripped when the series inductance or capacitance to ground was added to the test circuit. While the cause of this unwanted tripping is not fully understood, the common mode noise was particularly large (10 dBµA larger than the differential) when the capacitor was installed; therefore the capacitor could have allowed inverter or power supply noise to couple to the AFCI board through the inverter ground.

D. Loading Condition I - Conducted Noise Tests

Power supplies, DC/DC converters, power optimizers, inverters, and other power electronics devices generate noise on the DC system [17]. The majority of this noise is generated with respect to device switching frequency and harmonics, but depending on the spectral content, PV AFCIs could trip because of the heightened noise floor. As an example, the frequency with and without module-level DC/DC converters is shown in Fig. 3 at four different inverter power levels. In the case of this 2-string PV system at Sandia's Distributed Energy Technologies Laboratory (DETL), the conducted noise in the DC system was significantly higher when the module-level converters were operating.

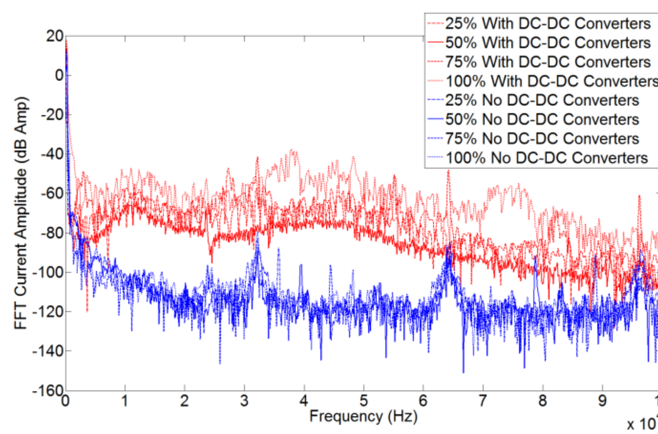


Fig. 3. Additional noise floor from DC/DC converters.

In this study, AFDs were installed with each of the inverters, power supply, PV with Tigo Energy DC/DC converters ("optimizers"), and a charge controller. The AFCIs were tested with the power supply and the PV system with optimizers. As shown in Table 2, one of the AFCI detectors tripped when connected to the power supply, but not when powered by the PV. The switching frequency of the power supply was 278 kHz at 78 dBμA (7.9 $mA_{rms}$) and likely the source of the unwanted tripping. For reference, the highest switching noise recorded by the spectrum analyzer was 105 dBμA (177.8 $mA_{rms}$) with inverter E, so the power supply was not particularly noisy. In the case of the UL-recognized product C and unlisted product D, there was only a single case when they experienced an unwanted tripping case. Unrecognized products A and B tripped with all five of the inverters (a) during the startup period when the inverter was not exporting power yet, (b) when the inverter closed the DC disconnect and there was a current inrush, or (c) during normal operation—all of which indicate the detection algorithm is too sensitive.

E. Loading Condition II – DC Disconnect

Operating a DC disconnect open and closed three times has always been in UL 1699B Outline of Investigation. When opening DC disconnects, there are short duration arc-faults as the contacts separate. These faults are typically less than 1 ms for spring loaded disconnects so AFD/AFCI detectors are programmed to not trip on these quick transient events. As shown in Table 2, none of the products tripped from these tests.

F. Loading Condition III – Irradiance Change

Some AFCI/AFD products use changes in current to detect arc-fault events. For those products, quick changes in irradiance or changes in the operating point can cause unwanted tripping. At Sandia, unwanted tripping has been experienced when changing the irradiance parameter on PV simulators and when switching between the PV simulator and real PV. In this experiment, one string of the two-string array was disconnected and reconnected three times or the resistance was changed from 6 to 12 Ω three times using a GIGAVAC GX11TA relay. Two of the listed AFCIs consistently experienced unwanted tripping in both cases. One of the AFCIs tripped when the $2^{nd}$ string was reconnected. This indicates the detection algorithms for these AFCIs are sensitive to low frequency changes in array current.

G. Frequency Sweep with Coupling Transformer

Many AFD/AFCI products analyze the spectral content of the DC system with a Fast Fourier Transform (FFT) or similar analysis of string/array current. Since arc-faults generate 1/f “pink” noise [11], these devices analyze one or more frequencies to determine when the arc-fault exists. In the case of monotone detection, conducted noise from other power electronics devices on the system or capacitive, inductive, or radiated coupling can cause unwanted tripping. To verify the AFD/AFCIs are resistant in those environments, a coupling circuit was created with an arbitrary waveform generator, shown in Fig. 4. The number of windings on the coupling transformer was adjusted to produce approximately 100 dBμA (100 $mA_{rms}$) of noise on the DC system, similar to the switching frequency of most of the PV inverters. This injected noise signal was adjusted from 1 to 500 kHz in 1 kHz steps at roughly 1 kHz/sec to determine if the AFCI/AFDs were sensitive to single frequency excitation. Experiments with sine and square waves were conducted, but square waves were ultimately selected because they produced the largest superharmonic content and caused more unwanted tripping. As shown in Table 2, multiple AFDs and the charge controller AFCI tripped with square wave injection. These nuisance trips show potential weaknesses in the AFCI/AFD algorithm and could manifest themselves in the field when installed with other power electronics equipment.

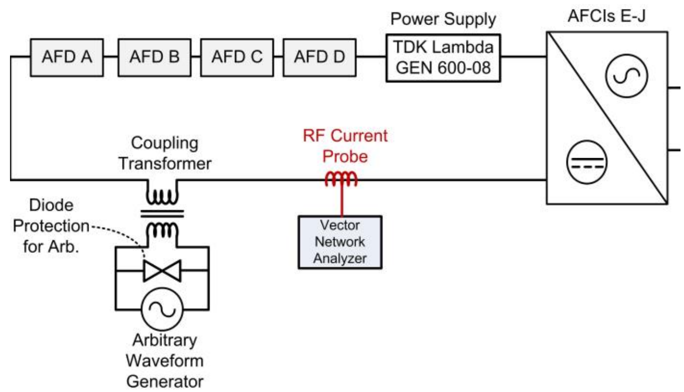

Fig. 4. Test circuit for the frequency sweep experiments.

H. Inductive Coupling between Arrays

It was reported that AFCIs were tripping when two different inverter manufacturers had DC source circuits running through the same conduit due to inductive cross-coupling. This scenario was simulated by running three inverters simultaneously through 16 meters of 12 AWG 3C, where each inverter was on one of the three bundled wires. The conductors were contained in a single sheath so the inductive coupling was fairly high between the parallel strands; using a signal generator at 10 kHz, a 270 mV signal was measured at 200 mV on the other lines and the 105 dBμA switching frequency from inverter E was measured on the other lines at 90 dBμA. Only one case of unwanted tripping was seen for these tests: AFD A tripped continuously when connected to the charge controller and inductively coupled to Inverters F and G. When disconnected from the 3C coupling line, AFD A did not trip. Since AFD A tripped only while coupled to Inverters F and G, it is believed the coupling caused the unwanted tripping.

I. AC-DC Coupling

There are reports of elevator operation and fluorescent light (low-pressure mercury arc lamp) startup tripping AFDs. In these cases, noise—likely from arcing—on the AC system reaches the DC side of the PV system. This is more of a problem for transformerless inverters because there is no galvanic isolation between the AC and DC sides of the inverter. In the lab, a paper shredder, bench grinder, and shop vacuum were connected to an AC outlet directly connected to the service panel for the PV inverter, shown in Fig. 5. In all cases, the AFD/AFCI did not trip. Then, to ensure that arcing noise was being produced on the AC side of the inverter, a relay connected to a 50 Ω load was paralleled with the inverter, as shown in Fig. 6. This relay was actuated at 10-20 Hz to generate relay-driven arcing noise on the AC side to simulate brushed motors and other devices that produce non-hazardous AC arc-faults. As shown in Table 2, two of the unrecognized AFDs tripped when the AC arc-noise was produced.

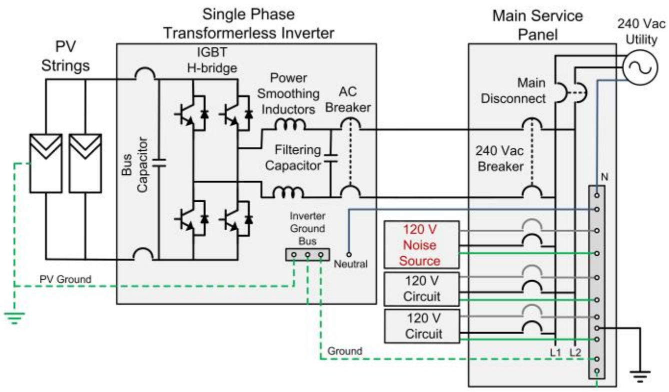


Fig. 5. AC-to-DC noise coupling test configuration.

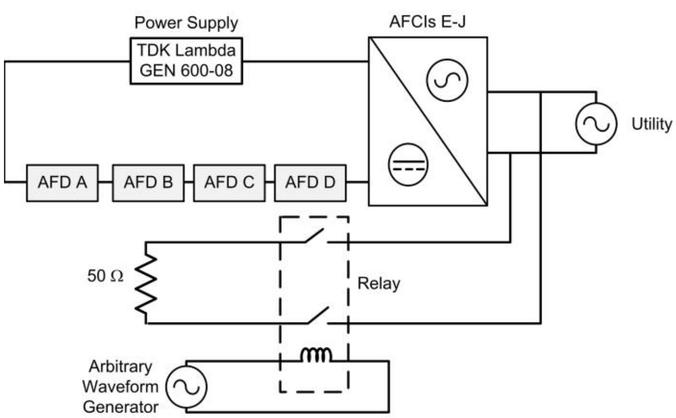


Fig. 6. AC-to-DC noise coupling with a relay connected to a load.

J. Broadband Noise Injection

Since there are many sources of short duration DC noise on PV systems, e.g., operating DC disconnects, AFCI/AFD devices should have the ability to ride-through short transient events. The required ride-through duration would still allow the devices to trip well before the arc energy dissipation reached the 750 J polymer combustion threshold (see [6]), but would harden the technology to unwanted tripping sources. These tests were not conducted in this study, but the trip times for some of the AFCI/AFD products were as short as 62 ms. Therefore, it is recommended that manufacturers and UL 1699B STP consider generating arc-fault noise for multiple durations (e.g., 50-150 ms) to ensure the products are resistant to transient noise events.

K. Injected Inverter Signatures with Coupling Transformer

It is possible to use an arbitrary waveform generator to replay pre-recorded inverter noise [16-17]. Ideally, a large library of hundreds of prerecorded healthy PV system signatures would be replayed to determine potential unwanted tripping issues with the AFCI/AFD technology. These experiments were not conducted as part of this survey but could be included in the design process for manufacturers. In fact, Sandia has a small library of healthy and arcing PV system signatures [17] that have been used to tune multiple AFCI/AFD products. Unfortunately, to add replay tests to UL 1699B, there are a number of unanswered questions including:

1. What is a ‘comprehensive’ set of PV system noise signatures? It should include different types of power electronics noise, topologies, and operating conditions.
2. What recording instrumentation, signature lengths, and sampling rates should be used?
3. How do NRTLs consistently inject signatures into the test circuit with coupling circuitry up to 500-1000 kHz? A specialized transformer with low parasitic capacitance is required to inject HF signals.
4. How would the NRTL ensure the experiments are repeatable, reliable, and do not differ between lab equipment?

These issues need to be addressed prior to adding this type of testing to the UL standard.

## III. Conclusions

This effort uncovered issues with detection, masking, and unwanted tripping associated with prototype and UL-listed/recognized AFCI/AFD products. The experimental results indicate a need for more comprehensive testing by manufacturers and additional tests as part of the certification process. This paper describes multiple realistic unwanted tripping tests that could be conducted during the design and certification process for improving resiliency to unwanted tripping. It is also evident from the results that there are limitations in many arc detection algorithms. Fortunately, there are new detection algorithms being proposed, such as wavelet detection methods [21-22], that could provide more robust solutions to unwanted tripping issues.

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TABLE II

ARC-FAULT CIRCUIT INTERRUPTER AND ARC-FAULT DETECTOR ARCING, MASKING, AND UNWANTED TRIPPING RESULTS

| | | | **Arc Detection Tests** | | **Masking Tests** | | **Unwanted Tripping Tests** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AFCI Product** | **UL 1699B Compliance** | **Product Specs** | **1. Arc-fault Generation at Different Power Levels** | | **2. Masking with Inductance/Capacitance** | | **3. Unwanted Tripping with Inductance/Capacitance in Circuit** | | **4. Loading Condition I** | | | | | | | |
| | | | **100-200 W*** | **300 W^** | **L[#]** | **C[#]** | **L[#]** | **C[#]** | **Power Supply[#]** | **Tigo Optimizers[$]** | **Inverter E[$]** | **Inverter F[$]** | **Inverter G[$]** | **Inverter H[$]** | **Inverter I[$]** | **Charge Controller J[$]** |
| A | Unrecognized | Stand-Alone AFD Product | ✓ | ✓ | Masked 234 W arc with 994 μH, ran indefinitely | Masked continuous arc with 1.5 μF | ✓ | ✓ | ✓ | ✓ | Trip on startup period | Trip on startup and normal operation | Trip on inrush and startup period | Trip on inrush | Trip on startup and operation | ✓ |
| B | Unrecognized | Stand-Alone AFD Product | ✓ | ✓ | Masked 234 W arc with 994 μH, ran indefinitely | Masked continuous arc with 1.5 μF | ✓ | ✓ | ✓ | ✓ | Trip on startup period | Trip on startup period | Trip on inrush and startup period | Trips when using power supply | Trip on startup and operation | ✓ |
| C | Recognized | Stand-Alone AFD Product | 169 W (36 V, 4.7 A), 30+ seconds, pull apart | ✓ | Masked 234 W arc with 994 μH, ran indefinitely | Masked continuous arc with 1.5 μF | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Trip (only once) | ✓ |
| D | Unlisted | 8-string Combiner Box with AFCI | 169 W (36 V, 4.7 A), 30+ seconds, pull apart | 298 W (42 V, 7.1 A), 20 sec, steel wool, Inv. I | Masked 234 W arc with 994 μH, ran indefinitely | Masked continuous arc with 1.5 μF | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Trip (only once) | ✓ |
| E** | Listed | 3.8 kVA, 1ϕ, inverter with transformer | 102 W (16 V, 6.4 A), 20+ seconds, pull apart | 328 W (40 V, 8.2 A), 20 seconds, pull apart | Masked arc with 994 μH | Masked continuous arc with 1.5 μF | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| F** | Listed | 8.2 kVA, 1ϕ, TL inverter | ✓ | 324 W (38.6 V, 8.4 A), 7 sec, steel wool | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| G | Listed | 3.0 kVA, 1ϕ, inverter with transformer | ✓ | ✓ | Masked arc with 994 and 127 μH | Masked continuous arc with 1.5 μF | ✓ | ✓ | Would run only with inductors | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| H | Listed | 4.2 kVA, 1ϕ, TL inverter | ✓ | ✓ | Tripped when inductor installed | Tripped when capacitor installed | Tripped with 994, 127, and 82 μH | Tripped with 1.5 μF | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| I | Listed | 5.5 kVA, 1ϕ, TL inverter | 169 W (36 V, 4.7 A), 30+ seconds, pull apart | 298 W (42 V, 7.1A), 20 sec, steel wool | N/A | N/A | N/A | N/A | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| J | Unlisted | 14.4 kVA, 1ϕ charge controller | ✓ | N/A | N/A | N/A | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| Recommended for Manufacturer Testing | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Test using as many inverters, converters, and charge controllers as possible for stand-alone devices. | | | | | |
| Recommended for UL 1699B Inclusion | | | ✓ | ✓ | Test with 1 mH unless otherwise specified by the mfr. | Test with 3 mF unless otherwise specified by the mfr. | Test with 1 mH unless otherwise specified by the mfr. | Test with 3 mF unless otherwise specified by the mfr. | ✓ | ✓ | Test using 1 single phase inverter, 1 three-phase inverter, 1 converter, and 1 charge controller for all stand-alone devices going to be UL 1699B recognition. | | | | | |

^ Test currently in the UL 1699B Outline of Investigation.

* Tests added to the UL 1699B Outline of Investigation in November, 2014.

[#] Tests not included in the UL 1699B Outline of Investigation.

[$] Only a single 1-phase or 3-phase inverter, converter, or charge controller is used as the load in the current version of Loading Condition I.

** These products are from the same manufacturer.

TABLE II

ARC-FAULT CIRCUIT INTERRUPTER AND ARC-FAULT DETECTOR ARCING, MASKING, AND UNWANTED TRIPPING RESULTS (CONTINUED)

| | | | Unwanted Tripping Tests | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AFCI Product | UL 1699B Compliance | Product Specs | 5. Loading Condition II – DC Disconnect ^ | 6. Loading Condition III – Irradiance Change* | 7. Frequency Sweep with Coupling Transformer# | 8. Inductive Coupling between Arrays | | | | 9. AC-DC Coupling | | | | 10. Broadband Noise Injection | | | 11. Injected Inverter Signatures with Coupling Transformer | | |
| | | | | | | Inverters F, G, H# | Inverters F, G, I# | Inverters F, G, Charge Controller J# | Inverters E, G, H# | Paper Shredder # | Shop Vacuum # | Bench Grinder # | Relay on AC load# | 50 ms# | 100 ms# | 150 ms# | Noise A# | Noise B# | Noise C# |
| A | Unrecognized | Stand-Alone AFD Product | ✓ | Tripped when 1/2 PV array is connected | Square wave tripped at 100 kHz, 133 kHz, 1-10 kHz; 73 & 76 kHz Trip with Inv. F | | | On J DC system | | ✓ | ✓ | ✓ | Tripped with Power Supply | N/A | N/A | N/A | N/A | N/A | N/A |
| B | Unrecognized | Stand-Alone AFD Product | ✓ | ✓ | Square wave tripped at 1 and 2 kHz for many Inv.; Sine wave tripped 3-10 kHz | | | ✓ On J DC system | | ✓ | ✓ | ✓ | Tripped with Power Supply | N/A | N/A | N/A | N/A | N/A | N/A |
| C | Recognized | Stand-Alone AFD Product | ✓ | ✓ | Square wave tripped at 2kHz with Inv. E, 12-14 kHz trips with Inv. H | | | ✓ On J DC system | | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| D | Unlisted | 8-string Combiner Box with AFCI | ✓ | ✓ | ✓ | | | ✓ On J DC system | | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| E** | Listed | 3.8 kVA, 1ϕ, inverter with transformer | ✓ | Tripped when 1/2 PV array is disconnected or resistance added | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| F** | Listed | 8.2 kVA, 1ϕ, TL inverter | ✓ | Tripped when 1/2 PV array is disconnected or resistance added | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| G | Listed | 3.0 kVA, 1ϕ, inverter with transformer | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| H | Listed | 4.2 kVA, 1ϕ, TL inverter | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| I | Listed | 5.5 kVA, 1ϕ, TL inverter | ✓ | ✓ | N/A | | ✓ | | | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A | N/A | N/A | N/A |
| J | Unlisted | 14.4 kVA, 1ϕ charge controller | ✓ | ✓ | Square wave tripped at 1-2 kHz and 4 kHz | | | ✓ | | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Recommended for Manufacturer Testing | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Test as many devices as possible. | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Recommended for UL 1699B Inclusion | | | ✓ | ✓ | ✓ (With sine wave injection) | Test with same devices from Loading Condition I | | | | | | | ✓ | ✓ | | | | | |

^ Test currently in the UL 1699B Outline of Investigation.

* Tests added to the UL 1699B Outline of Investigation in November, 2014.

# Tests not included in the UL 1699B Outline of Investigation.

** These products are from the same manufacturer.