Techniques for Commissioning Arc-Flash Mitigation Systems

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TECHNIQUES FOR COMMISSIONING ARC-FLASH MITIGATION SYSTEMS

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Abstract—The power industry well understands the safety hazards and equipment destruction associated with arc-flash events. Several arc-flash mitigation techniques can minimize incident energies during arc-flash events by detecting the light-and-current signature of an arc flash in a fraction of a power system cycle. Like all protection schemes, arc-flash mitigation systems must be field-tested and proven to meet design specifications. This paper explains best-known practices and tools available for commissioning these systems. Topics discussed include how to select and configure test equipment, interpret device self-test diagnostics, and validate system performance with event reports and time-synchronized devices. It also introduces system trip matrices and explains their utility for commissioning personnel. Oscillographic event report data and lessons learned are shared. Best design practices such as fiber loss calculations and fiber terminations are also shared.

Index Terms—Arc flash, safety, incident energy, fiber, commissioning, field-tested.

I. INTRODUCTION

Arc-flash sensing and mitigation is an integral part of electrical protection design and coordination. Implementing arc-flash detection (AFD) features is every bit as common as setting a 51 time-overcurrent element. While there are many ways to achieve AFD, the most reliable and capable arc-flash mitigation schemes use light detection sensors supervised by ultra-fast current detection technologies, making this type of protection secure and fast [1] [2] [3].

Light-and-current protection schemes have been used for systems requiring arc-flash protection for years. As the industry becomes more confident in the security and reliability of these schemes, engineering teams are designing more sophisticated arc-flash protection schemes, making testing the AFD schemes challenging. However, it is essential to test both the current measurement capability and light-detecting performance in AFD schemes to verify that the system responds properly for every incident.

This paper shows a proven method of testing light-and-current AFD schemes. It describes how to select, configure, and validate test equipment; determine fiber losses; and use a system trip matrix (STM) to determine and account for all zones of coverage. Example arc-flash events with oscillographic event reports are evaluated to provide context for the method. The methods in this paper are suitable for commissioning and testing new equipment in a switchgear facility or after a brownfield installation.

The method allows for documentation to be produced to comply with Article 240.87 of the 2017 National Electrical Code (NEC). The NEC code requires arc energy reduction when a circuit interruption device is rated for more than 1,200 A. The code requires that documentation be provided for these installations.

II. TEST EQUIPMENT AND CALIBRATION

Testing a light-and-current-based arc-flash mitigation system requires a secondary current injection test set and a light source. Test engineers must select a test set capable of injecting three-phase or single-phase current and providing different test states, such as pre-fault, fault, and post-fault. To duplicate a trip sequence accurately, the test set should support a high-speed digital input to monitor a relay's trip output. The test set must be able to record events with 1-millisecond (ms) or better resolution. Finally, the test set needs a contact output to trigger an external flash (to simulate the light generated by an arc flash) that is synchronized with the fault current state. See Fig. 1 for an overview of the required equipment and connections.

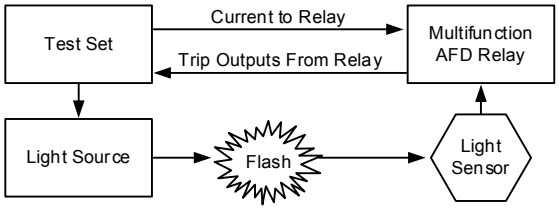

Fig. 1 Test System Block Diagram

A. Selecting the Proper Light Source

Test engineers should carefully select the light source. Some multifunction AFD relays have a light pickup element, referred to here as a light inverse-time (LIT) element, that requires light to be present during a specific window of time and to be of a specific amplitude. The LIT element has a similar characteristic to an inverse-time current element. Some flash

test devices may not output sufficient light to assert the LIT element. Fig. 2 shows a flash test device that does not provide sufficient light amplitude and time for an AFD relay.

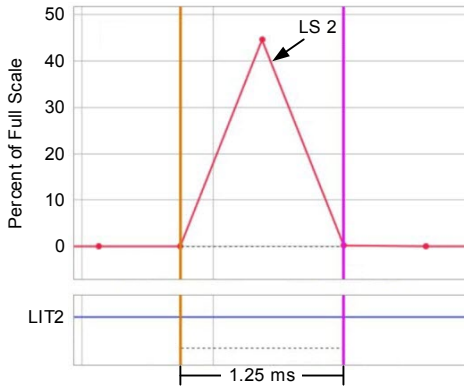

Fig. 2 Light Source Inadequate to Pick Up Light Element

Fig. 2 is an oscillographic (event report) waveform capture from an AFD relay. The relay captures analog inputs, including the light intensity measured by each light sensor, at 32 samples per cycle and binary logic states at 4 samples per cycle. In Fig. 2, the flash measured by light sensor Input 2 (LS 2) lasted less than 1.25 ms, which was too short to assert the LIT2 element triggered by the LS 2 input. In contrast, the flash shown in Fig. 3 from a different external flash lasts 6.25 ms, which is long enough for the LIT2 element to assert. This manufacturer's LIT element has a built-in 1-cycle dropout timer, so the element remains asserted even when the light from the flash is no longer present.

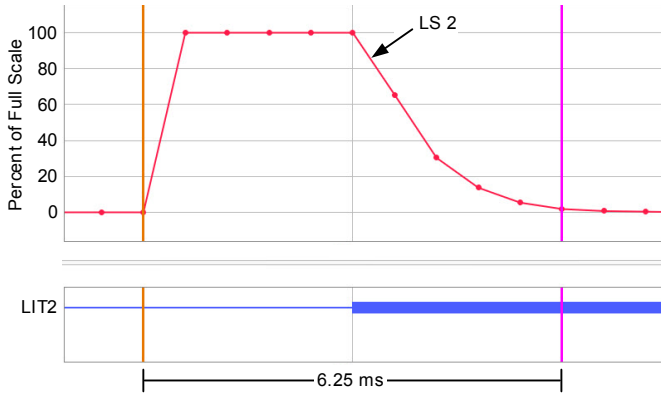

Fig. 3 Light Source Adequate to Pick Up Light Element

Test engineers can test point sensors with a single light source. Loop sensors, however, are more complicated to test and may require multiple light sources. The longer the fiber-optic loop sensor, the more light is necessary to provide the same light level to the relay. For example, testing a 40-meter fiber loop sensor requires more light than testing a 20-meter fiber loop sensor to achieve the same light level at the relay.

Using a second light source is an efficient way to increase the light captured by the fiber-optic loop. Test engineers can wire a second flash test device (light source) to the output contact of the test set that initiates the flash. Alternatively, some light sources include a master/slave mode where a master light source initiating the flash can wirelessly trigger a remote light source. See Fig. 4 for example results from such a setup. In this test, the test engineers used two different LIT elements to demonstrate the timing between the light source flashes. The relay measured light from the slave flash approximately 0.625 ms after the master flash.

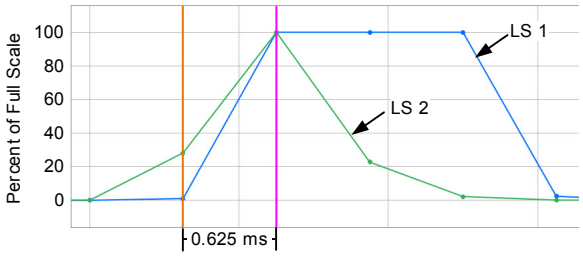

Fig. 4 Slave Light Source Triggered by Master Light Source

B. Calibrating the Light Source

To accommodate delays in the output contact operate time and light source triggering associated with specific test equipment, a typical test sequence should include pre-fault, triggering the light source, fault, and post-fault states. Test engineers need to adjust the timing of each state to verify that the flash coordinates with the fault current. To configure the test equipment, engineers must use relays that have oscillographic waveform capture to permit detailed analysis. Engineers must analyze the triggering of the light source and compare it with the fault injection state. The sequence and timing must match the expected sequence and timing of the actual power system.

In the example in Fig. 5, there is zero delay between triggering the light source and the fault state. As a result, there is an approximate 7.5 ms delay between the relay sensing the fault current and sensing the flash of light. This 7.5 ms delay is due to the test kit output contact operating time and the light source response time.

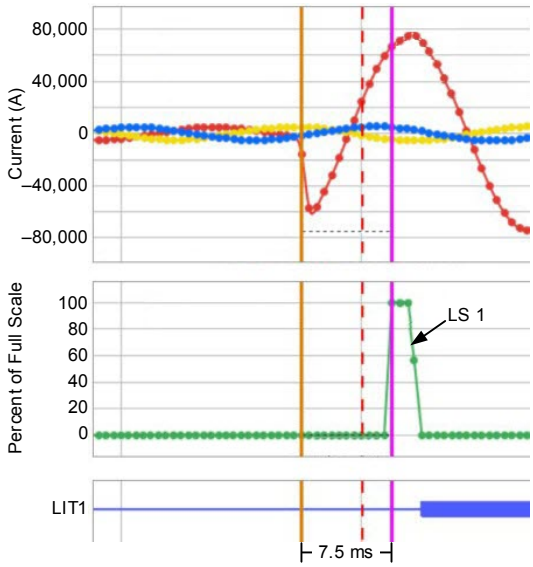

Fig. 5 Light Source and Fault State Triggered at Same Time

The results of Fig. 5 must be adjusted since visible light from an actual arc-flash event lags the application of current by an average of 1.5 ms [4].

In Fig. 6, to account for the dry contact closure time and light source response, the test engineer triggered the light source 7 ms before the fault state. For further accuracy, the light source should trigger approximately 6 ms before the fault state to best simulate a real arc-flash event. The timing may vary based on the specific test equipment used.

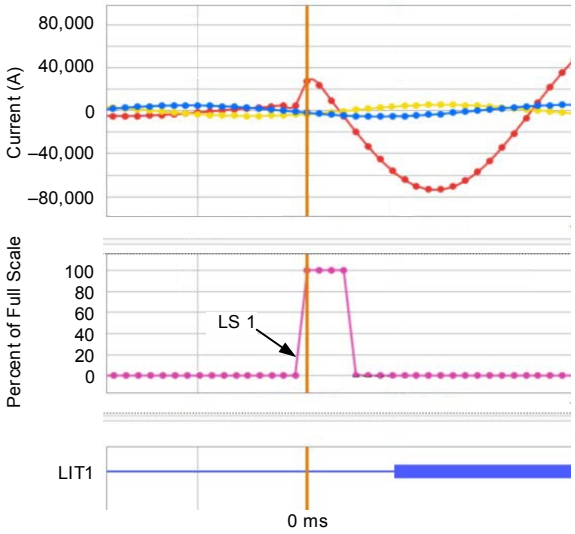

Fig. 6 7 ms Advanced Trigger of Light Source

III. SYSTEM CONFIGURATION

Fig. 7 shows a typical main-tie-main system with a comprehensive arc-flash mitigation scheme. This system is used as the example system in this paper.

In Fig. 7, the incomers, bus tie, and feeder cubicles are protected by digital feeder relays and circuit breakers (CBs). The motor starters are of the bucket (drawer) design and are protected by digital low-voltage motor relays (LVMRs), contactors, and molded case CBs (MCCBs). All the relays used in this design are AFD-capable. The incomer, bus tie, and outgoing feeder relays support up to four light sensor inputs. Each sensor covers a specific zone in the switchgear.

The light sensor inputs use a combination of point and fiber loop sensors. Each relay has current transformer (CT) inputs for validating the light with a high-speed current supervision element. The LVMRs each have a built-in light sensor input monitoring inside the bucket (drawer) and are also equipped with built-in CTs for current detection.

In Fig. 7 , the two buses are separated by a bus-tie CB. Because the two buses are several meters apart, a bus duct electrically connects Buses A and B. Due to the physical construction, fiber cannot be installed in the bus duct. This is acceptable due to the low probability of arc-flash events in the bus duct and because it is unlikely that humans would be exposed if there were such an event.

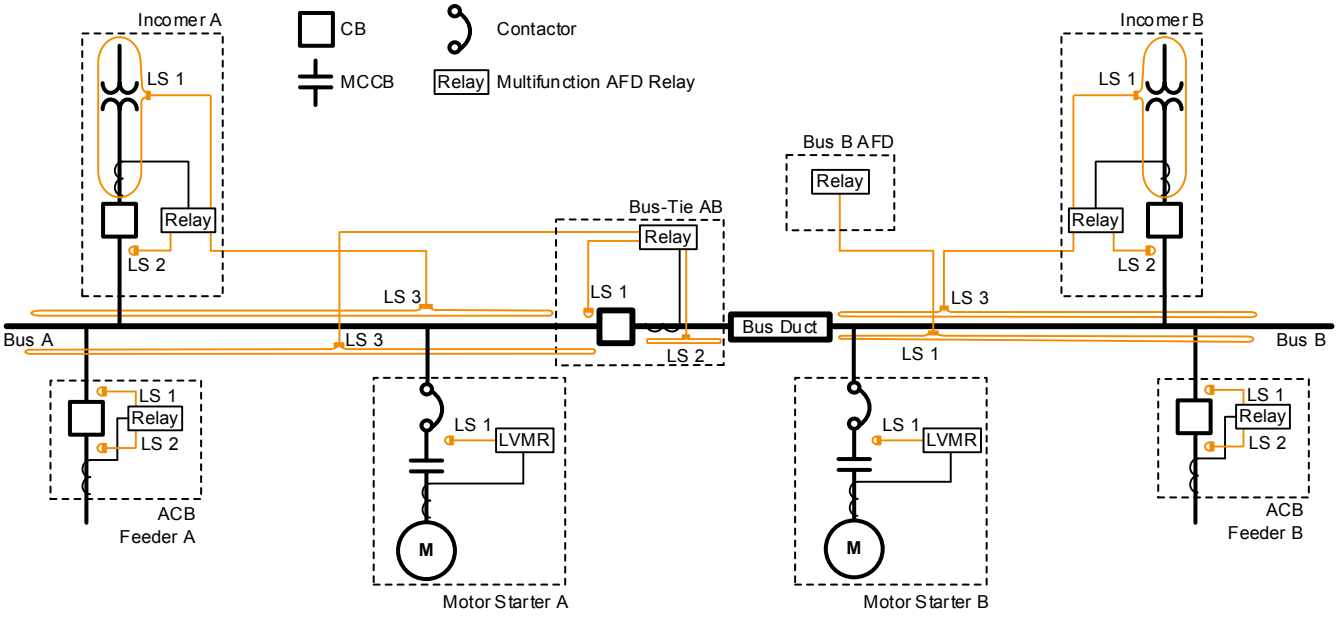

Fig. 7 Example Main-Tie-Main Arc-Flash Protection Scheme

Table I shows each of the light sensor coverage areas associated with Fig. 7.

TABLE I
ARC-FLASH ZONES OF PROTECTION

AFD Relay	Light Sensor Input	AFD Zone
Incomers A and B	LS 1—loop	Transformer and cable compartments
	LS 2—point	CB compartment
	LS 3—point	Busbar A/B
	LS 4—loop	Spare for longer bus runs
Bus tie	LS 1—point	CB compartment
	LS 2—loop	Bus duct compartment (Bus A side)
	LS 3—point	Busbar A
	LS 4—loop	Spare for longer bus runs
Bus B AFD	LS 1—point	Busbar B and bus duct compartment (Bus B side)
	LS 2—loop	Spare for longer bus runs
Feeders A and B	LS 1—point	CB compartment
	LS 2—point	Cable compartment
Motor Starters A and B	LS 1—point	Internal to bucket (drawer)

When configuring the system, the commissioning engineer or test technician should confirm the following to ensure that the arc-flash mitigation scheme will operate as intended:

1. Light-detecting threshold settings in the AFD relay are set above the ambient light level to prevent false operations of the light sensor.
2. Attenuation in the fiber cable is below manufacturer-specified limits.
3. The zone of coverage is correctly monitored, i.e., all zones are accounted for and relays are not overreaching other zones.
4. Trip timing is within design specification limits of energy reduction.

Each of these topics will be covered in the subsequent sections.

IV. FIBER LOSSES AND TERMINATIONS

Fiber-optic light sensors are an integral part of a light-and-current-based arc-flash mitigation scheme. System designers must understand optimal design criteria and commissioning engineers must understand how to verify performance with test procedures. Reference [3] discusses light sensor types and how the sensors can be applied to low- and medium-voltage panels. System designers must follow manufacturer guidelines for sensors, fiber-optic cable lengths, terminations, and fiber routing.

A. Fiber Loss Calculations

Routinely testing fiber-optic light sensors is important to ensure the AFD functions when required. An ideal solution is a relay that performs automatic and routine fiber health self-tests. Such a relay performs self-tests by sending a periodic flash of light down the entire length of fiber and verifying that a second input on the relay receives that signal. The relay calculates the percentage of light lost across the fiber and declares a failed fiber if the relay detects that less than the specified percentage of the transmitted light is received. The percentage of light received should be converted to a decibel (dB) unit per industry standard.

Relay self-tests are very useful for switchgear manufacturers to ensure that they have properly installed fiber-optic sensors and the associated fiber terminations. End users should monitor these AFD self-test alarms continuously when switchgear is in service so that they are alerted to any fiber failures that could lead to delayed tripping times and associated increases in incident energies.

Engineers must calculate losses and the AFD relay optical budget in their designs. For the AFD relay used in this example, the fiber self-test alarm will be asserted if fiber losses are greater than 12.25 dB for a point sensor or 17 dB for a bare-fiber loop sensor. For the example system, the fiber-optic sensor manufacturer lists the fiber (jacketed or clear) losses at 0.175 dB/meter and each splice (V-pin or ST) loss at 2 dB.

In a low-voltage motor control center (MCC) system recently designed by the authors, six splices on a 30-meter fiber run violated the link optical budget (refer to Table II). An arc-flash alarm was triggered, informing the commissioning team there was an issue.

TABLE II
OPTICAL BUDGET EXAMPLE

Optical Budget		Component Losses	
Point sensor	<12.25 dB	Fiber	0.175 dB/m
Bare loop sensor	<17 dB	Splice	2 dB

Loop Sensor Example Parameters		Component Loss (dB)
Total fiber (m)	30	5.25
Expected splices	4	8
Additional splices	2	4
	Total loss (dB)	17.25
	Remaining optical budget (dB)	–0.25

This system included 5 meters of jacketed fiber and 25 meters of bare fiber. Jacketed fiber was used from the relay to the bus compartment to avoid any light detection from the out-of-zone area. Bare fiber was used in the zone of protection throughout the bus compartment. Two splices were required to transition from jacketed to bare fiber. At the time of design, the MCC was to have a single shipping split requiring an additional two splices. The total attenuation loss was calculated to be 13.25 dB, satisfying the optical budget. During the construction

phase, the MCC manufacturer added a shipping split that required two additional fiber splices, increasing the attenuation loss by 4 dB and exceeding the optical budget. This necessitated a design change to reduce the total light attenuation loss.

In Table I, the incomers, bus tie, and Bus B AFD relays have spare light sensors. It is recommended to include at least one spare light sensor in the design to account for unforeseen scenarios such as the one described in this section.

B. Fiber Terminations

Fiber-optic cables may be supplied in either pre-terminated lengths or fiber in bulk, where a technician can cut the fibers to length and then apply the terminations onsite. While cutting fiber to length onsite eliminates coiled excess-fiber loops, this can also lead to unnecessary fiber losses if the technicians are not familiar with best practices for terminating the fiber ends. To achieve the losses shown in the top half of Table II, fibers must be terminated, polished, and crimped according to the manufacturer's guidelines. For both pre-terminated and build-your-own fibers, technicians should watch for fibers that are not flush or not polished with the end connectors because this can lead to additional optical losses.

It can be difficult to determine termination quality with the human eye; therefore, the authors recommend verifying the light attenuation loss of all arc-flash fiber cables after installation. As mentioned in Section IV Subsection A, some AFD relays have a fiber health self-test that measures the dB loss along the length of the fiber that can be used for this validation.

V. ZONES OF COVERAGE

Designers and test engineers need to know which relays are covering each zone and to verify that all zones are protected in an arc-flash mitigation scheme. In typical protection schemes, zones are dictated based on CT placement and time-overcurrent coordination. For arc-flash mitigation schemes, CT placement is still integral to zoning, but the light sensor coverage area is just as important.

For some zones of coverage, the relay can detect both the light and current produced during a flash, allowing for a single relay to operate during the event. However, depending on the system configuration, a relay could sense the light from the arc but not detect the current because of the CT placement. In this case, the light information must be communicated to an upstream relay that can verify the current and send a secure trip command to the appropriate CB.

A. Single-Relay Arc-Flash Testing

In a single-relay arc-flash mitigation scheme, a single protective relay includes one or more light sensors and current measuring inputs to detect, verify, and issue a trip command to extinguish the arc. These schemes do not require communication to or from other devices, leading to faster tripping times when compared with schemes requiring multidevice interaction. But, they can be limited on coverage zones and selectivity due to system-specific physical constraints.

The following scenario uses the example in Fig. 7. The CBs at Incomers A and B are closed with the Bus-Tie AB CB open. This is the normal configuration for this system. The buswork of Bus A is covered by LS 3 of the Incomer A relay and LS 3 of the Bus-Tie AB relay. If an arc flash occurs on the buswork of Bus A, the scheme should open the Incomer A CB and clear the fault as quickly as possible. In the example system, both the Incomer A and the Bus-Tie AB relays see the light from the fault. But in this case, only the Incomer A relay detects the current. The relay on Incomer A receives a light signal from LS 3, verifies the increase in current, and sends the tripping command to Incomer A, clearing the fault.

B. Multidevice Arc-Flash Testing

System designers must consider solutions that involve multiple devices to quickly isolate the fault and reduce the arc-flash incident energy. For example, if the fault occurs inside one of the buckets (drawers) on Bus B, LIT1 from the LVMR picks up. However, neither the contactor nor the MCCB is able to interrupt an arcing fault, and, depending on the fault location, the LVMR may not detect the fault current. The following subsections evaluate possible solutions for this scenario.

1) Relay-to-Relay Communications

With relay-to-relay communications, the LVMR transmits the light threshold element via direct communication to the Incomer B relay and the Bus-Tie AB relay. Both relays supervise the communicated light element status with a local high-speed current element. Depending on the system configuration at the time of the fault, either the Incomer B relay or the Bus-Tie AB relay will detect the fault current and issue the trip command. This is the preferred solution suggested by the authors for small systems. In the example in this paper, the bus-tie relay can handle 64 concurrent IEC 61850 Generic Object-Oriented Substation Event (GOOSE) connections from light-sensing relays; thus, this method is acceptable for buses with up to 64 AFD relays.

2) AFD Controller

For large systems with more than 64 relays per bus, an intermediate AFD controller can be used. AFD controller logic tracks system configurations and AFD light sensing from distributed AFD relays. The AFD controller logic then issues the light trigger to the target relay, which has a high-speed overcurrent element to supervise the received light signal. This type of detection scheme works well for low-voltage MCCs where the relays can number in the hundreds.

C. System Trip Matrix

An arc-flash protection scheme may incorporate both single-relay and multidevice tripping. To comprehensively test the entire scheme, engineers should create an arc-flash STM that defines the arc-flash devices, the light zones of protection, the potential system configurations, and the expected tripping device and method. An arc-flash STM is shown in Table III for the example system shown in Fig. 7.

TABLE III
EXAMPLE TRIP MATRIX

AFD Relay	Light Sensor Input	AFD Zone	Current Detected				
			Incomer A	Bus Tie	Incomer B	Upstream Source A or B	Feeder A or B
Incomer A or B	LS 1	Transformer and cable compartments				Direct transfer trip (incomer → upstream CB)	
	LS 2	CB compartment	Self-trip		Self-trip	Definite-time backup trip*	
	LS 3	Busbar A/B	Self-trip		Self-trip		
	LS 4	Spare for longer bus runs					
Bus Tie	LS 1	CB compartment	Definite-time backup trip*	Self-trip	Definite-time backup trip*		
	LS 2	Bus duct compartment (Bus A side)	Direct transfer trip (Incomer A → Bus-Tie AB)				
	LS 3	Busbar A		Self-trip			
	LS 4	Spare for longer bus runs					
Bus B AFD	LS 1	Busbar B		Direct transfer trip (Bus B AFD → Bus-Tie AB)	Direct transfer trip (Bus B AFD → Incomer B)		
	LS 2	Spare for longer bus runs					
Feeder A or B	LS 1	CB compartment	AFD controller trip (feeder → AFD controller → Incomer A)	AFD controller trip (feeder → AFD controller → Bus-Tie AB)	AFD controller trip (feeder → AFD controller → Incomer B)		
	LS 2	Cable compartment					Self-trip
Motor Starter A or B	LS 1	Internal to bucket (drawer)	AFD controller trip (feeder → AFD controller → Incomer A)	AFD controller trip (feeder → AFD controller → Bus-Tie AB)	AFD controller trip (feeder → AFD controller → Incomer B)		

* If the arc persists after the CB opens, a backup trip will be issued to an upstream CB.

When developing an STM:

1. Define all possible system configurations.
2. Define each light sensor input zone.
3. Define which AFD relay detects current based on the fault zone and system configuration.
4. Define which CB should clear the fault for each system configuration and fault location.

D. Overlapping AFD Zones

Redundant AFD schemes are designed for systems with critical processes or that are high risk to personnel. While time-overcurrent protection provides some backup, a redundant AFD scheme overlaps fibers from different relays into a single zone. Fig. 7 is not designed to be a redundant AFD scheme; however, some of the light sensors cover the same areas due to necessity.

For example, the Incomer A and Bus-Tie AB relays have overlapping fiber-optic loop sensors on Bus A. This is to simplify the AFD system and provide protection during maintenance outages, not provide redundancy. For example, if the Incomer A relay is de-energized to service the incomer cubicle, Bus A is no longer protected by the Incomer A relay. During this time, the Bus-Tie AB CB is supplying power to Bus A; thus, the Bus-Tie AB relay provides a full AFD coverage area during this maintenance operation.

Note that a Bus B AFD relay was added to the design to monitor Bus B. This was required because the Bus-Tie AB relay cannot monitor Bus B because the bus duct creates a physical barrier to fibers. This device only detects and transmits the AFD light signal to the Bus-Tie AB relay. In a normal configuration,

this relay would also send the signal to Incomer B as a form of redundancy.

E. Normal Light Events

Within low-voltage MCC buckets (drawers), MCCBs, motor circuit protectors, or contactors may emit sparks and light under normal operation [5]. This light emission is common during the closing operation of the contactor for motor starts or during the clearing of cable faults by the MCCB or motor circuit protector. In both scenarios, the light emission is accompanied by a rise in current. If not accounted for in a light-and-current based arc-flash scheme, this type of scenario can lead to a misoperation.

A method for mitigating the potential misoperation of the arc-flash scheme during such events is to have the LVMR send a blocking signal to the upstream relay when the LVMR detects light and current. The blocking signal is only held for a specified time, and it releases to allow the upstream relay to issue a backup trip if the MCCB or contactor does not interrupt the fault. If the LVMR is only detecting light, the upstream relay trips instantaneously upon a rise in current.

VI. ARC-FLASH TEST EXAMPLES

To highlight the importance of the STM while testing, consider the following two examples based on the system in Fig. 7. For each example, the fault location, the expected tripping device, and results from event reports are indicated.

A. Example 1—Arc Flash in Bus-Tie Cubicle

For this example, the Incomer A and Bus-Tie AB CBs are closed and Incomer B is racked out. The CTs of the Bus-Tie AB relay are placed on the bars behind the back stabs of the CB (see Fig. 8).

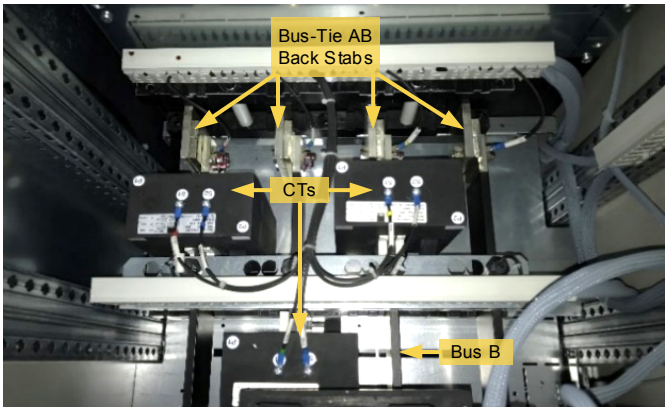

Fig. 8 Bus Tie Rear CT Placement

Consider an AFD event on the back stabs of the Bus-Tie AB CB, as shown in Fig. 9. The arc flash occurs in the Bus-Tie AB cubicle on Bus B, but it is fed power via Bus A. In this case, the Bus-Tie AB relay detects the light from the arc flash; however, the Bus-Tie AB relay CTs do not detect current.

To minimize the outage caused by the arc, the Bus-Tie AB CB should open and clear the fault since the fault is electrically on Bus B; however, the Bus-Tie AB relay cannot see the current. Ensuring the security of the scheme requires maintaining both light and current validation, so the Bus-Tie AB relay passes the light information (2:VB035 in Fig. 10) to the Incomer A relay via IEC 61850 GOOSE messaging. The Incomer A relay validates the light from this specific zone with the increased current. With the validation satisfied, the Incomer A relay sends a trip signal (1:VB014) to the Bus-Tie AB relay via GOOSE messaging to clear the fault.

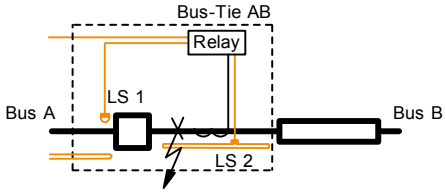

Fig. 9 Arc Flash in Bus-Tie Cubicle

In this example, the system behaved exactly as expected based on the STM. Refer to Fig. 10 for the event report from this simulated scenario. Relay 1 is at Bus-Tie AB, and Relay 2 is at Incomer A. Their digitals are prefaced with 1 or 2, respectively, in the event report.

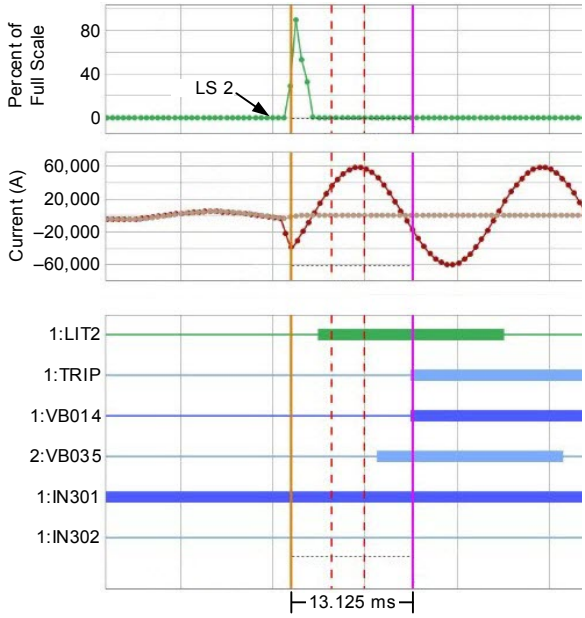

Fig. 10 System Performance for Arc Flash in Bus-Tie AB Cubicle

B. Example 2—Arc Flash on Bus B With Incomer B Open

In this scenario, the Incomer B CB (and the associated Incomer B relay) is out of service for maintenance, The Incomer A CB is closed, and the Bus-Tie AB CB is closed (as shown in Fig. 11). For a fault on Bus B and with the Incomer B relay de-energized, the light from the arc flash is only sensed by the Bus B AFD relay.

Based on the STM, the Bus B AFD relay should assert the LIT1 element. The Bus B AFD relay sends the status of the LIT element to the Bus-Tie AB relay, which validates the light signal with an overcurrent element prior to asserting a trip.

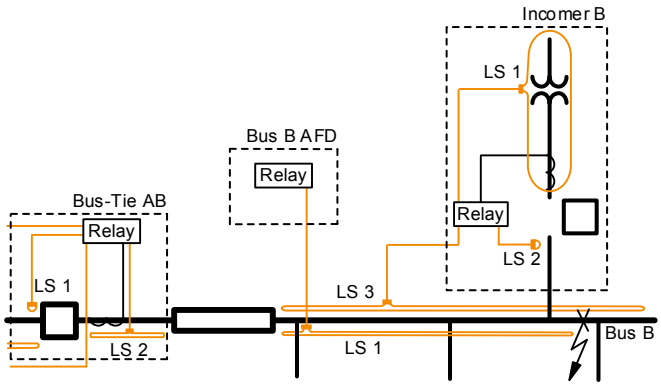

Fig. 11 Arc Flash on Bus B With Incomer B Open

Fig. 12 shows the oscillography for this testing event. In this example, the Bus-Tie AB relay is Relay 1 and the Bus B AFD relay is Relay 2. The Bus B AFD relay sends the LIT1 status (2:LIT1) via GOOSE messaging to the Bus-Tie AB relay (1:VB005). Because the high-speed current element (1:50) has asserted in Bus-Tie AB, this results in the Bus-Tie AB relay asserting a trip (1:TRIP) within 9.25 ms.

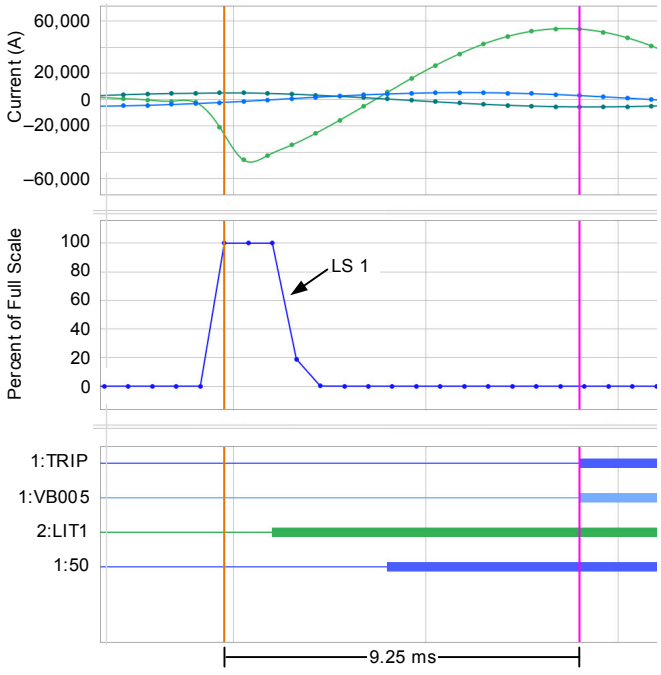

Fig. 12 System Performance for an Arc Flash on Bus B With Incomer B Open

VII. OBSERVATIONS

The authors made eight critical observations during the design and commissioning stages of arc-flash mitigation systems:

1. Damaged or poorly terminated fibers are often found during the commissioning stage. The issues range from tight turns exceeding the bending radiuses of the fiber to improperly terminated fiber or broken fibers. Before any scheme testing begins, a fiber integrity test should be run to prove the fiber is installed per the specification. This can involve a physical inspection or the use of a light source to test the loop attenuation loss. AFD relays with built-in self-tests for performing this action make this test accurate and efficient.
2. Both point and loop sensors are required for optimal AFD protection. Point sensors are suitable for small, contained spaces. Loop sensors are excellent for busbars.
3. Unprotected zones can occur anywhere there are exposed conductors and no light sensors. The commissioning engineer must thoroughly examine every cubicle, cable compartment, busbar, and CB. Any locations where equipment is withdrawn, cables are terminated, spades are inserted, or moving parts are adjacent to conductors should have AFD light sensors.
4. CT placement has a critical impact on the AFD mitigation scheme functionality. Test engineers should verify that the protection zones will work as intended. This can be done with the help of the STM explained in Section V. The STM should be developed with the design team prior to field testing, but the commissioning team should physically verify the actual CT and fiber locations once in the field. The commissioning team can uncover additional unprotected areas not seen by the design team.
5. The time-overcurrent (50) elements supervising the light elements must be fast and secure and remain operational as the CTs saturate to ensure a reliable system [6]. CTs must be chosen carefully to ensure sufficient energy is let through to the relay during the high-current conditions of an arc-flash event [7].
6. Overlapping AFD zones of protection are critical for reliability and simplicity. For example, relays can operate without communications-assisted messaging if the AFD loop fibers from all the bus incomer and bus-coupler relays are overlapped.

7. During the commissioning of an arc-flash mitigation scheme, the test engineer should verify tripping times for each zone of AFD protection. These tests should be repeated multiple times for each zone and put into a test report delivered to the end user. Proof of timing should come from oscillography and sequential events recorder reports from the relays in the AFD scheme.
8. Relay models, even from the same manufacturer, have different sample rates for different data. For example, typical analog signals in a feeder relay may be sampled at 32 samples per cycle, and digital inputs and digital internal bits may be processed at 4 samples per cycle; however that same relay may process arc-flash-specific elements (light, unfiltered current elements, trip, and output contacts) at 16 samples per cycle. This must be kept in mind by the engineer performing the analysis.

As an example of the above observation, Fig. 16 shows an AFD test event where the relays have different sample rates. This event report shows a 5 ms delay from when light and current were detected to when the digital relay word bit associated with these elements asserted. The test engineer should not assume the detection time of this event to be 5 ms. This relay reports the digital bit (LIT1 and 50) at 4 samples per cycle, but the tripping decisions for the arc-flash event are made every 1/16 of a cycle. Because of such complexity, the best measure of an AFD scheme timing is a test set measuring the time from when light and current are applied to when a trip contact on the relay closes.

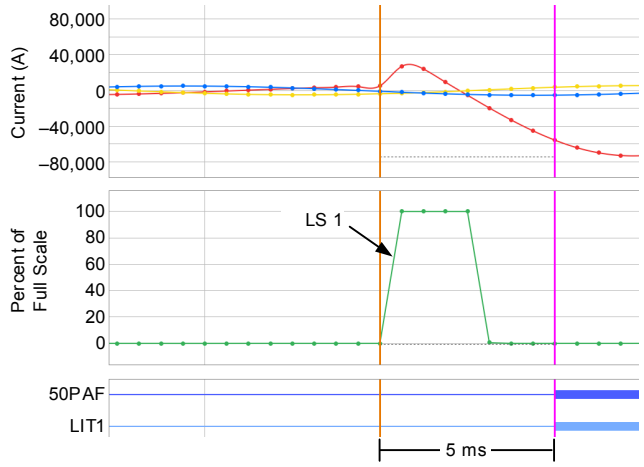

Fig. 13 Combined Analog and Digital Data With Different Sample Rates

VIII. CONCLUSIONS

Testing that an arc-flash scheme meets required clearing times provides a safer work environment and reduces equipment damage by reducing incident energy. Commissioning personnel should verify that proper test equipment is available prior to commissioning activities. Once onsite, the team should verify the location and integrity of all AFD fiber cables and that they meet design specifications prior to testing the scheme.

An engineered arc-flash STM that identifies the zones of protection and expected clearing devices helps commissioning engineers accurately test and account for all potential tripping scenarios. The STM should guide all test cases. Commissioning engineers must document each test case with relay event reports to accurately document the tripping time for each test case and to verify the intended design.

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X. VITAE

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