

### Application Note

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## Multilin 3 Series Arc Flash Protection

# MULTILIN 350 ARC FLASH DETECTION SYSTEM INSTALLATION, TESTING AND MAINTENANCE

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## Introduction

This document describes what arc flash is, its hazards and mitigations, and how arc flash detection protection is implemented in the Multilin 350 including light sensors, as well as how to install, test, troubleshoot and maintain the Multilin 350 arc flash solution.

General definition: An **arc flash** (also called a **flashover** or **electric arc**), is an ongoing plasma discharge, a type of electrical explosion or discharge resulting from a low-impedance connection through air to ground or another voltage phase in an electrical system. For discussions in this document, reference is to low voltage (LV) and medium voltage (MV) electric systems.

Definition from NFPA70E<sup>1</sup> for Arc Hazard: "A dangerous condition associated with the possible release of energy caused by an electric arc. An arc flash hazard may exist when energized electrical conductors or circuit parts are exposed or when they are within equipment in a guarded or enclosed condition, provided a person is interacting with the equipment in such a manner that could cause an electric arc." In other words, an electrical explosion that damages equipment and can cause serious injury.

Definition from OSHA<sup>2</sup>: simply put, an arc flash is a phenomenon where a flashover of electric current leaves its intended path and travels through the air from one conductor to another, or to ground. The results are often violent and when a human is in close proximity to the arc flash, serious injury and even death can occur.

The effects of an electric arc vary based on arc energy released, but all are dangerous due to: extreme temperatures reaching up to 35,000°F (20,000°C); explosive forces caused by the rapid expansion of gases and elements such as copper; intense light; high noise levels; and toxic fumes.

To put this in perspective, an arc flash can result in:

- Temperatures up to 35,000°F (20,000°C) where the surface of the Sun is 9,000°F (5,000°C), skin temperature for a curable (2<sup>nd</sup> degree) burn is 176°F (80°C), and skin cell death occurs at 205°F (96°C).
- A pressure wave upwards of 2,000 lbs/sq.ft (9765kg/sq.m) caused by copper expanding by 67,000 times when vaporized meaning 1" (2.54cm) of copper expands to be the size of a refrigerator.
- Sound up to 145dB at 2 feet (61cm) away where 140dB can cause immediate hearing nerve damage.
- A flash of light that can cause serious injury and permanent loss of vision.
- Toxic and heated gasses that can cause internal injuries through inhalation.

Hence, Arc Flash (AF) protection is very important for all power and process industries to maintain the safety of personnel at the workplace.



From OSHA 1910.269, arc flash protection requirements are:

1. Assess the workplace to identify employees exposed to hazards from flames or from electric arcs.
2. Estimate incident energy values.
3. Ensure employees wear flame-resistant clothing and PPE with adequate arc ratings that will not melt or ignite and continue to burn.

Arc flash events are mainly caused by:

- Switchgear internal faults
- Bad connections, hot spots, inadequate maintenance
- Presence of birds or rodents inside switchgear
- Dust, harsh environment particles or moisture (condensation) on insulating surfaces of switchgear
- Dropped tools
- Accidental (or even intentional!) touching
- Material failure
- Corrosion
- Faulty installation

Based on the high-risk factors, arc flash energy has a very large impact which can be reduced and mitigated by: (in order of effect)

- Reducing total fault clearing time by decreasing tripping time
- Reducing fault current magnitude
- Increasing working distance
- Improving safety through design

Improved safety through design can be achieved by using switch gear/breaker systems that have selectivity features but do not compromise protection and reliability. The selectivity must be able to detect low-level arc flashes and operate instantaneously, without any impact on maintenance and productivity requirements.

Products such as Arc Vault\* Protection System, ArcWatch\*, Entellisys\* LV Switchgear, Medium Voltage Arc Resistant Switchgear, Arc Flash Mitigation MCC Units, Limitamp\* AR Medium Voltage MCC, EntelliGuard\* TU Trip Unit can be used to mitigate arc flash energy, some in new installations and some in retrofit solutions as safety improvements through design.

Available protective relaying arc flash solutions are

1. The standalone [Multilin A60](#) utilizing pressure and light (point sensors) where current transformers (CTs) or current measurement is not available;
2. The [8 Series](#) utilizing light (point sensors) and a dedicated high-speed current detection.
3. The [350](#) utilizing light (point and loop sensors) and a dedicated high-speed current detection.

These solutions can be used to drastically reduce trip times of less than 6ms on LV and MV switch gear applications, which are significantly faster than any conventional overcurrent or bus protection applications and much more economical.

This document describes how trip time can be reduced using the light sensors (point and loop/line) and current detection of the Multilin 350 relay arc flash solution, including sensor installation/placement, testing and commissioning, trouble shooting and maintenance.

# Arc Flash Background

## Arc Flash Ratings

Arc flash energy is calculated based on the NFPA 70 and IEEE 1584 standards. Figure 1 shows the linear relationship of arc flash energy with respect to fault clearing time for a calculated 30 kA arcing current, and with a sample set of panel box conditions<sup>1</sup>. It is evident that the arcing duration plays a large role in the amount of arc flash energy produced. Different flash hazard risk categories are defined by NFPA 70E based on the amount of arc flash energy with a specific personal protective equipment (PPE) clothing requirement as highlighted in Figure 2. Based on the category level, appropriate PPE is required when performing work on energized equipment. In some cases, depending on the maximum bolted fault current level, the ability to limit the arcing duration can be life-saving. At a minimum, the breaker takes 3 to 5 cycles (50 to 83ms) to operate. Any additional time required for detection and assertion of the relay output drastically adds to the accumulated arc flash energy. In some cases, a reduction in the overall operating time can mean a lower category of arc flash level, and thus more lenient PPE requirements.

Some Zone Selective Interlocking (ZSI) schemes can increase the trip time by as much as 50ms (to allow the blocking signal enough margin to reach the main incoming feeder breaker/protection), and if used with a 3 to 5 cycle breaker, can cause the incident energy to be in level 2 or above 4 cal/cm<sup>2</sup>, which has more stringent PPE requirements. Using an arc flash solution can ensure PPE requirements of level 1 or less.

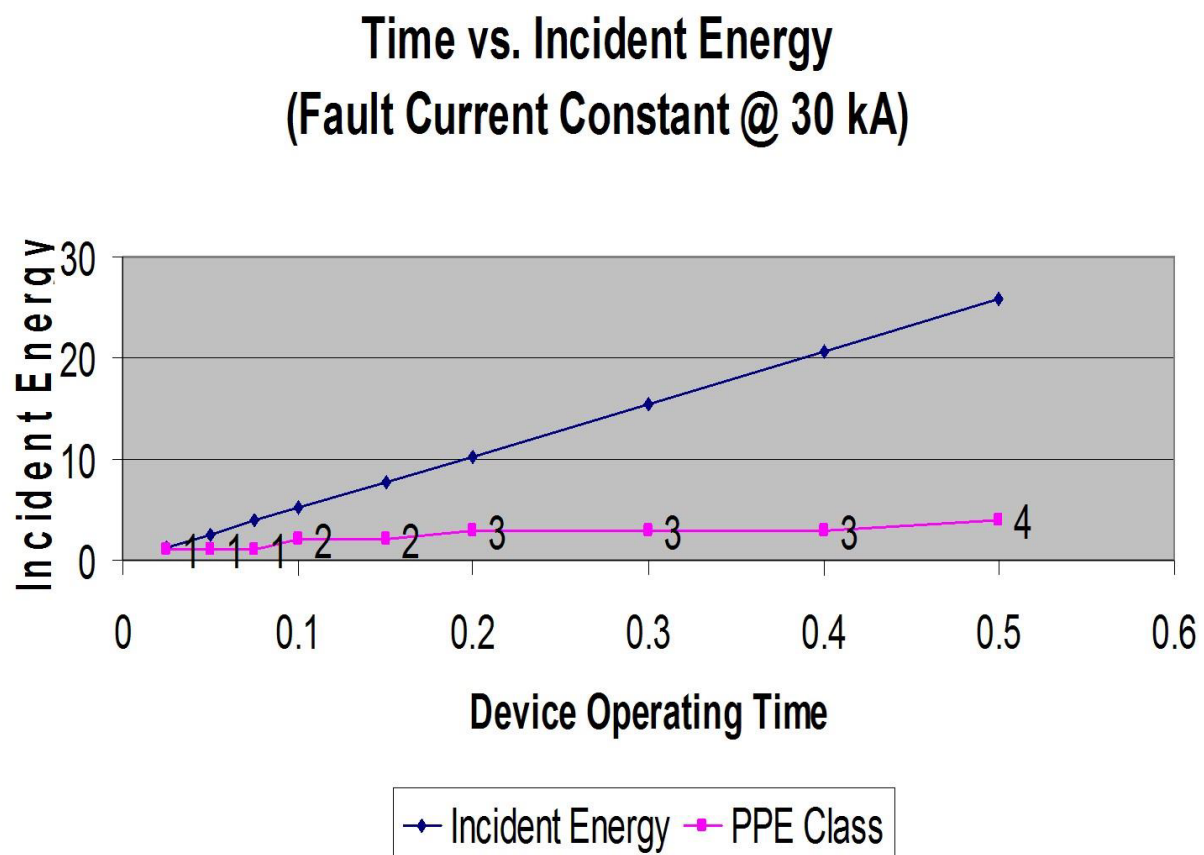


Figure 1. Arc Flash Incident Energy (cal/cm<sup>2</sup>), Arcing Duration(S) and PPE Class (Flash Hazard Risk Category)

<sup>1</sup> Davis, C., St. Pierre, C., Castor, D., Luo, R., Shrestha, S., Practical Solution Guide to Arc Flash Hazards, National Technology Transfer, Inc., ESA, Inc., 2003.

| FLASH HAZARD RISK CATEGORY | RANGE OF CALCULATED INCIDENT ENERGY [cal/cm <sup>2</sup> ] | MIN. PPE RATING [cal/cm <sup>2</sup> ] | CLOTHING REQUIRED   |
|----------------------------|--|--|---|
| 0                          | $0 \leq E \leq 1.2$  | N/A                                    | 4.5- 14.0 oz/yd <sup>2</sup> untreated cotton   |
| 1                          | $1.2 < E \leq 4$   | 4                                      | Flame Retardant (FR) shirt and pants  |
| 2                          | $4 < E \leq 8$   | 8                                      | Cotton underclothing plus FR shirt and pants  |
| 3                          | $8 < E \leq 25$  | 25                                     | Cotton underclothing plus FR shirt, pants, overalls or equivalent                                   |
| 4                          | $25 < E \leq 40$   | 40                                     | Cotton underclothing plus FR shirt, pants, plus double layer switching coat and pants or equivalent |
| 5                          | $40 < E \leq 100$  | 100                                    | Cotton underclothing plus FR shirt, pants, plus multi-layer switching suit or equivalent            |

Figure 2. Arc Flash Risk Categories, Incident Energy Levels and PPE requirements

## Benefits

Using light and fast current detection to detect an arc flash provides a much faster and more secure response than traditional protection devices, and a much faster response than Zone Selective Interlocking (ZSI) Schemes, traditional overcurrent (which is based on either half-cycle or full-cycle Fourier transform) or even bus protection. A much larger LV or MV bus can also be covered with the use of multiple point or loop light sensors, compared to bus protection schemes (which are not always economical and feasible, especially for larger busses).

## Applications (MV/LV)

Different technologies are available for arc flash mitigation and detection for MV and LV applications. Mitigation can be achieved by improved safety through design, which can be achieved by using switch gear/breaker systems that have selectivity features that don't compromise protection and reliability. The selectivity must be able to detect low-level arc flashes and operate instantaneously, without any impacts on maintenance and productivity requirements.

GE Vernova solutions for arc flash detection and mitigation are listed above in the Introduction

## Arc Flash Protection in the Multilin 350

Arc flash protection in the Multilin 350 feeder protection system uses a total of four light-detection fiber sensors which can be any combination of point and transparent fiber loop sensors, and a dedicated high-speed instantaneous overcurrent element with secure Finite Impulse Response (FIR) Filtering. A large change in light from the light sensor AND operation of the high-speed overcurrent element is required to ensure fast but secure operation of the arc flash function. Light-only arc flash protection can also be achieved by simply assigning the light pickup operand to an output relay (solid state relay outputs recommended) via a logic element, however some form of supervision is recommended. The light sensors are self-monitoring – the relay provides a self-test trouble indication if the sensor, fiber or connector is damaged, cut, or unplugged. The high-speed overcurrent element uses RMS current values every 1/8th of a cycle. High-speed tripping is accomplished using one of the high-speed Solid State Relay (SSR) outputs, hence a typical operation of 2-4ms (6ms or less) has been confirmed during arc flash lab testing at 50Hz.

Currently, the arc flash option is available only on the non-drawout version of the Multilin 350 relay.

The Multilin 350 arc flash sensor connectors use only of one type of input; the same input with connector is used for both point sensors and transparent fiber loop sensors, hence no special order codes are needed for different sensor combinations.

**Note:** Voltage inputs are not used by the arc flash functionalities of the Multilin 350 or typically required, however Undervoltage can be used for arc flash light-only supervision.



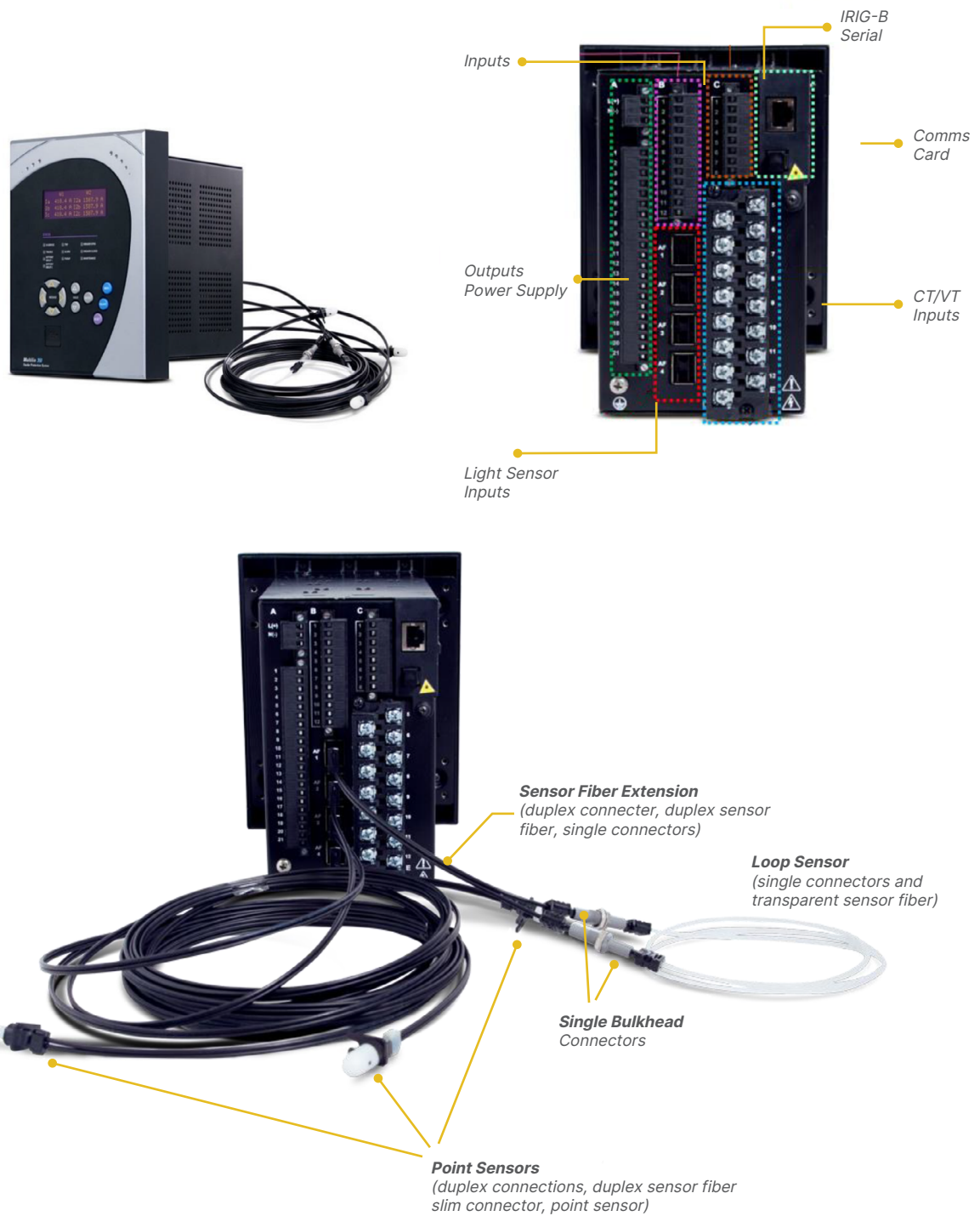


Figure 3. Multilin 350 with Arc Flash Sensors

## Point Sensor

The point sensor used with the Multilin 350 Feeder Protection System arc flash solution is available in any length from 1 to 35m, in 1m increments. The order code for the point sensor is AFC-P XX where XX is the fiber length in meters. The point sensor has a duplex connector on one end (that plugs into the 350, as seen above right) and a slim connector (into which both fibers terminate as seen above left) onto which the point sensor head snaps on. The point sensor head can easily be removed during installation, commissioning and maintenance activities.

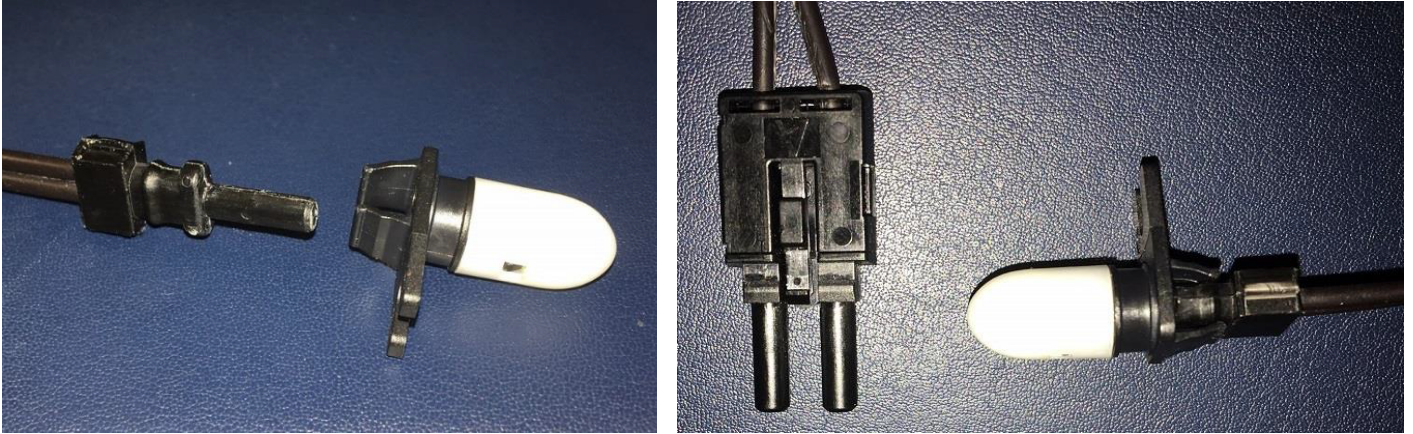


Figure 4. Arc Flash Point Sensor Head with Slim Connector (left) and Rear Connector to Multilin 350 (right)

## Transparent Fiber Loop Sensor with Sensor Fiber Extension

The transparent fiber loop sensor used with the Multilin 350 Feeder Protection System arc flash solution is available in any length from 1 to 70m, in 1 meter increments. The order code for the Loop Sensor is AFC-L XX where XX is the fiber length in meters. The loop sensor has a single connector on either end, and can be used with a black-jacketed fiber extension designed to connect the loop sensor to the 350 relay. The fiber extension has a duplex connector on one end (the end that plugs into the 350) and two single connectors that connect via two single bulkhead connectors, to the loop sensor. The Fiber Extension order code is AFC-E YY where YY is the fiber length in meters (from 01 to 34 in 1m increments). At least 1m of loop sensor is required.

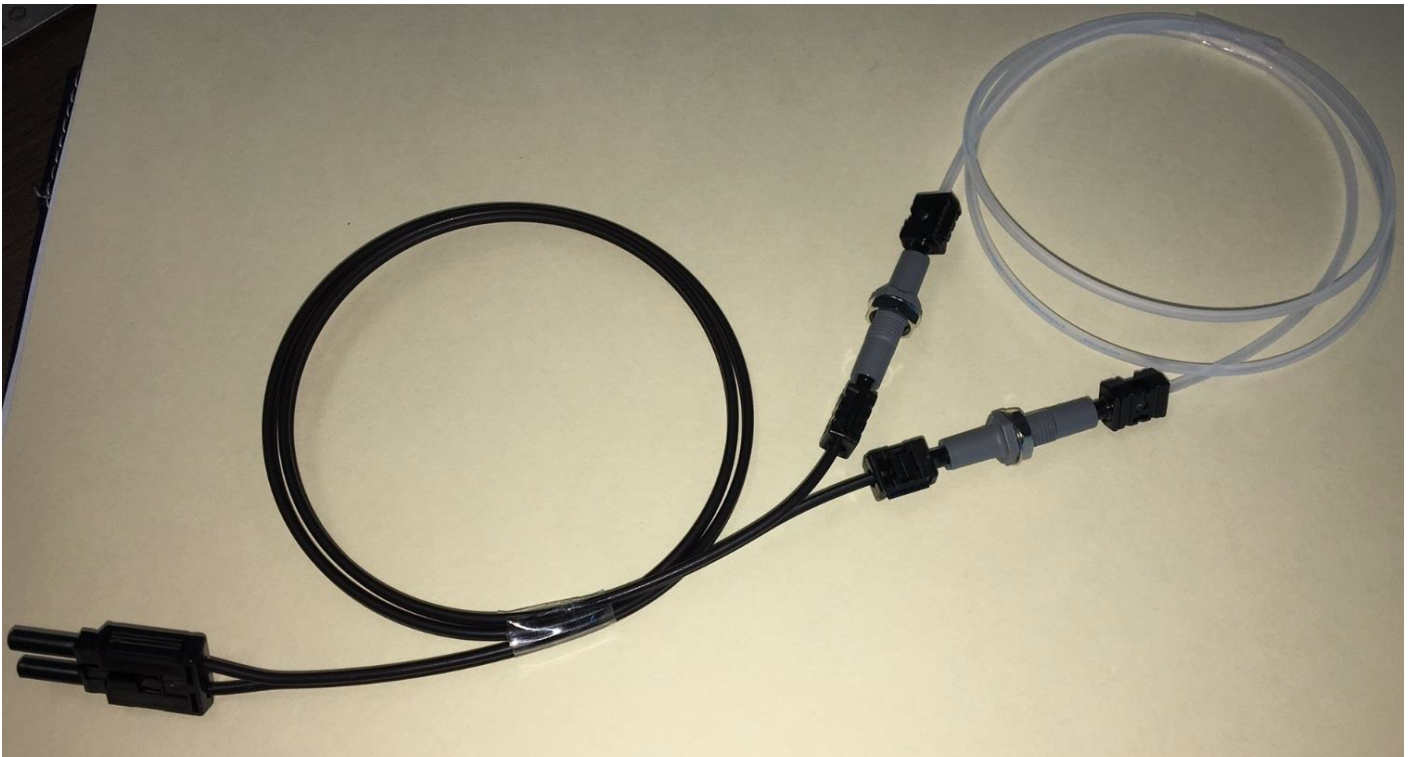


Figure 5. Arc Flash Transparent Loop Sensor with Jacketed Fiber Extension and connectors

**Note:** The length of the sensor fiber extension is duplex (double the path), and the total length of transparent fiber loop sensor and sensor fiber extension cannot exceed 70m; i.e.  $XX + (2 \times YY) \leq 70$ .

It is not mandatory to use a sensor fiber extension when connecting the loop sensor to the 350; the two single connectors can connect directly into the back of the 350. Refer to the **Optical Budget** section for more details and allowable sensor lengths.

## Arc Flash Settings

The following settings are required for the Multilin 350 relay:

| SETTING                     | PARAMETER        |
|-----------------------------|------------------|
| Arc Flash Function          | Trip             |
| Arc Flash HS Phase Pickup   | 2.00 x CT        |
| Arc Flash HS Ground Pickup  | 1.00 x CT        |
| Arc Flash Light Sensor 1    | Enabled          |
| Arc Flash Light Sensor 2    | Enabled          |
| Arc Flash Light Sensor 3    | Enabled          |
| Arc Flash Light Sensor 4    | Enabled          |
| Arc Flash Sel-in Timer      | 1.00 s           |
| Arc Flash Block             | Off              |
| Arc Flash Output Relays 5-6 | Relay : Disabled |

350ArcFlash.sr3 S4 Controls

Figure 6. Arc Flash configuration settings

**Arc Flash Function** must be set to anything other than Disabled to be enabled and active.

If set to:

**Trip:** The **Arc Flash OP** operand will engage the Trip LED, Output Relay 1 (Trip) (not a SSR output) and Alarm LED. (Normally used)

**Alarm or Latched Alarm:** The **Arc Flash OP** operand will engage only the Alarm LED.

**Control:** Only the **Arc Flash OP** operand will engage. Tripping or activating any of the other output relays (except output relays 5 and 6) must be done via Logic Elements.

**Arc Flash HS Phase Pickup** is the RMS phase pickup current setting. A setting of 50% minimum expected phase arc flash fault current based on 3-phase faults and 2-times maximum load current is recommended.

**Arc Flash HS Ground Pickup** is the RMS ground pickup current setting. If the Multilin 350 has a sensitive ground input, this setting will be **Arc Flash HS Sens Ground Pickup**. A setting of 50% minimum expected ground arc flash fault current is recommended, based on single-phase faults.

**Note:** Arc flash fault currents are not necessarily the same current levels as 3-phase or single-phase bolted fault currents. This depends on installation and voltage level and must be reviewed during the short circuit study of the application.

**Arc Flash Light Sensor 1 (4)** is the setting used to enable/disable a specific light sensor. It is important to disable each unused light sensors, even if nothing is connected to it. If not, the **Light Sensor 1 (4) Trouble** operands and **Light Sensor Trouble** operand will engage for the unused sensors.

**Note:** No light settings are needed due to the automatic threshold capabilities included in the Multilin 350, described in the next section.

**Arc Flash Seal-in Timer** is a timer to extend the **Arc Flash OP** operand by a time beyond which any of the light sensors AND any of the HS current elements are picked up. The recommended time is the expected breaker operating time plus some margin, typically 30%.

**Note:** The **Arc Flash OP** operand is typically much shorter than the actual breaker operating time; hence there is a risk that the 350 trip contact could attempt to open the DC trip circuit long before the breaker auxiliary contacts open the DC trip circuit, which could damage the 350 trip contact. Hence the need for this seal-in delay: during an actual arc flash event, the light pulse can be as short as ¼ of a cycle. The arc flash logic of the Multilin 350 extends the arc flash light operands by ¼ of a cycle for added dependability, however this is still much shorter than the expected breaker operating time. With the **Seal-in Timer** Setting, the **Arc Flash OP** operand can be coordinated with expected HS current operating time, which is very similar to the breaker trip time.

**Arc Flash Output Relays 5-6** are the high-speed SSR outputs that should be used with the arc flash protection function to perform high-speed breaker tripping.



## Arc Flash Light Automatic Threshold

The arc flash light automatic threshold feature of the Multilin 350 arc flash function allows adaptive changes to ambient light conditions, hence ambient optical measurements are not needed to determine threshold settings. The optical detection systems do not distinguish between the light coming from arc flashes or from other sources; instead, discrimination is based on comparing the incoming light level with a threshold. In rest state (normal operating conditions) the threshold is pre-programmed higher, around 4 kilolux (klx) (seen as 23 mV by the optical transceiver) higher than the incoming light level detected. The automatic threshold feature means that the comparator of the arc flash optical detection reference level is continuously updated to the incoming light (ambient conditions), so there is adaptation to ambient light without the intervention or modification of any of the light operators. This means that no light pickup settings need to be determined; this simplifies installation since light pickup settings can vary significantly between various installations due to exposure to different switch gear configurations with different ambient light conditions. The reference signal for the optical comparator is integrated to ensure a more gradual change in reference signal during changing ambient light conditions, however with a drastic change in light signal (expected during an arc flash event) fast operation is achieved.

Below is an example indicating transceiver output voltage from the optical transceiver (in green) and reference voltage to the arc flash comparator (in purple). Since the output voltage remains below the reference signal, the comparator does not issue an arc flash light detection operand.



Figure 7. Arc Flash Auto-adjust during Ambient Changes

Speed of operation during an arc flash is not compromised due to the very high change in light conditions. Arc flash light conditions vary between 150 to 3300 klx which is significantly higher than any expected ambient conditions, including direct sunlight. Below is an example of an arc flash event that lasted 100ms.

Ambient light condition changes of more than 4 klx (which is rare under normal circumstances) could operate the arc flash light detection, however a trip operation can only occur in conjunction with a high-speed current operation.

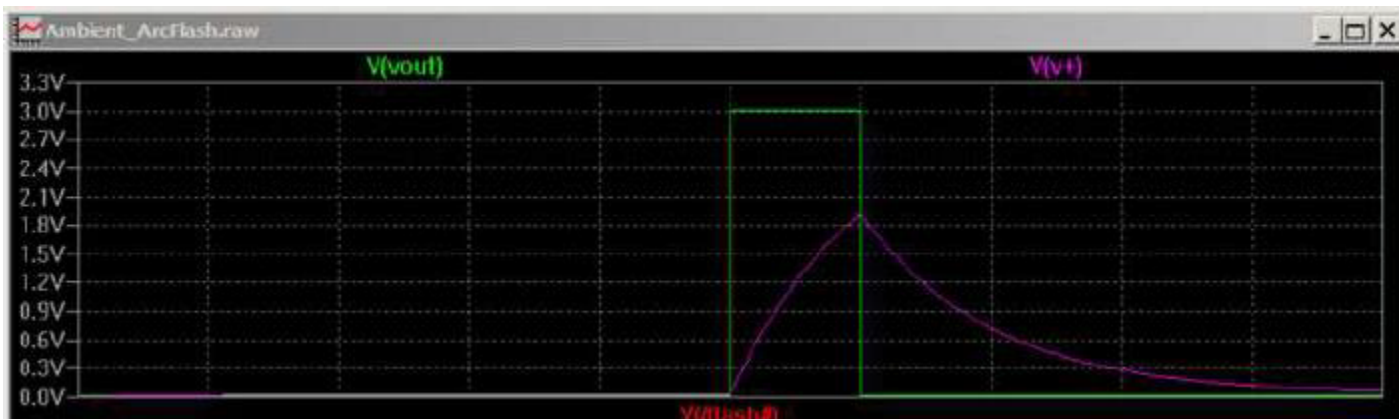


Figure 8. Arc Flash Auto-adjust during an Arc Flash Event

In this case, the output signal went above the reference signal within micro seconds, hence the comparator issued an arc flash light detection operand.

## Arc Flash Sensors Health Check

The integrity of all enabled sensors and connected fiber is checked by a periodic heart-beat pulse signal on the transceiver. The pulse duration is very short, less than 1ms, to ensure it can't be mistaken for an actual light event. An output of the same duration as the pulse is an indication that the sensor, and connected fiber, is healthy and in working order.

Below is an example of a heart-beat pulse that occurred at 0.5s, and an arc flash event that occurred at 0.7s.



Figure 9. Arc Flash Heart-beat pulse and an Arc Flash Event

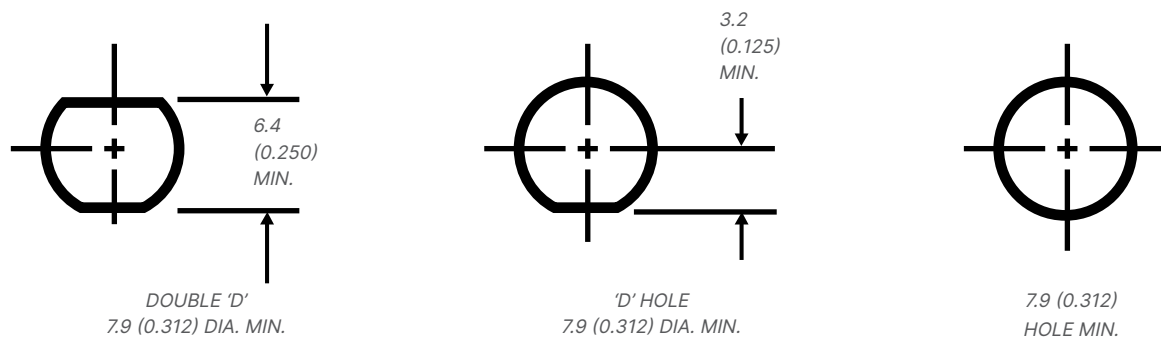
If any of the sensors or fibers are not perceived as healthy (the output signal is not received), the operand **Light Sensor Trouble** and **Light Sensor 1(4) Trouble** (depending on the sensor number) will engage and seal-in until the next heart-beat pulse is issued and output received.

## Installation Guidelines

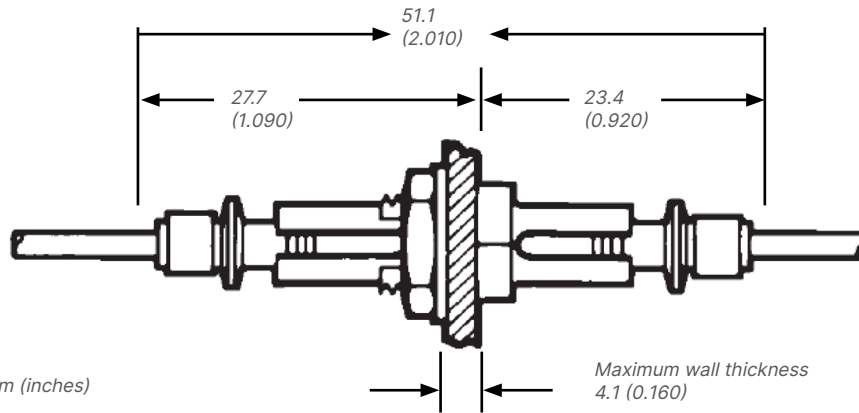
**Arc Flash sensor fiber is pressure sensitive and must be handled carefully to avoid damage. Read the following guidelines fully before proceeding.**

Care must be taken when handling the Arc Flash sensor fiber, which can be damaged if twisted, bent, or clamped tightly during installation.

- Do not bend sensor fiber sharply, or with a radius of less than **35 mm (1½ inches)**. Sharp bends can damage the fiber. Do not pull or tug loops of sensor fiber, as sharp bends may result.
- Do not clamp sensor fiber tightly during installation. Sensor fiber should be held in place loosely for the best long-term performance. Avoid over-tightening ties which may deform or break the sensor fiber.
- Do not pull or tug sensor fiber with force, as this may cause internal damage or separate the fiber from the cable connector.
- Do not twist the sensor fiber, as twisting can damage the fiber resulting in substandard performance.
- Do not attach sensor fiber directly to the bus or live conductors.
- Avoid installing sensor or sensor fiber on surfaces where temperatures might go above 70°C or 158°F to prolong the life of the fiber.
- Secure all sensor fibers (loosely but securely) away from any moving parts.
- When holes are drilled for sensor fiber installation, install rubber grommets around the drilled holes to protect the sensor fiber.
- Before installing arc flash sensor units, ensure that all other drilling and installation is complete to minimize possible damage to the sensitive unit and connected sensor fiber cable.
- Ensure that sensor fiber cable is installed clear from any switchgear moving parts, and can't be snagged or damaged during any switchgear operations, including maintenance activities.
- Ensure there is no dirt or dust inside the point sensor or on the surface of both the point sensor head and transparent loop sensors because it reduces the capturing efficiency of the device, increases its transmission loss, or both. If the sensor is covered with dust, clean it by blowing or wiping the dust off the point sensor. Dish soap or organic solvents (ethanol based) can be used. **Avoid using any other type of corrosive solvents.**
- For each of the sensors, plan the path of the sensor carefully, keeping it as short as possible for the point sensor, however extra looping is recommended for the loop sensor
- If a sensor fiber extension is used, ensure that it is long enough to reach the loop sensor without pulling or bending sharply.
- If the bulkhead connectors are used to connect the fiber extension to a loop sensor, mount the bulkhead connector through the drilled ends of the switch gear chamber (if needed to extend from one to another chamber) using below dimensions. Keep in mind that the maximum thickness the bulkhead connector can tolerate is 4.11mm (0.16"), and space the bulkhead connector holes properly to allow for the 11mm (0.42") installation washers.



Note: All dimensions in mm (inches)



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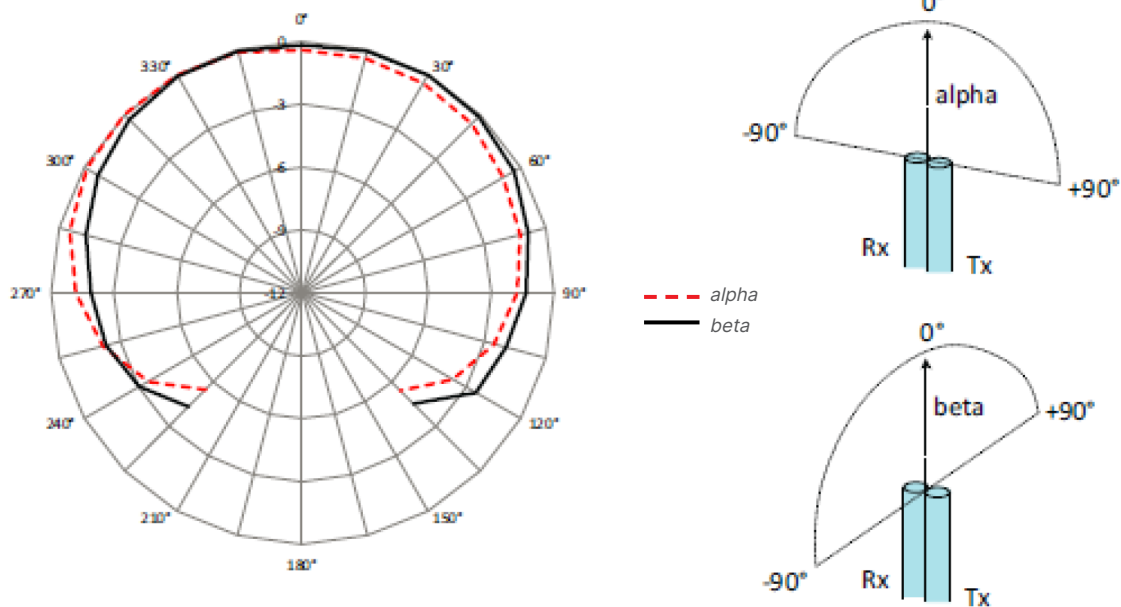
Figure 10. Bulkhead Connector Cutout and Dimensions

## Point Sensors

Arc flash point sensors should be installed in a location for the sensor clear of any obstructions that could shield the sensor from arc flash light, and less than 2m (6ft 6") from any potential arc flash source. The sensor head should be pointed towards the most likely source of arc flash; however, it does have a range of sensing angles as follows:

Minimum 180° spherical.

Figure 1 Typical Acceptance Cone



Note: The values in the vertical axis are in dB.

Figure 11. Arc Flash Point Sensor Range

The dimensions of the point sensor and the slim connector are as follows:

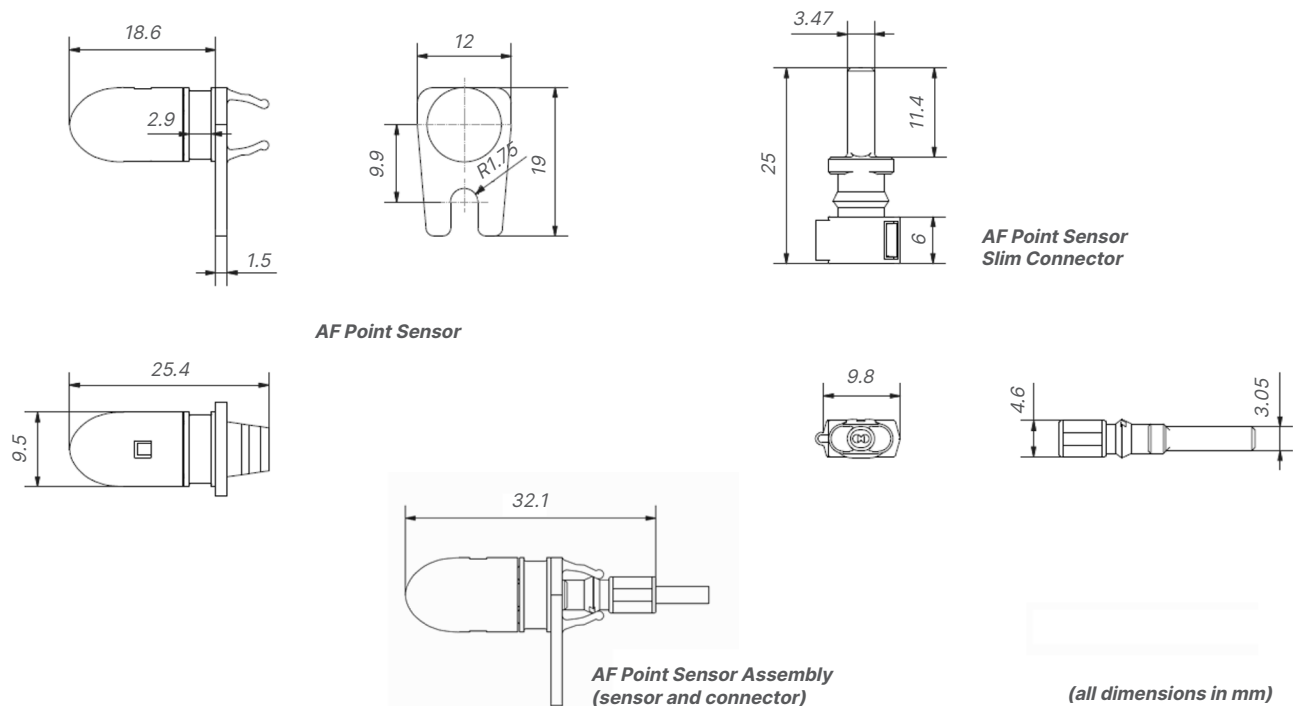
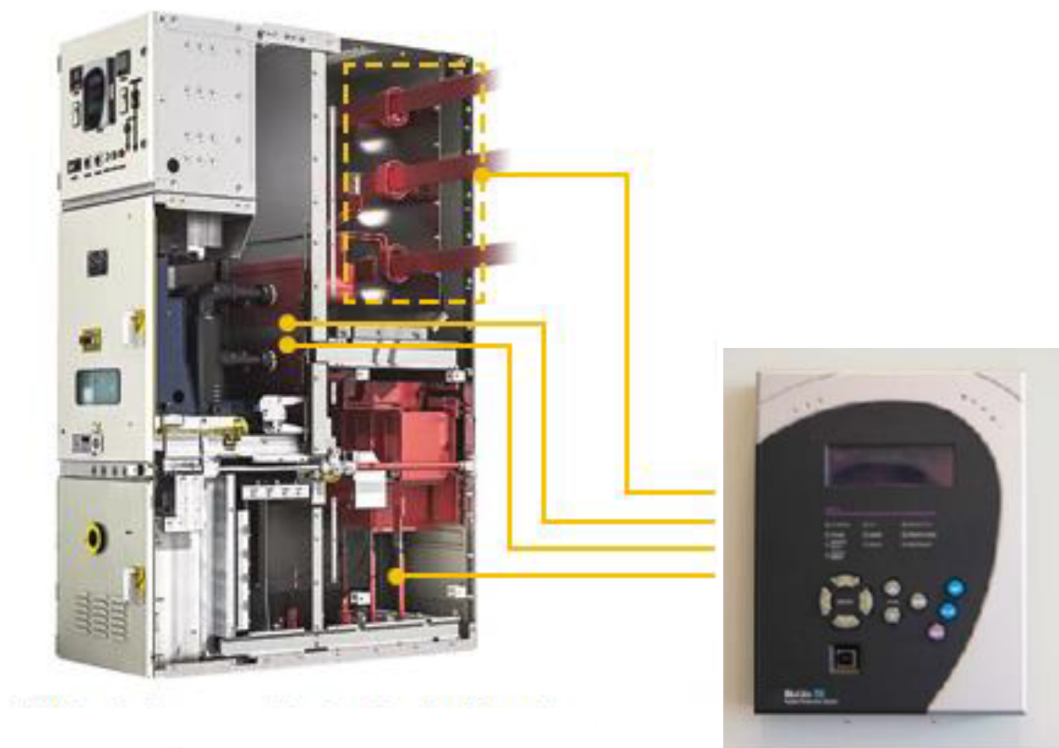


Figure 12. Arc Flash Point Sensor and Slim Connector Dimensions (In mm)

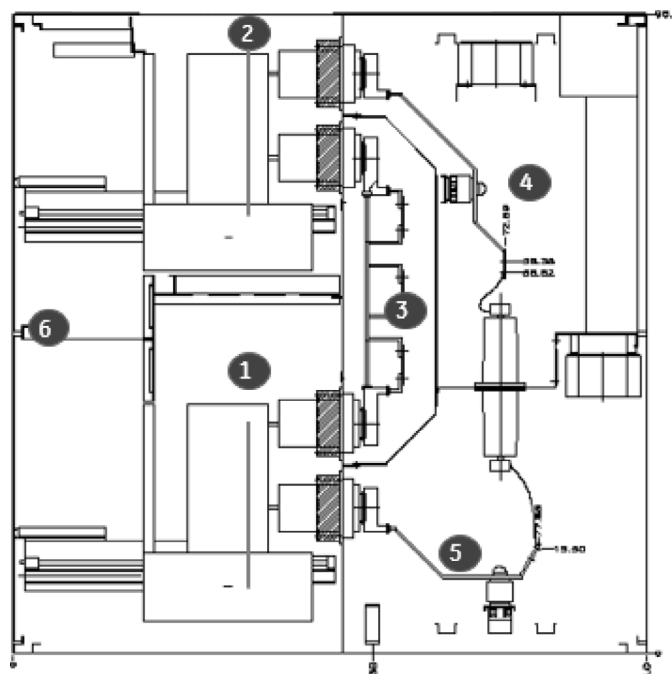
Sensor positioning is very important. Below are some recommended locations for point sensors:



MV Switchgear or Motor Control Center



## GE Vernova PowerVac Switchgear



*Two-High Breaker design with Arc Flash Sensors:*

- 1 - Breaker 1 Compartment
- 2 - Breaker 2 Compartment
- 3 - Main Bus Bar Section
- 4 - Upper Cable Exit Section
- 5 - Lower Cable Exit Section
- 6 - Location of Arc-Flash Module in Instrument Compartment

Figure 13. Point Sensor Locations

The Multilin 350 supports up to four point sensors. If five or more areas within the switch gear must be covered, use one or more loop sensors for better coverage.

Point sensors are recommended for switch gear components that could experience an arc flash in a single location, such as the breaker compartment and cable exit sections.

For ease of installation, the point sensor head can be removed from the slim connector. The slim connector fits through holes with a radius of 11 mm (0.42") or greater, and can be threaded carefully through holes in any panels between the relay and arc flash detection location.

### General installation:

1. Choose a location for the point sensor based on the above recommended positions.
2. Remove the slim connector from the point sensor assembly.
3. Carefully route the duplex sensor fiber from the point sensor location to the back of the relay unit, minimizing loops and curves for the strongest possible signal. Ensure all sensor fiber handling precautions are followed. Install protective grommets when routing sensor fiber through metal walls.
4. Mount the point sensor using either a cable tie mount or through-hole mount, as detailed below.
5. Reconnect the slim connector to the point sensor.
6. Arc flash point sensors can be installed in two different ways, using a cable tie mount or a through-hole mount.

## Cable Tie Mount:

- Requires a 2.5-mm-wide (0.1") cable tie
- Mount the sensor on a stick or similar using the cable tie, as shown in the following figure.



Figure 14. Point Sensor Cable Tie Mount

## Through-hole Mount:

- Requires a standard or self-tapping M3 screw, and optionally an M3 washer
- Mount the sensor through a hole 10mm (3/8") made in the surface of any mechanical structure inside the switchgear or on the surface of one side of the switchgear itself, as shown in the following figure:

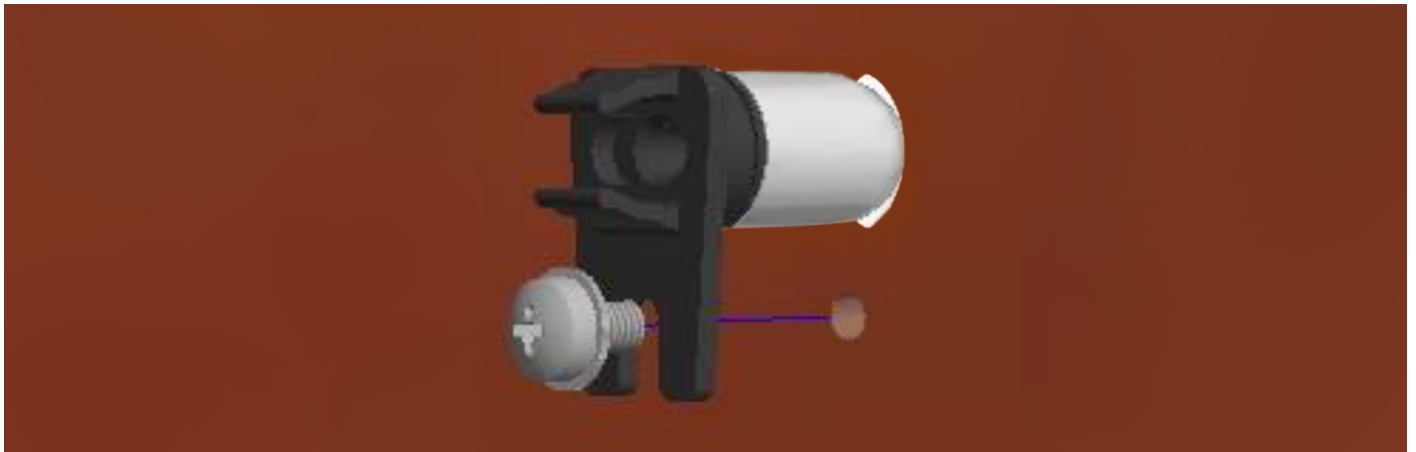


Figure 15. Point Sensor Through-hole Mount

Once the point sensor is securely mounted, carefully route the sensor fiber from the point sensor to the back of the relay unit, minimizing loops and curves for the strongest possible signal.

## Loop Sensors

Arc flash transparent fiber loop sensors should be installed in a location where the sensor is less than 2m (6ft 6") from potential arc flash source. The sensor consists of a plastic optical fiber core, cladding and transparent jacket that is halogen free and dust/harsh chemicals resistant. The diameter of core and cladding is 1mm, and of total fiber sensor including jacket, 2.2mm (less than 0.1"). The cross-section of the fiber sensor is as follows:

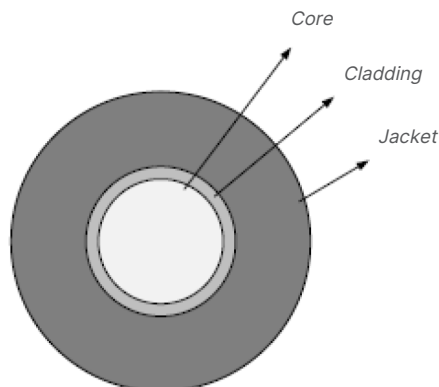


Figure 16. Cross-section of Transparent Fiber Loop Sensor.

The same installation guides should be followed as listed above. Recommended sensor locations are as follows:

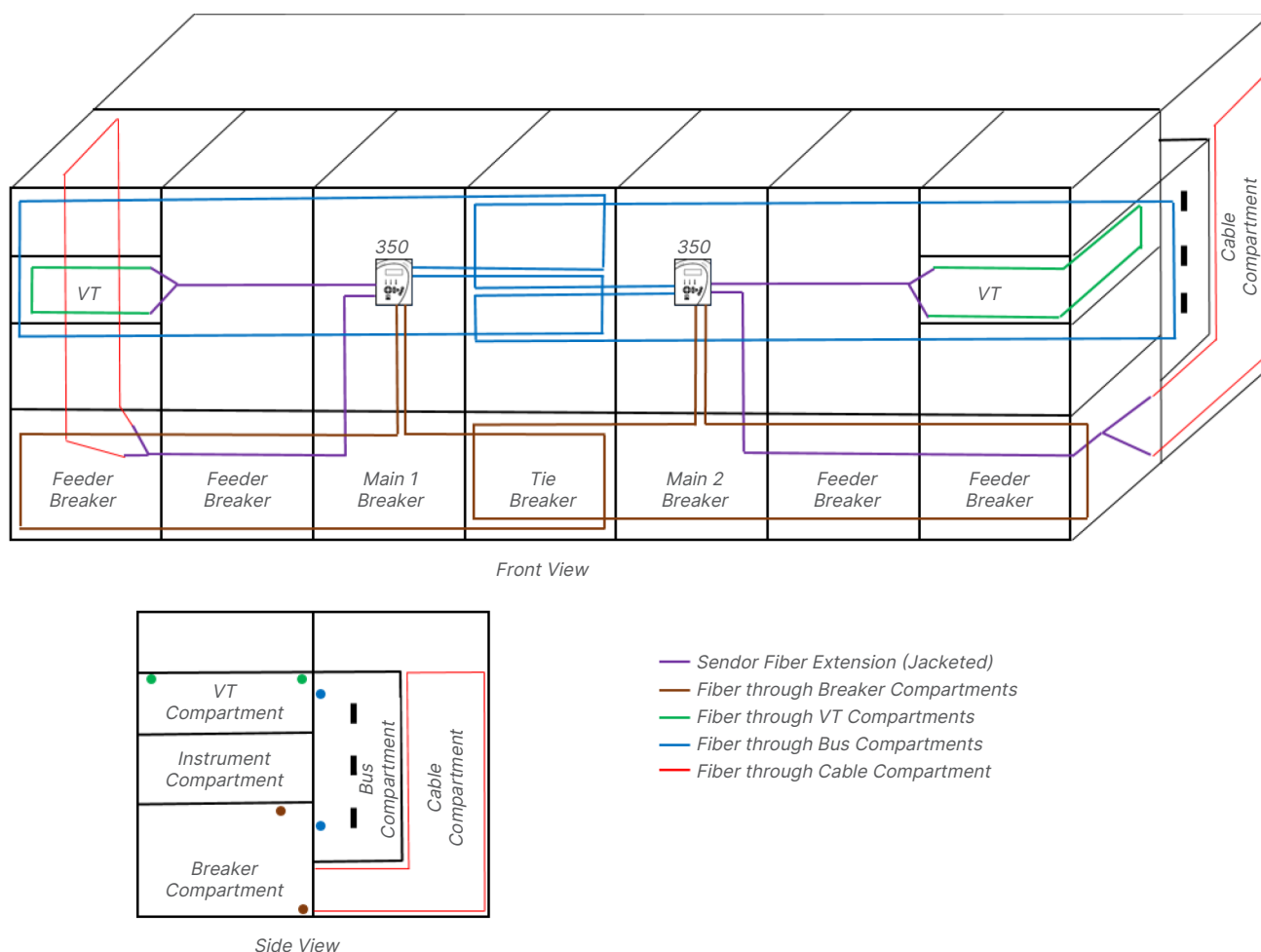


Figure 17. Transparent Fiber Loop Sensor installation position.

Four different zones can be covered by one Multilin 350; hence can a 2-bus application, with two main breakers, tie breaker and multiple feeder breakers be covered by two 350 relays. The zones covered are: breaker compartments, bus compartments, VT compartments and cable compartments.

Connections between compartments can be made using the fiber extension, keeping the optical power budget in mind.

Loop sensors are recommended for switch gear components which could experience an arc flash in multiple locations, such as busbars. Loop sensors have the sensitivity to detect an arc flash in multiple switch gear compartments, hence can be used to replace several point sensors, however the loop sensor will not distinguish at which location or in what compartment the arc flash occurred.

## Optical Budgets

Generally, it is not necessary to calculate optical losses if one point sensor is used with up to 35m of duplex fiber, or one transparent loop sensor with up to 70m of single fiber. Loop sensors can be used with a fiber extension, or multiple extensions, to allow interconnection between different switch gear compartments, which would have a larger impact on the signal strength and optical budget.

A simple rule-of-thumb that can be used to ensure the optical budget won't be exceeded, is to reduce the overall fiber length by 10m for every added connector. This means, for extension fiber, since it is duplex (one sending and one receiving) subtract 5m, and for the transparent loop sensor, subtract 10m. Multiple extension fibers with bulkhead connectors can be used, with the reduced overall length to compensate for optical losses in the connectors.

Maximum fiber lengths are as follows:

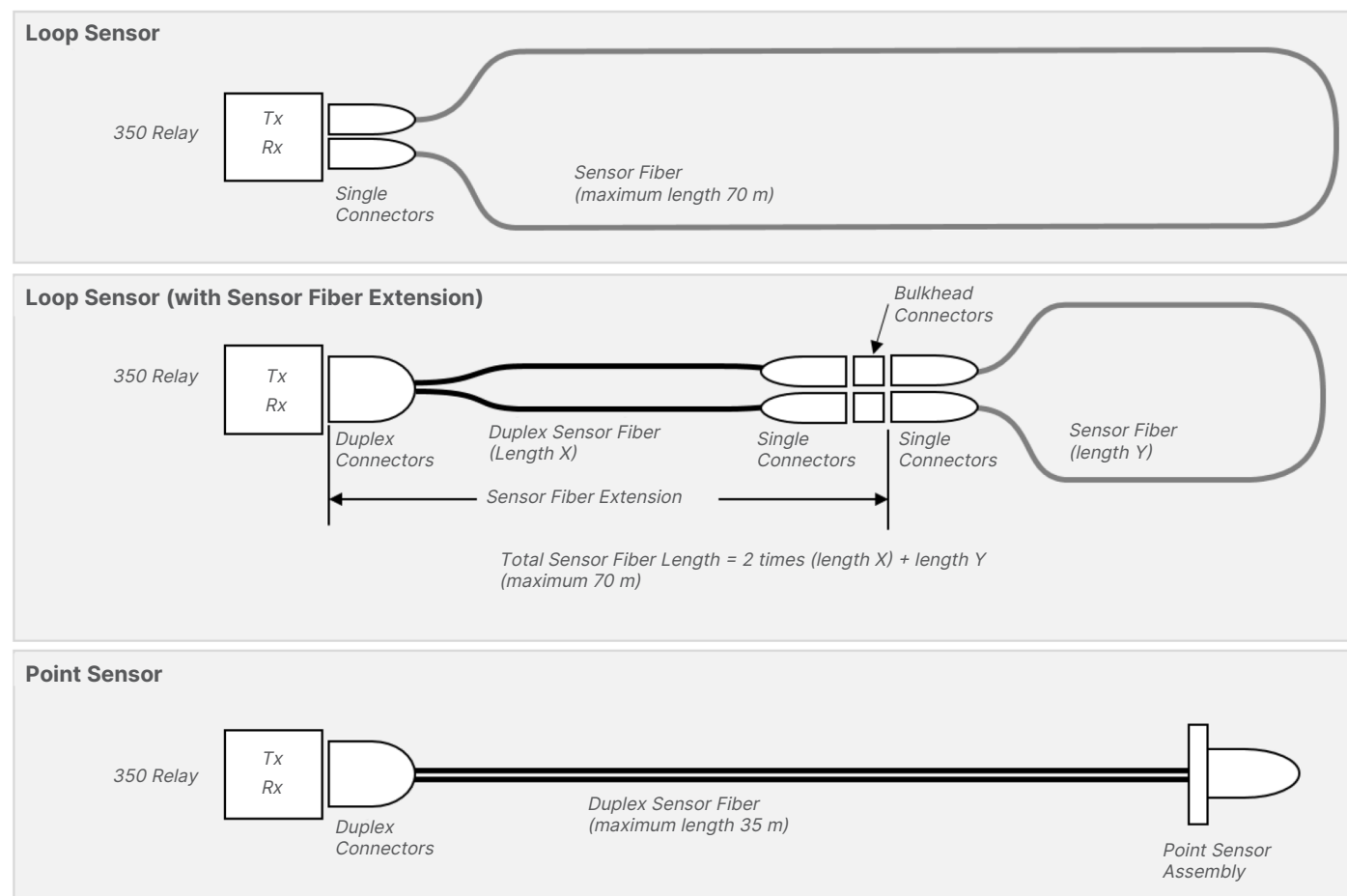


Figure 18. Point Sensor and Transparent Fiber Loop Sensor Lengths.

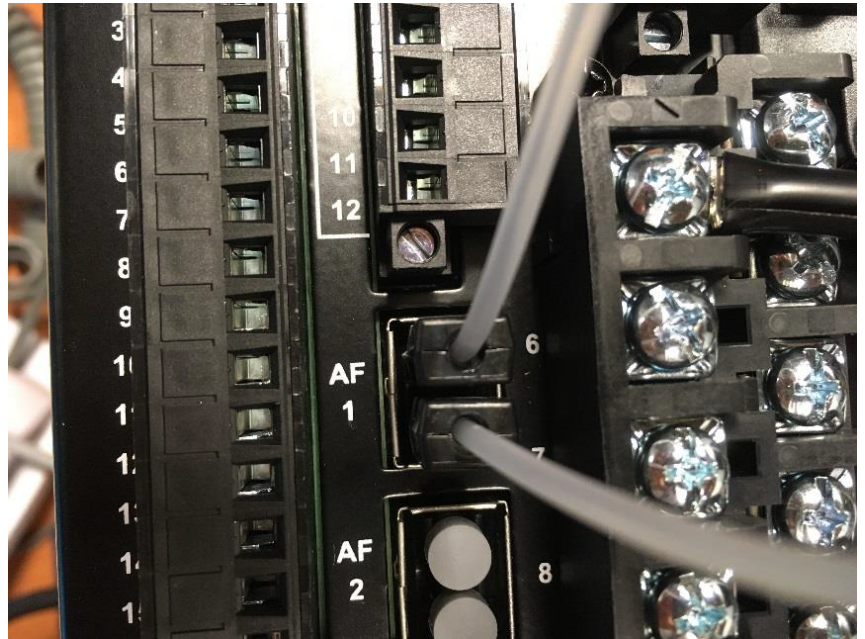
## Loop Sensor Installation

The loop sensor can be installed directly into the 350, however care must be taken to ensure correct alignment of the loop sensor single connectors into the 350 light sensor input.

Examples of incorrect and correct installation are as below:



Figure 19. Loop Sensor Incorrect Installation;



Loop Sensor Correct Installation.

## Special Applications

In some cases, arc flash detection can be used to enhance protection coordination and reduce incident arc flash energy; i.e. to have a fault that must be cleared by a remote protective device cleared more quickly than even using the zone interlocking scheme.

Below is such an example:

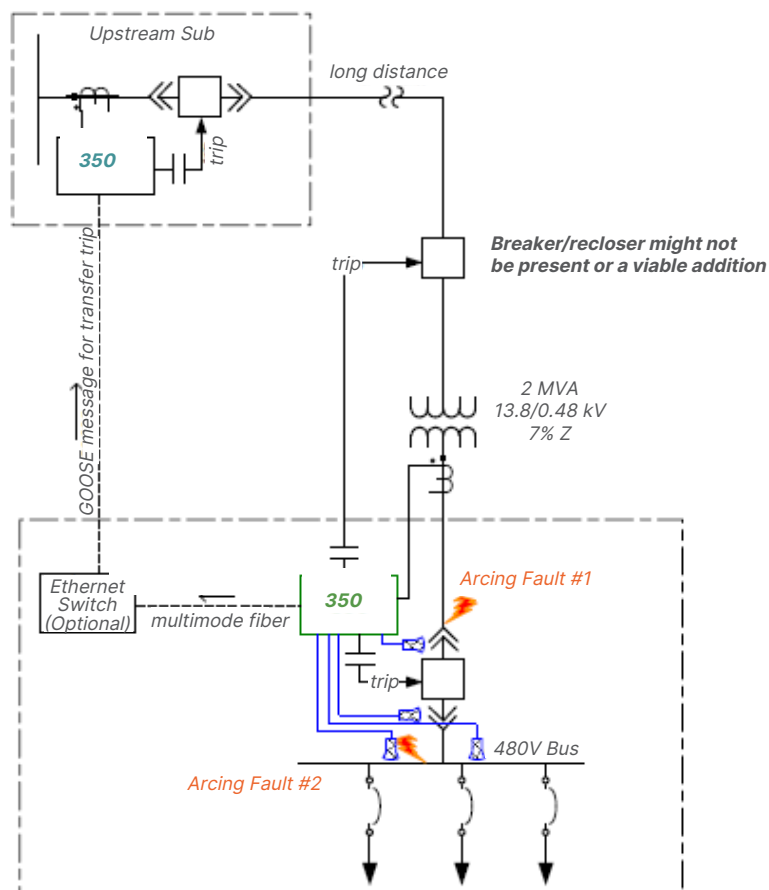


Figure 20. Utilizing Arc Flash for Enhanced Protection Coordination.

In this example, a **350** relay has been applied with four optional arc flash point sensors. Two sensors have been designated to monitor the main breaker, and two sensors have been installed to monitor the busbar. The **350** can trip the main breaker and/or trip the upstream breaker depending on which sensors detect the light flash.

The **350** main breaker relay's overcurrent function might not detect the arc flash of **Arcing Fault #1** in this example because the switchgear bushing CT's may or may not sense the arcing fault current at the stabs of the breaker.

In this application, it might not be possible or economically viable to install a recloser or breaker upstream of the transformer, instead IEC 61850 GOOSE messaging upon operation of light detection operand **Light Sensor 1 OP** of the main breaker **350** relay can be used to transfer trip a breaker at remote upstream substation **350** which is supervised by instantaneous overcurrent (high-speed overcurrent of the arc flash feature is recommended).

## Testing and Commissioning

Proper commissioning and testing of an arc flash scheme is crucial to ensure the scheme is fully operational and ready for service, as for any other power system protection scheme. Factory acceptance testing (FAT) (after installation in cabinets) is recommended to ensure all sensors and IEDs are functioning prior to shipping to the site. Sensors and all extension fibers to be installed on site should also be included in the testing during FAT.

Note: Using the high-speed SSR output relays 5 or 6 is highly recommended for the arc flash application, and for testing.

### Preparation for Testing

Since the Multilin 350 with point and/or fiber loop sensors utilizes both light and current as an arc flash solution, a light source and a current injection test set is required to simulate an actual arc flash event. A camera flash, or specific arc flash light source testing unit with light pulse of at least 6ms can be used to test the light sensors. Any current injection test set typically used for protective relay testing during FAT and commissioning would be adequate. **The Light Sensor 1(4) OP** operands can be viewed separately for each sensor; hence can the light pickup of each sensor can be tested individually. Similarly, the high-speed overcurrent operands **HS Ph A IOC OP**, **HS Ph B IOC OP**, **HS Ph C IOC OP** and **HS Ph GND IOC OP** are also available and can be tested separately.

### FAT Testing

During FAT, testing the following is recommended:

- Fiber sensor health check of each light sensor
- All current inputs using Secondary Injection testing
- All light sensors using the light-only testing
- All enabled protection and control functions
- All 350 inputs and contact outputs

### Commissioning Testing

Commissioning checking should begin only once all sensors are installed and switchgear installations are concluded. Recommended testing includes:

- Fiber sensor health check of each light sensor
- All current inputs using Secondary Injection testing
- All light sensors using light-only testing
- Simulated arc flash for each sensor, including tripping of circuit breaker
- All enabled protection and control functions
- All 350 inputs and contact outputs all the way to/from primary devices
- Load checks (or primary injection if load checks are not feasible)

## Sample Test Procedures

The following can be used as a sample test procedure for each of the above recommended tests:

### Fiber Sensor Health Check

1. Set the **Arc Flash Function** to **Trip**, to ensure Arc Flash is enabled and not blocked.
2. Connect all fiber light sensors as per application. All extension fibers and loops must be connected.
3. Set **Arc Flash Light Sensor 1** to **Enabled** if a sensor is connected to it. Do the same for all other connected sensors (2, 3 and 4 if applicable).
4. Ensure that none of the **Light Sensor X Trouble** operands are engaged. If any of them is engaged, refer to the trouble shooting section for suggestions.
5. Disconnect sensor 1. Observe that **Light Sensor 1 Trouble** operand is engaged with "LightSns1TRBL" and "LightSns TRBL" messages on the front panel. This can take up to 10 minutes for the periodic health check pulse to be sent, however by setting **Arc Flash Light Sensor 1** to **Disabled** and then back to **Enabled**, the health check pulse will be sent after only 10 seconds.
6. Reconnect sensor 1. Observe that **Light Sensor 1 Trouble** operand is reset with "LightSns1TRBL" and "LightSns TRBL" messages resetting. This can again take up to 10 minutes, however by setting **Arc Flash Light Sensor 1** to **Disabled** and then back to **Enabled**, the health check pulse will be sent after 10 seconds.
7. Repeat steps 5 and 6 for all other connected sensors.

### Current Injection Testing with Secondary Injection

Follow these steps to set up secondary-injection based arc flash testing of current inputs:

| SETTING                     | PARAMETER |
|-----------------------------|-----------|
| Arc Flash Function          | Control   |
| Arc Flash HS Phase Pickup   | 0.50 x CT |
| Arc Flash HS Ground Pickup  | 0.50 x CT |
| Arc Flash Light Sensor 1    | Enabled   |
| Arc Flash Light Sensor 2    | Enabled   |
| Arc Flash Light Sensor 3    | Enabled   |
| Arc Flash Light Sensor 4    | Enabled   |
| Arc Flash Sel-in Timer      | 1.00 s    |
| Arc Flash Block             | Off       |
| Arc Flash Output Relays 5-6 | Relay : 5 |

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Figure 21. Arc Flash Current Testing

1. Navigate to **Setpoints > Control > Arc Flash** and set the function to "Trip". Ensure that all other elements are either disabled or configured to not interfere with arc flash testing.  
The **HS Phase Pickup** is the high-speed instantaneous over current (HS IOC) element. It is similar to regular IOC but with much faster pickup. Under normal operation, this setting should be set at 2 x CT to 4 x CT or higher. However, for testing purposes, set the HS Phase Pickup to 0.5 x CT.
2. Enable the sensor to be tested, and save the settings. (This is not mandatory, but is recommended) If the sensors are enabled but disconnected, a light sensor trouble message appears in the target messages window. In the case of a light sensor trouble message, check all sensors one by one by disconnecting them from the relay to ensure that the sensor diagnostics are working properly.
3. Use the secondary injection unit of your choice to inject Phase A current greater than 0.5 x CT. If the relay is 1 A, inject > 0.5 A and if the relay is 5 A, inject > 2.5 A. The relay should pick up with the "HS PhA IOC OP" operand in the target messages window. This can also be monitored in the Events.
4. Repeat step 3 for phases B and C, connect to Ground input and repeat for GND.



## Arc Flash Light-Only Element Testing:

For an application where the arc flash protection operates based only on light detection or to test only the light sensors, the following steps can be performed:

1. Navigate to **Setpoints > Control > Arc Flash** and set the Function to "Control". Enable the light sensors that are connected. The current pickup values can be kept as default since they will not be used in this test. Ensure that all other elements are either disabled or configured to not interfere with the arc flash testing.
2. Navigate to **Setpoints > Control > Logic Elements > Logic Element 1** and design the logic shown in Figure 20. Arc flash light from the desired sensors is brought together in an OR gate and taken out as a contact output 3 in the example shown. Note: A different logic element and contact output can be used.

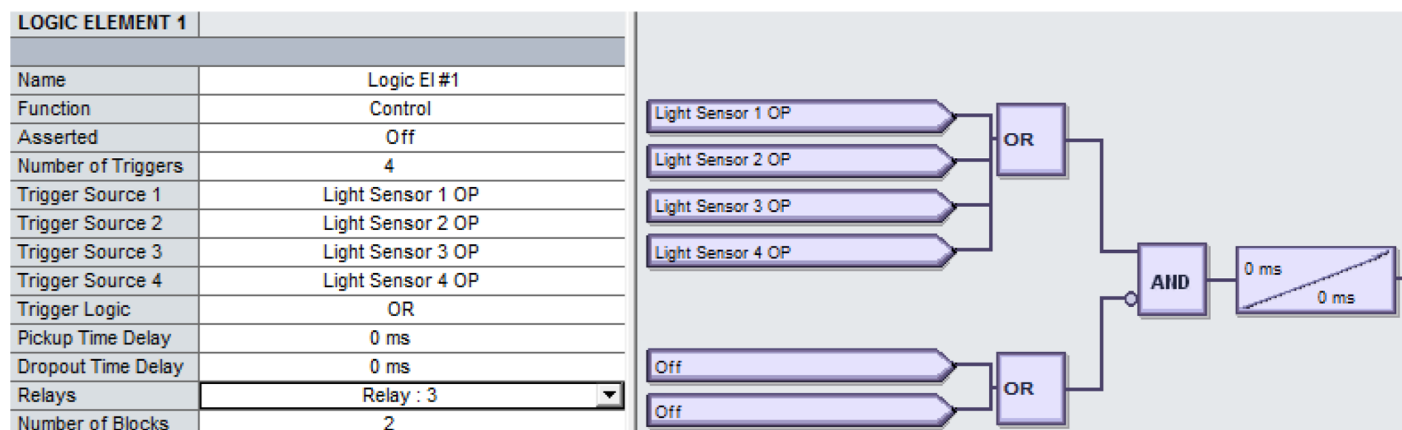


Figure 22. Logic Element for Arc Flash Light Testing

3. Use the camera flash (press the PILOT button on the camera flash module) on an individual sensor. (Refer to the section below "Use of a camera flash" for more details). The light on the sensor should pick up and the target messages window show the operation of the sensor input and relay output 3. Verify that the Light Sensor X OP operand is present in the Events, where X is the sensor number.
4. Reset the trip and repeat the previous step for each connected sensor.

### Use of a Camera Flash

Since the arc flash protection in the 350 uses light and current for detection purposes, it is important to understand how the light is measured. In photometry, "luminous flux" or "lumen" is a standard SI unit for the quantity of visible light emitted. This differs from "radiant flux" which is the total power of electromagnetic radiation including infrared, ultraviolet, and visible light.

Lux on the other hand is the standard SI unit for illuminance.  $1 \text{ lux} = 1 \text{ lumen per square meter}$ . The lux measurement of sunlight varies from 30K to 200K lux; this broad spectrum of lux values for sunlight comes from the variability in the ambient environment. Hence, using a fixed lux value for sunlight is incorrect. In addition, most measurements use readily available light meters which have a range of 0 to 400 kLux after which they saturate and require filters to scale down the light level. These light meters vary in accuracy from one meter to another but are still within the limits of the illumination measurement standards for accuracy, and hence acceptable to use for arc flash light measurement.

Following are some common light measurement units (lumen=lm, lux=lx, foot candle=fc):

- $1 \text{ lx} = 1 \text{ lm/m}^2 = 0.0001 \text{ phot} = 0.0929 \text{ fc}$
- $1 \text{ phot} = 1 \text{ lm/cm}^2 = 10000 \text{ lm/m}^2 = 10000 \text{ klx}$
- $1 \text{ fc} = 1 \text{ lm/ft}^2 = 10.752 \text{ lx}$

Ideally, the source of light should mimic the optical behavior of an arc flash with equivalent brightness. However, this type of light source is not readily available since it requires separate control for brightness, duration, and pulsation with decay. The most readily available and cost-effective alternative is a professional camera flash used with professional cameras. The brightness of a camera flash is adequate for arc flash testing; the only other parameter of concern is the duration of the flash.

The duration of light from camera flashes is measured in two ways: the t0.5 and t0.1 methods. The t0.5 is the time between rising and falling of the curve at 50% of the maximum curve height. Similarly, t0.1 is the time between the rising and the falling curve at 10% of the maximum curve height. A typical Canon Speedlite Flash has a t0.1 duration of 1/200 s (5ms) at full power and 1/20,000 s (50µs) at the lowest output levels.

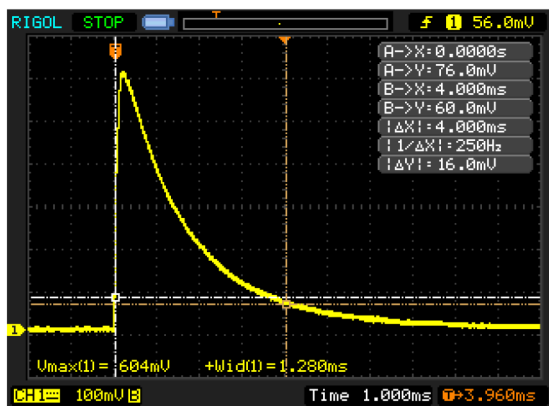


Figure 23. Camera Flash Duration



Figure 23. Canon Speedlite

Ideally, the camera flash should have a  $t_{0.1}$  duration of 8 to 10ms, however a 6ms pulse is adequate for testing purposes. The camera flash must have a “PILOT” button to test the flash, which is a useful feature for sensors that are far from the relay. On most camera flash modules, settings allow adjustments to the output power. The flash should be set on the highest output power and the longest flash duration possible. This can generally be done by selecting the “mode” button to switch from “ETTL” to “Manual” mode. Once in the manual mode, the output power can be adjusted to “1/1” for full power and longest duration. Using a light meter, the camera flash gives on average 1430 klx of light at 16” from the flash. The light level is not as high as a real arc flash but it is adequate for test purposes.

## Arc Flash Testing with Secondary Injection

Follow these steps to set up secondary injection based arc flash testing of sensors:

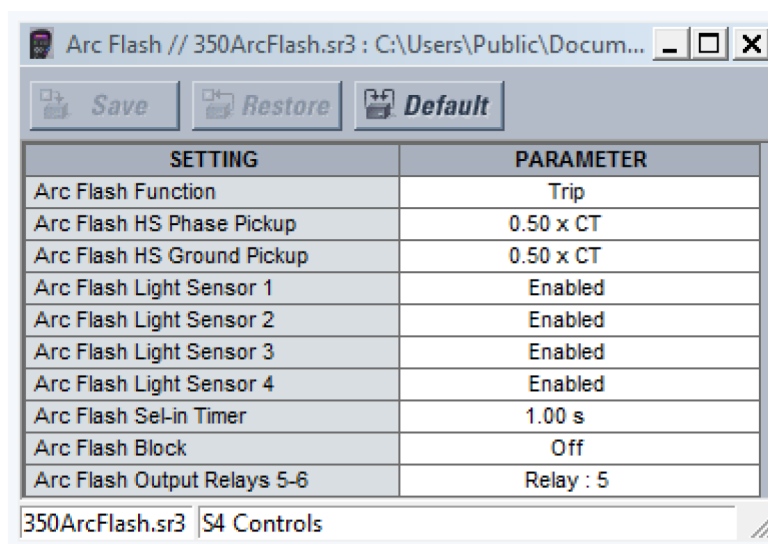


Figure 24. Arc Flash Current Testing

1. Navigate to **Setpoints > Control > Arc Flash** and set the function to “Trip”. Ensure that all other elements are either disabled or configured to not interfere with arc flash testing.  
The **HS Phase Pickup** is the high-speed instantaneous over current (HS IOC) element. It is similar to regular IOC but with much faster pickup. Under normal operation, this setting should be set at 2xCT to 4xCT or higher. However, for testing purposes, set the **HS Phase Pickup** to 0.5xCT.
2. Enable the sensor to be tested, and save the settings. If the sensors are enabled but disconnected, a light sensor trouble message appears in the target messages window (after 10 min). In the case of a light sensor trouble message, check all sensors one by one for trouble by disconnecting them from the relay to ensure that the sensor diagnostics are working properly.
3. Use the secondary injection unit of your choice to inject Phase A current greater than 0.5xCT. If the relay is 1A, inject >0.5A and if the relay is 5A, inject >2.5A. The relay should pick up with the “HS PhA IOC OP” operand in the target messages window.

4. While the high-speed IOC element is picked up, use the camera flash (press the PILOT button on the camera flash module) on one of the sensors. (Refer to the section "Use of a Camera Flash" for details). The light on the sensor should pick up and the target messages window show "**Light Sensor X OP**" where X is the sensor number. Immediately, the relay will assert the trip output with target messages window showing "Arc Flash OP" message.
5. The TRIP LED on the 350 relay will light up. Reset the trip and repeat steps 5 and 6 for each enabled sensor on the 350 relay. Use SSR relays 5 or 6 if trip timing is to be monitored.

If a relay test set is used for the current and light injection and is injecting both at exactly the same time, ensure that the light pulse is not shorter than 6ms. The light input can register an input after 1 ms, however the high-speed current needs up to 6 ms to ensure reliable operation.

In addition to testing the arc flash, the current signals can be recorded in the transient recorder. To view the operation of digital signals, the Events must be used; hence to view currents and digital arc flash signals, it is necessary to refer to both the Transient recorder and the Event recorder captures.

## Trouble Shooting/FAQs

1. One of the 350 sensors doesn't respond to the camera flash.
  - Ensure that the 350 Arc Flash Function is set to Trip, Alarm, Latched Alarm or Control
  - Ensure Arc Flash Light Sensor X is set to Enabled where X is the sensor number being tested.
  - Check that Light Sensor Trouble is not engaged, i.e. sensors are healthy
  - Ensure that the flash's pulse length is not too short. It must be minimum of 1 ms if only the light input is being monitored. If light AND current are monitored and engaged at exactly the same time, the light pulse should not be less than 6ms.
  - The flash's intensity may not be strong enough. A medium to high power flash is required, and a separate professional quality camera flash is recommended. Built-in camera flashes might not have sufficient light levels.
  - Disconnect the fiber at the Multilin 350 arc flash sensor connector, and apply the camera flash directly on the arc flash sensor input. If the 350 detects the light pulse, the problem is outside the relay.
2. The TROUBLE LED is on and the display shows LightSns TRBL.
  - The sensor fiber health check has detected a break in the loop or point sensor. First, check that the sensor fiber connector is properly connected to the 350 relay. Next, trace the fiber loop sensor or point sensor path to locate the break and re-install as per above installation instructions
  - Re-test all light sensors, including the 350 light sensor inputs and verify light operation using the above instructions.
3. The Arc Flash operating time, when current and light is applied concurrently, is more than 6ms
  - Ensure that one of the Solid State Relays (SSR) 5 or 6 is used for arc flash performance monitoring.
  - Verify that the light signal is applied at exactly the same time as the current.
4. Can arc flash sensors be interchanged between inputs, and between different Multilin 350 relays?
  - Yes, point and loop sensors are fully interchangeable between different arc flash inputs and Multilin 350 relays, given that all 350 relays do have the arc flash option.
5. Can an existing 350 be upgraded/changed to include the arc flash option?
  - No, different hardware (light sensors and solid state relays) is required, which is not field upgradable.

## Maintenance

Periodic visual inspection is recommended for the following:

- Ensure there is no dirt or dust inside the point sensors or on the surface of either point sensors and transparent loop sensors because it reduces the capturing efficiency of the device, increases its transmission loss, or both. If the sensor is covered with dust, clean it by blowing or wiping the dust off the point sensor. Dish soap or organic solvents (ethanol based) can be used. **Avoid using any other type of corrosive solvents.**
- Visual inspections can be performed during station visual inspections, and should be conducted at least annually, however if the switchgear is installed in a much more dusty or harsh environment, inspections should be more frequent.
- Verify that none of the operands **Light Sensor Trouble** or **Light Sensor 1(4) Trouble** are engaged in the Multilin 350 the sensors are connected to. Remote monitoring of these operands is recommended using SCADA/HMI or any system being monitored regularly by maintenance staff.
- Current injections are typically not regularly required and can be done together with feeder maintenance, unless any CTs or CT wiring is changed.

In the event that an actual arc flash occurs, the following is recommended:

- Perform a visual inspection of all sensors and sensor fiber, including monitoring the **Light Sensor Trouble or Light Sensor 1(4) Trouble** operands. Replace any of the sensors or sensor fiber that was blackened or damaged due to an arc flash.
  - Perform switchgear maintenance as per manufacturer requirements.
  - Secondary current injections and load readings (monitoring currents from CTs once energized) is recommended in this case, including that the 350 trips the circuit breaker.
  - Testing of arc flash sensors that were exposed to the arc and not replaced, and commissioning of replaced sensors.
- 

## Conclusion

The new Multilin 350 arc flash function consists of a secure light AND current operation. Up to 4 sensors can be used; either point sensors or transparent fiber loop sensors, which are completely interchangeable. This means, that as switchgear is expanded, a point sensor that previously covered only part of one switchgear line-up, can be changed to a loop sensor to cover multiple switchgear line-ups without the need to make changes to the 350. The new high-speed overcurrent function ensures that arc flash events will be detected in less than 6ms; significantly faster than any conventional current protection methods. This note describes how the Multilin 350 with its sensors can be installed, tested and maintained.

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## References

1. NFPA 70E-2012, Standard for Electrical Safety in the Workplace, National Fire Protection Association
2. OSHA Standards 29 CFR, Parts 1910 and 1926

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