A Novel Approach for Arc-Flash Detection and Mitigation: At the Speed of Light and Sound

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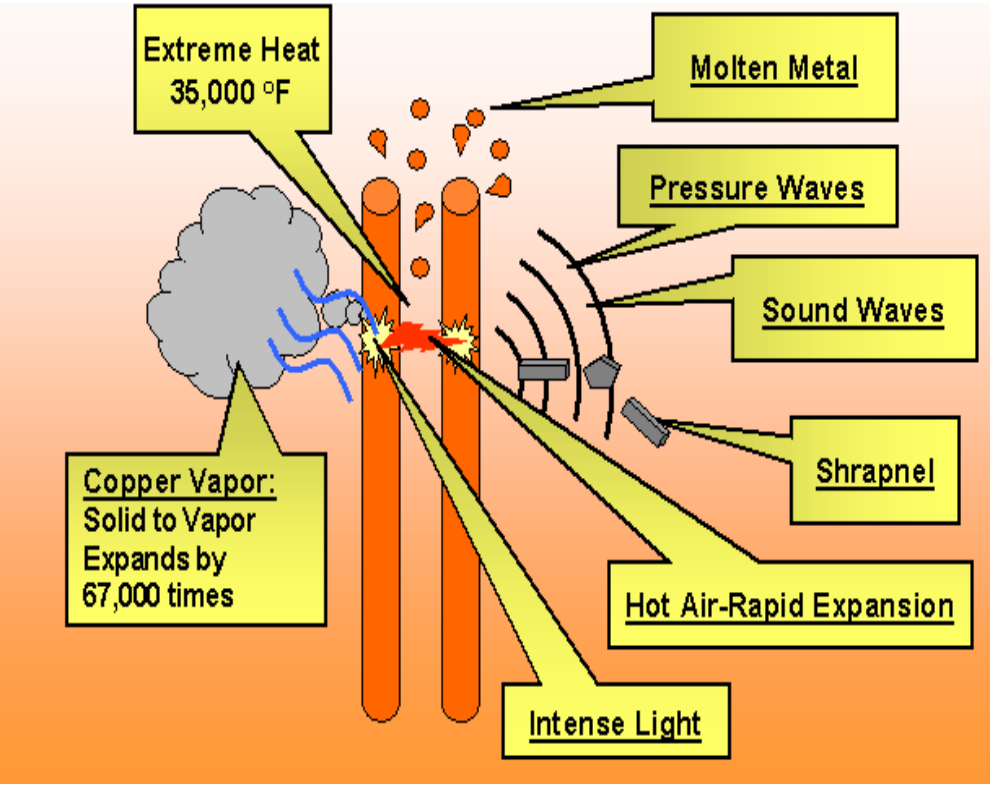
Introduction



What is Arc Flash?

Arc Flash is the sudden release of electrical energy through the air. The forces produced are known as the arc blast, characterized by:

- Temperatures up to 35,000 ºF, in less than 1/1000 of a second
- Copper is turned to plasma, expanding 67,000 times
- Pressure wave has been measure at thousands of pounds
- Shrapnel travels at speeds of 700 miles/hr
- Intense flash of light
- Sound wave that reaches up to 160 dB

Introduction

Every day, one to two arc flash related fatalities occur across North America.

2,000 workers are treated in specialized burn trauma centers across North America each year as a result of arc flash injuries
(source Electrical Safety Foundation International)

What Can Cause an Arc Flash?

- Switchgear internal fault
- Bad connections, hot spots, lack or inadequate maintenance.
- Presence of birds or rodents inside switchgear
- Moisture or dust on an insulating surface

System Objectives

- Fast, secure and reliable detection and operation
- Manage production loss risks
- Minimize equipment damage
- Reduce repair time and costs
- Reduce Arc Flash Energy

ARC FLASH DETECTION METHODS

Traditional Arc Flash Detection Methods

Light Sensing

- Why Light Sensors?
  - Accelerate the trip time during arc flash events

- Two types of light sensors:
  - Point sensors – provides a focused view, which minimize susceptibility to external light noise, but has limited range
  - Loop sensors – provides ability to collect light and channel it to a sensor along the fiber to the end of the fiber, but can be challenging to install and troubleshoot

- Cons:
  - High susceptibility to false triggers if light sensing threshold not set high enough
  - Fiber loops can be easily damaged due to bending or pinching
  - Difficult to install or re-install if fiber loop is damaged

Traditional Arc Flash Detection Methods

Light and Current Sensing

- Pros:
  - Additional Current input minimizes the probability of a false trigger

- Cons:
  - Requires the use of CT's and overcurrent protection device
  - Comparatively more cost and complexity

A Novel Approach : Light And Sound Sensing based Detection

A Unique Light and Sound Signature

Light & Pressure Wave Detection

- In an arc flash condition, every millisecond counts…
- Known and standard time relationship from the difference between a light signal ($3x10^8$m/s) and an associated pressurized sound wave (343 m/s) generated unique time delay signature

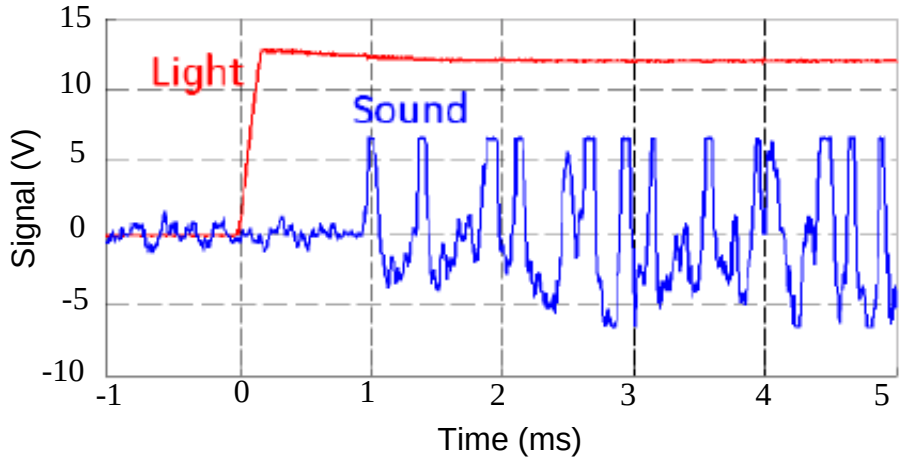
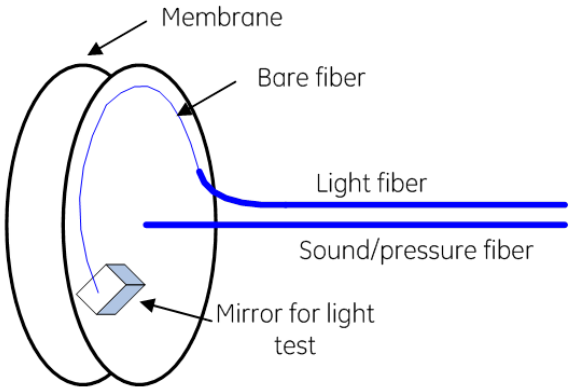


Figure 1: light and pressure wave signal during the Arc Flash event

Light & Sound Sensor – US Patent

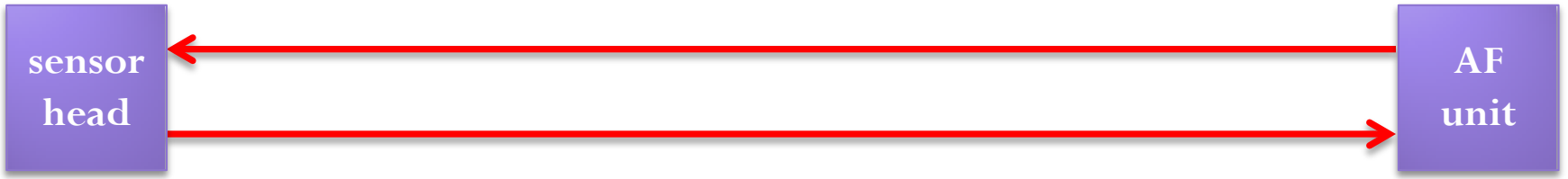
- US Patent 8040517- novel sensor technology to detect both arc flash induced light and sound



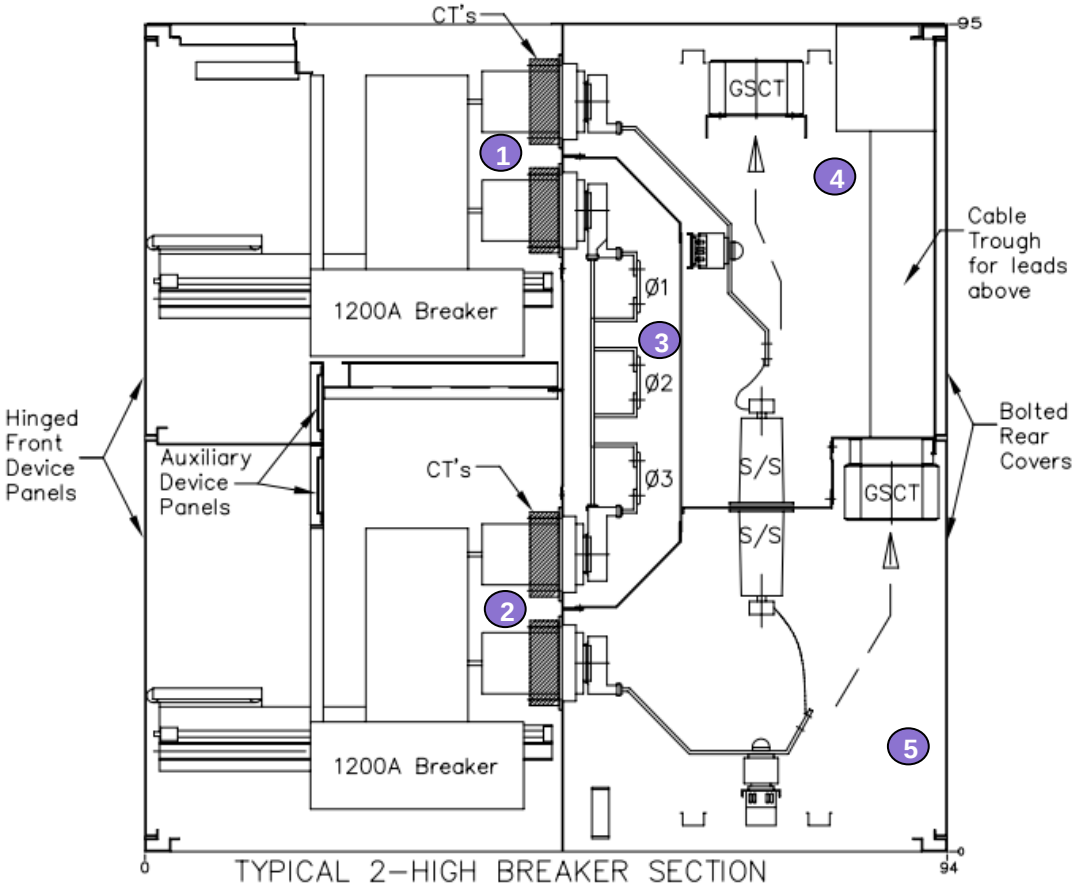
- Jacket of the light fiber inside the sensor head is removed which provides better sensitivity to the light from all angles through transparent head cover. Mirror reflects the light for testing.
- The Light Fiber picks up the flash of light from the Bare Fiber in the sensor head and transmits that to the unit
- The Sound/Pressure Fiber emits light which gets reflected back by the diaphragm, then collected by the same sound/pressure fiber and sent back to the unit
- During an arc flash event, the diaphragm vibrates from the pressurized sound wave creating a signature which is detected by the sensor head

Continuous System Self-testing

- To ensure high reliability of the system all sensor heads and fiber are continuously tested.
- For the “light path fiber every second short duration light pulse is sent from the laser diode: once reflected in the small mirror installed in the head and received by the photo detector, path is considered healthy.
- For the “sound” path the light is sent continuously from the laser diode to be reflected by the shiny membrane and received by the photo detector which confirms health of the sensor path.



Sensor Placement



The above is a representation of a Two-High 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

Test Setup and Results

Test Setup

- Testing was carried out in a certified high current arc testing lab facility Test setup design based on guidance from the IEEE 1584-2002 standard (“IEEE Guide for Performing Arc Flash Hazard Calculations”)
- High current arcing electrodes were placed in a chamber and fault level currents applied
- Various testing scenarios were created to test performance criteria of the Arc Flash System at various distances, fault levels and sensor mountings / orientations

Figure 1: Arc Flash detection testing

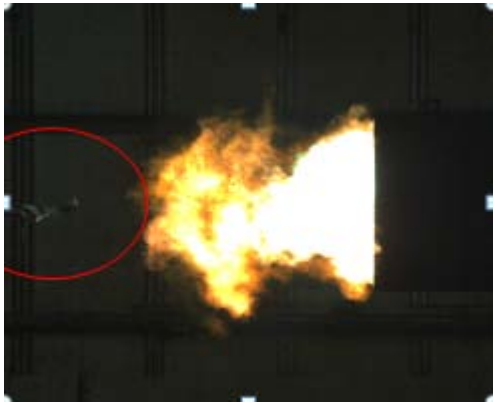


Figure 2: Sensor head arc flash detection testing

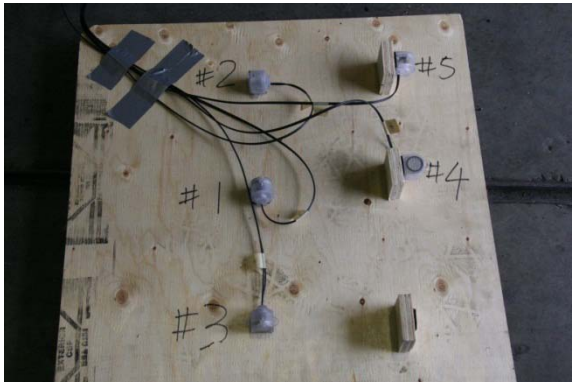


Figure 3: Sensor head directionality testing setup

Test Setup (video)

Test Scenarios

Distance Between Arc and Sensors

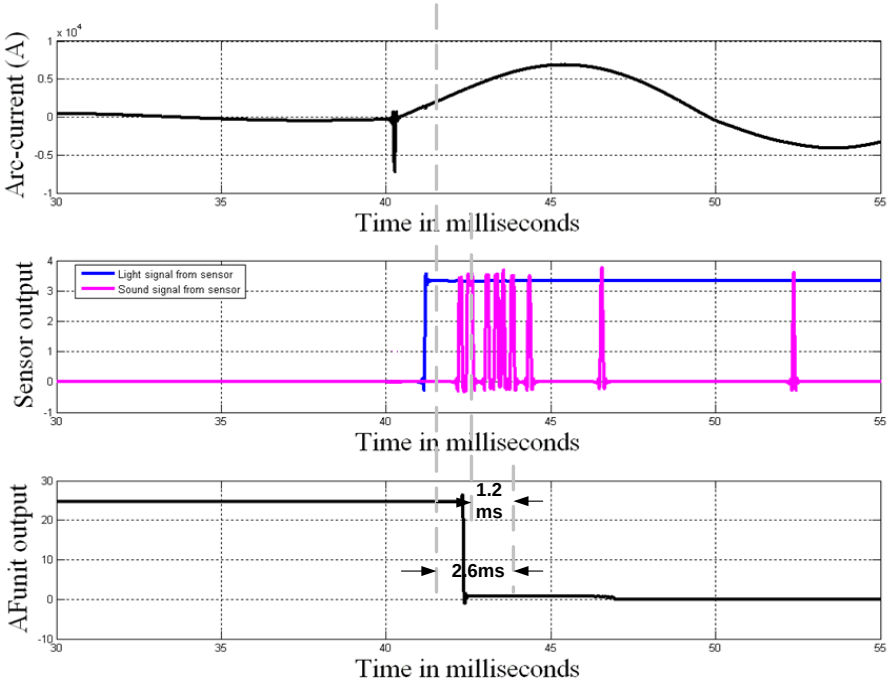
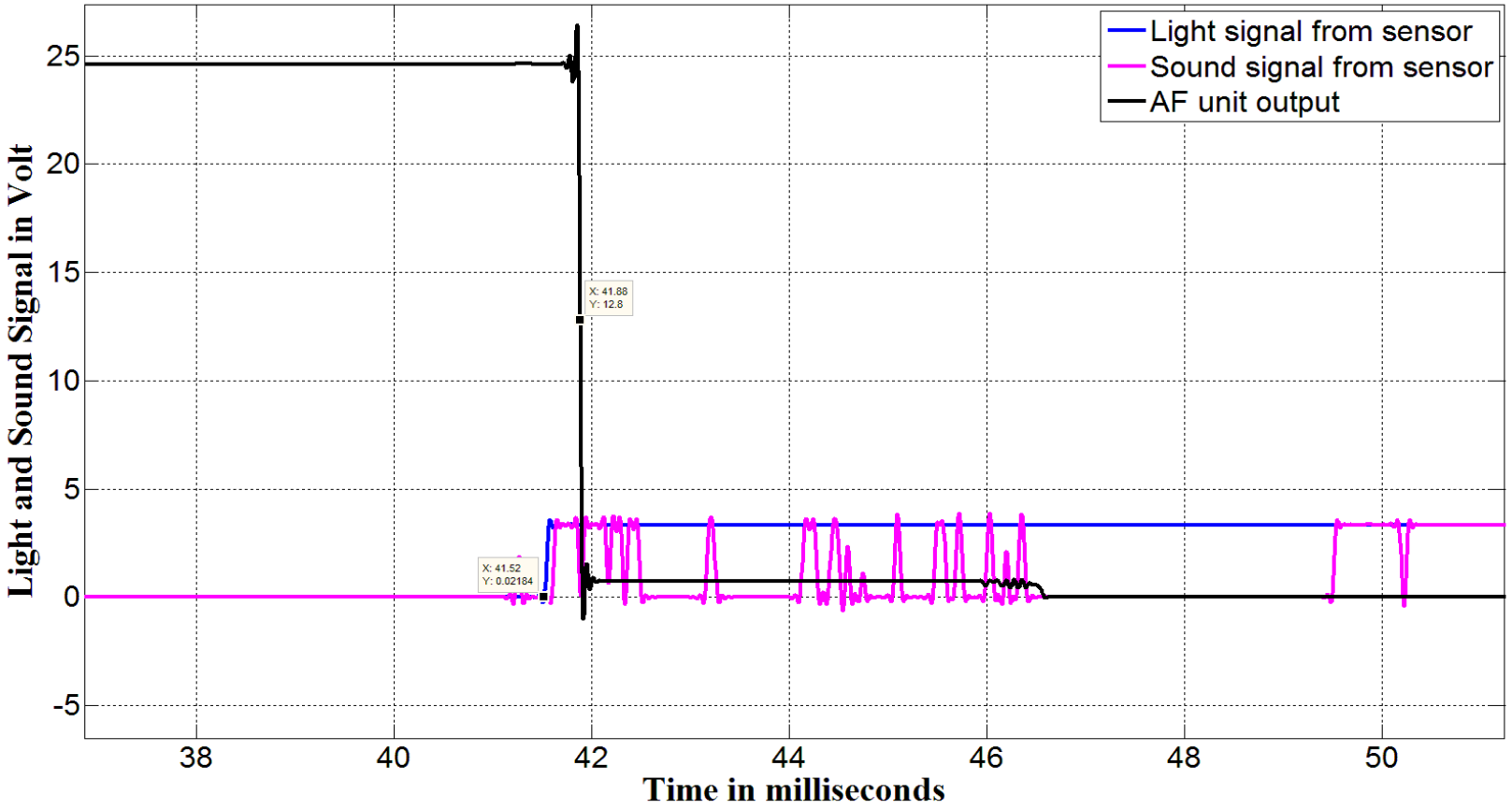


Figure. Arc-flash unit signals with 15 kA current at 1 feet distance.

TABLE I
Results of Time Of Operation (TOP) of arc flash unit at various distances between Arc and sensor

Test	Distance (feet)	TOP w.r.t. Arc-current (ms)	TOP w.r.t. Light detection (ms)
1	1	2.6	1.2
2	2	3.3	1.78
3	3	3.5	2.1

Sensor exposed to Arc-flash



- High current (15kA RMS) arc flash generated across the electrode, passing through the sensor
- Unit operated within 1.3ms , sound signal detected with in 360 µs after the detection of light

Direction/Angle Between Arc Source and Sensor's Line of Sight

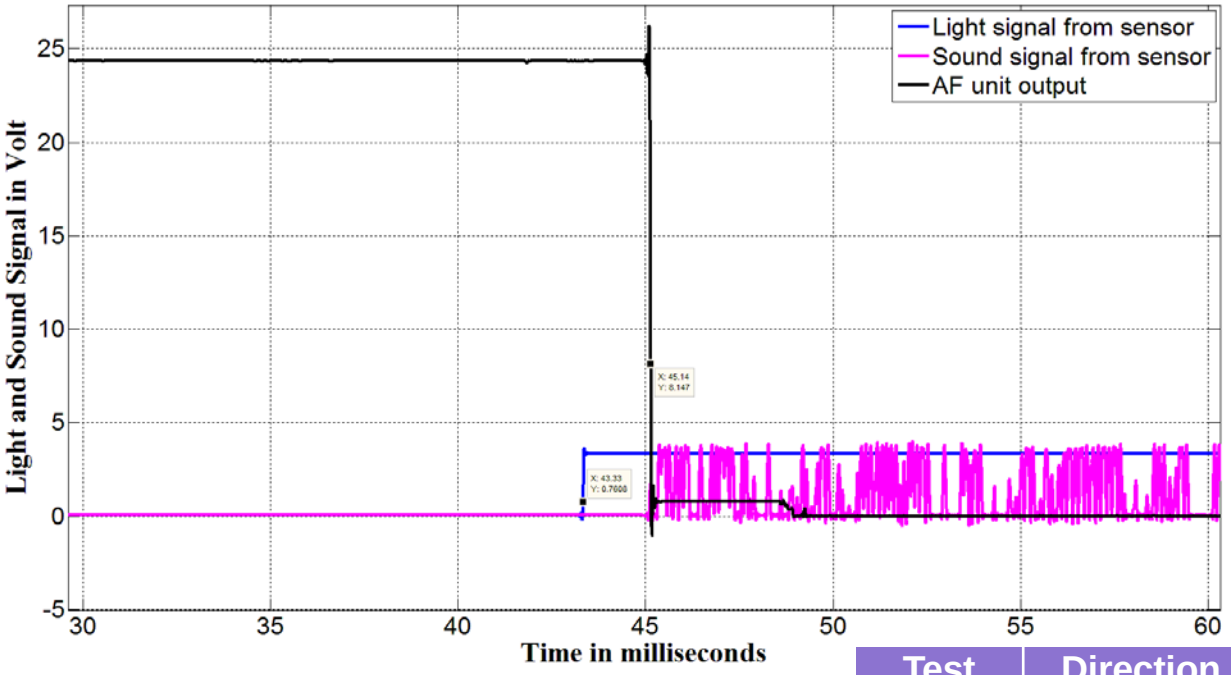


Figure. Arc-flash event at right-side of sensor

Test	Direction w.r.t. Arc	TOP w.r.t. Arc inception (ms)	TOP w.r.t. Light detection (ms)
1	Face	3.32	1.80
2	Up	3.32	1.80
3	Down	3.41	1.88
4	Right	3.38	1.86
5	Left	3.40	1.88

Various Arcing Currents

Test	Arc-current RMS (kA)	TOP w.r.t. Arc inception (ms)	TOP w.r.t. Light detection (ms)
1	1	3.54	2.04
2	2	3.48	1.96
3	7	3.38	1.88
4	17	3.3	1.80

- For various arc-current injections, from 1k A to 17 kA at a distance of 2 feet, the intensity of the arc flash (even at lower current) sufficient to operate unit within 3.5 ms

Conclusion

- The challenges with the arc flash protection is not only the fast (in terms of 2 – 4 ms due to rapid expansion of arc hazardous) to maintain workplace safety, but also secure from the mis-operation

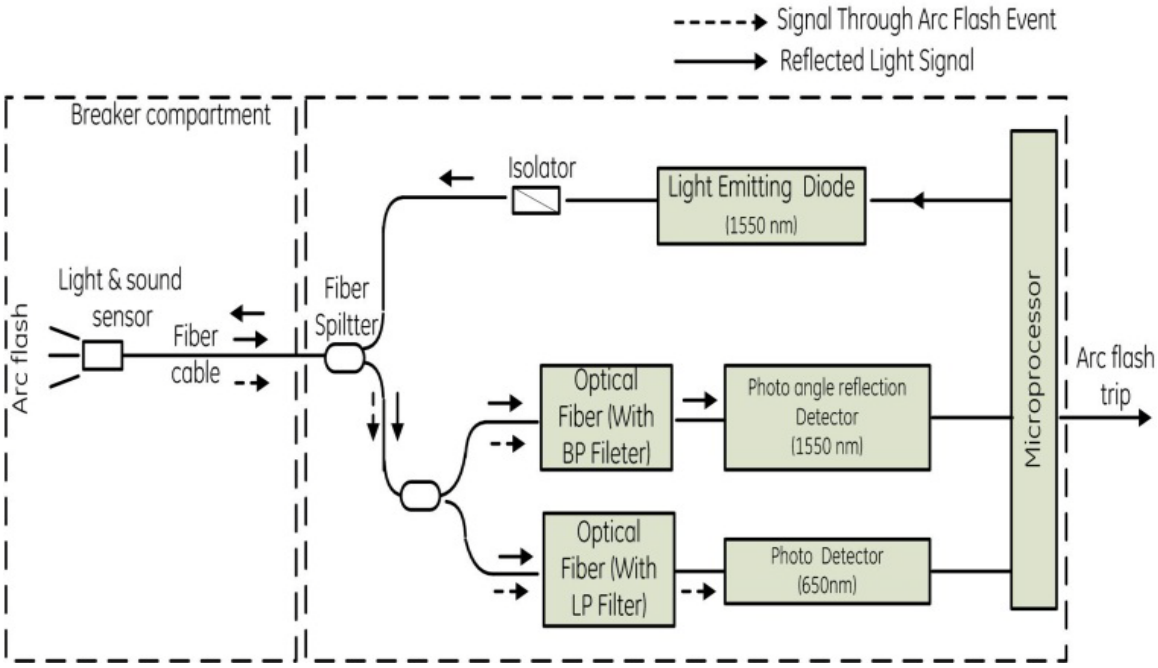
- An innovative solution is proposed, which utilizes the unique signature of light and pressurized sound for application of closed metal clad switchgear compartments

- The proposed solution also facilitates simple and cost effective installation
  - No fiber loop routing in the compartment
  - pressurized sound is used for additional security

- The overall speed of protection measured is less than 4 ms (with 3 feet distance)

Thank You

Light-Sound Sensor Block Diagram



- The light-sound sensor system developed to sense light and sound
- The system consists of a sensor head installed nearby the potential arc flash source, fiber cables, fiber couplers, interface card and a central processor unit.