Add Trip Security to Arc-Flash Detection for Safety and Reliability

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***Abstract*—Arc-flash detection sensors provide a cost-effective way to reduce arc-flash energy by minimizing detection times. High-speed light detection and tripping can compromise protection security by misoperating during changing light conditions. Trip circuits using arc-flash light detection should be supervised using overcurrent protection with similar fast detection speeds. Combining arc-flash detection and high-speed overcurrent from a protective relay provides fast tripping and security, using both instantaneous overcurrent and light from the arc flash. The combination of relay and arc sensor provides independent fault detection with two separate technologies, thereby eliminating false trips from lighting and providing the fastest detection and tripping possible. Time coordination delays are eliminated when the arc is detected concurrently with an overcurrent. This paper presents the advantages of fast overcurrent detection combined with arc-flash measurement to produce a sensitive, fast, and secure tripping scheme.**

I. INTRODUCTION

Electrical arc-flash hazards are a serious risk to worker safety.

> On the average, every day in the U.S. five to ten people are sent to special burn units due to arc-flash burns. “There are one or two deaths per day from these multi-trauma events,” said Dr. Mary Capelli-Schellpfeffer, principal investigator, CapSchell, Inc., Chicago-based researching and consulting firm specializing in preventing workplace injuries and death. [1]

The National Fire Prevention Association (NFPA) published *NFPA 70E®: Standard for Electrical Safety in the Workplace®* to document electrical safety requirements [2]. It defines specific rules for determining the category of electrical hazards and the personal protective equipment (PPE) required for personnel in the defined and marked hazard zones. OSHA enforces the NFPA arc-flash requirements under its “general rule” that a safe workplace must be maintained. These regulations are forcing employers to review and modify their electrical systems and work procedures to reduce arc-flash hazards. This paper uses the IEEE 1584 model for calculating arc-flash hazards [3].

The most common arc-flash hazard reduction methods are:

- Avoid the hazard area
- Install arc-resistant switchgear
- Add current-limiting devices
- Reduce the relay time coordination settings
- Improve protection schemes

There have been many papers highlighting the hazards and possible prevention of electrical arc flash, starting in 1985, when Ralph Lee published the paper “The Other Electrical Hazard: Electric Arc Blast Burns.”

IEEE 1584-2002 provides information on how to calculate arc energy and establish boundary distances for personnel when working around energized electrical equipment.

The energy produced by an arc-flash event is proportional to the voltage, current, and duration of the event (V • I • t). IEEE 1584-2002 concluded that arc time has a linear effect on incident energy. Therefore, reducing fault clearing times proportionately reduces arc flash.

This paper evaluates the effect of adding arc-flash detection to protection schemes in order to reduce the arc-flash hazard. It reviews and builds on the information presented by Jim Buff and Karl Zimmerman in their paper “Application of Existing Technologies to Reduce Arc-Flash Hazards,” presented at the 2006 Western Protective Relay Conference [4]. Additional calculations using arc-flash detection are included, using the same example system.

II. AVOID THE HAZARD AREA

The safest way to prevent arc-flash injuries is to avoid the danger zone. Eliminate working in hazard zones by performing work on de-energized equipment. Technology offers several ways to gather information and perform operations without entering the hazard area [5]. Communications links to the equipment in the zone provide key maintenance and operating data. Switching can be performed remotely and relay event reports gathered without exposure. Manufacturers are providing remotely controlled breaker racking mechanisms to perform actions previously done by workers in the arc-flash zone.

III. ARC-RESISTANT SWITCHGEAR

Switchgear manufacturers have modified the designs and construction of electrical switchgear to withstand the blast of an arc flash. This includes reinforcement of doors and structures as well as providing a discharge path for the blast pressure and material away from personnel working areas. Although this system does provide a level of safety for the worker, it does not in itself extinguish the arc. Arc-resistant switchgear typically also includes circuit breakers with high-speed clearing times.

IV. ADDITION OF CURRENT-LIMITING DEVICES

Electrical designers have used current-limiting devices to reduce the available fault current for many years. Transformers can be specified with high impedance, and in-line reactors can reduce the fault current. Both of these techniques create a continuous loss in the system. Current-limiting fuses on low-voltage systems and high-speed circuit breakers provide fast clearing times to reduce incident energy [6].

V. ARC-FLASH HAZARD EXAMPLE

The example system shown in Fig. 1 is used to help analyze the arc-flash hazard.

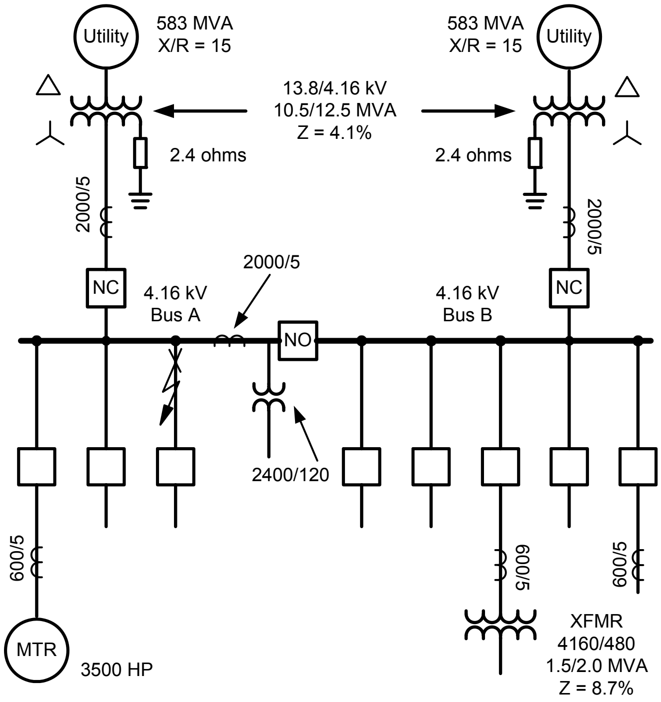

Fig. 1. Example system

A. Determine the Bolted Fault Currents

The first step is to calculate the maximum available three-phase fault current. The utility has given the available source fault MVA as 583 and the X/R ratio as 15.

Use the following equation to convert to a percent impedance, based on the transformer MVA and kV:

$$\%Z = 100 \bullet \left(\frac{kV_u^2 \bullet MVA_t}{kV_t^2 \bullet MVA_u} \right) \angle \text{Tan}^{-1} \left(\frac{X}{R} \right) \tag{1}$$

where:

%Z = utility impedance in percent, based on transformer base

kV_u = utility voltage base

kV_t = transformer voltage base

MVA_u = utility fault MVA

MVA_t = transformer MVA base

X/R = utility X/R ratio

The impedance is now shown as:

$$\begin{aligned} \%Z &= 100 \bullet \left(\frac{13.8^2 \bullet 10.5}{13.8^2 \bullet 583} \right) \angle \text{Tan}^{-1}(15) \\ &= 1.8\% \angle 86° \qquad (2) \\ &= 0.13 + j1.8\% \end{aligned}$$

Since the example switchgear has no cable impedance, we only need to add the transformer impedance of 4.1 percent. Assuming the transformer impedance is all inductive, the total impedance to the bus is:

$$\begin{aligned} \%Z_{\text{total}} &= 0.13 + j1.8 + j4.1 \\ &= 0.13 + j5.9 \\ &= 5.9\% \angle 89° \end{aligned}$$

Calculate the fault current with (3).

$$\begin{aligned} \text{Base Fault } I_B &= \frac{\text{BaseVA}}{\text{BaseV} \bullet 1.73} \\ I_f &= \frac{I_B}{Z_B} \\ I_f &= \frac{10.5(1000)}{4160 \bullet 1.73 \bullet \frac{5.9}{100}} \qquad (3) \\ I_f &= \frac{10.5 \bullet 57735}{4.16 \bullet 5.9} = 24.7 \text{ kA} \end{aligned}$$

where:

I_f = maximum bus fault current

kV_t = transformer voltage base

MVA_t = transformer MVA base

$\%Z_{\text{total}}$ = total impedance on transformer base to bus in percent

B. Determine the Arc-Fault Currents

The addition of the arc impedance reduces the arc-fault current below the level of a bolted fault.

Equation (4) is used to calculate the arcing current.

$$\begin{aligned} \text{Log}I_a &= 0.00402 + 0.983 \bullet \text{Log}I_{bf} \qquad (4) \\ I_a &= 10^{\text{Log}I_a} \\ \text{Log}I_a &= 0.00402 + 0.983 \bullet \text{Log}(24.7) = 1.373 \\ I_a &= 10^{1.373} = 23.6 \text{ kA} \end{aligned}$$

where:

I_{bf} = maximum bus fault current in kA

I_a = maximum arcing current in kA

The 85 percent value is 20 kA.

C. Determine the Protective Relay Operate Times

The relay coordination for this system was extracted from the time coordination curves. The breaker time of five cycles was added to obtain the total trip time. For the 23.6 kA current, the bus relay trip time is:

$$0.69 + 5/60 = 0.77 \text{ s}$$

For the 20.0 kA current, the bus relay trip time is:

$$0.88 + 5/60 = 0.96 \text{ s}$$

D. Document the System Voltages, Equipment Class, and Working Distances

IEEE 1584-2002 includes tables that provide typical bus gaps and working distances for 15 kV, 5 kV, and low-voltage switchgear, low-voltage motor control centers, panel boards, and cables.

For 5 kV switchgear, the gap between conductors is assumed to be 102 millimeters, and the working distance is assumed to be 910 millimeters. Other factors, like the configuration of the switchgear, cable, or box and the system grounding, are taken into account.

E. Determine the Incident Energy

The empirically derived model presented in IEEE 1584 provides two equations to calculate the incident arc-flash energy. The first is the normalized incident energy. The second is the incident energy with specific parameters.

The normalized incident energy assumes a "typical working distance" of 610 millimeters and an arc duration of 0.2 seconds. The equation for this example is:

$$\mathrm{LogE_n} = \mathrm{K_1} + \mathrm{K_2} + 1.081 \bullet \mathrm{LogI_a} + 0.0011 \bullet \mathrm{G} \tag{5}$$

$$\mathrm{E_n} = 10^{\mathrm{LogE_n}}$$

where:

E_n = normalized incident energy in J/cm^2

K_1 = –0.555 for a box configuration

K_2 = 0.0 for a resistance-grounded system

I_a = maximum arcing current in kA

G = gap between conductors = 102 mm

Calculating the normalized incident energy for the 23.6 kA arc current in this example is as follows:

$$\mathrm{LogE_n} = -0.555 + 1.081 \bullet \mathrm{Log}(23.6) + 0.0011 \bullet 102$$

$$\mathrm{LogE_n} = 1.0413$$

$$\mathrm{E_n} = 10^{1.0413} = 11\ \mathrm{J/cm^2}$$

The incident energy for the 20.0 kA arc current in this example is as follows:

$$\mathrm{E} = 4.184 \bullet \mathrm{C_f} \bullet \mathrm{E_n} \bullet \left(\frac{\mathrm{t}}{0.2}\right) \bullet \left(\frac{610^{\mathrm{x}}}{\mathrm{D^x}}\right) \tag{6}$$

where:

E = incident energy in J/cm^2

E_n = normalized incident energy in J/cm^2

C_f = 1.0 for voltages above 1.0 kV

t = arcing time in seconds

D = distance from the possible arc point = 910 mm

x = distance exponent = 0.973 for 5.0 kV switchgear

For this system at 23.6 kA, the incident energy is:

$$\mathrm{E} = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 120\ \mathrm{J/cm^2}$$

and at 20.0 kA, it is:

$$\mathrm{E} = 4.184 \bullet 1.0 \bullet 9.2 \bullet \left(\frac{0.96}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 125\ \mathrm{J/cm^2}$$

Note that the 85 percent current actually has more incident energy due to the longer trip time delay from the bus relay.

Convert the arc energy into cal/cm^2 using the conversion:

$$5.0\ \mathrm{J/cm^2} = 1.2\ \mathrm{cal/cm^2}$$

For the 23.6 kA current, the arc-flash energy at the bus is:

$$\mathrm{E} = 120 \bullet \frac{1.2}{5} = 29\ \mathrm{cal/cm^2}$$

F. Determine the Flash-Protection Boundary

The flash boundary is calculated from (7).

$$\mathrm{D_b} = \left[4.184 \bullet \mathrm{C_f} \bullet \mathrm{E_n} \bullet \left(\frac{\mathrm{t}}{0.2}\right) \bullet \left(\frac{610^{\mathrm{x}}}{\mathrm{E_b}}\right)\right]^{\frac{1}{\mathrm{x}}} \tag{7}$$

where:

E_b = incident energy at the boundary in J/cm^2 = 5.0 for bare skin

C_f = 1.0 for voltages above 1.0 kV

t = arcing time in s

D_b = distance of the boundary from the arcing point in mm

x = distance exponent = 0.973 for 5.0 kV switchgear

E_n = normalized incident energy in J/cm^2

For this system, the flash boundary is:

$$\mathrm{D_b} = \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}}$$

$$\mathrm{D_b} = 23867\ \mathrm{mm} = 24\ \mathrm{m}$$

This indicates that within 24 meters of the arc flash, any unprotected person could sustain second-degree burns from the fault incident energy.

VI. REDUCING THE RELAY TIME COORDINATION SETTINGS

The protection settings for relays in a distribution scheme are generally set with time coordination. This method allows time for the device closest to the fault to clear the fault before the next closest device attempts to clear the fault. Using this method, a time delay is added to each device to provide for the time coordination. Typically, these delays are a minimum of 0.3 seconds to provide some margin for coordination. These delays are added to the trip times and can result in significant trip delays, raising the available fault energy. Careful analysis of the protection curves can allow for reduction in the trip delay times, thereby reducing the available fault energy. Careful testing and analysis are needed as these margins shorten.

VII. IMPROVED PROTECTION SCHEMES

Engineers have implemented improved protection schemes in order to reduce the arc-flash hazard. These enhanced schemes include:

- High-impedance bus differential
- Low-impedance bus differential
- Fast bus trip scheme
- Maintenance mode
- Arc-flash detection

Bus differential has been used for protection for many years, but because of the cost and complexity, many engineers chose not to implement bus protection. There has been resurgence in the application because the bus differential has both high-speed and trip security.

A. High-Impedance Bus Differential Protection

Dedicated CTs are required for this scheme because all of the CT inputs are paralleled and then connected to a high-impedance input in the relay. The relay measures the voltage across its internal impedance—typically about 2,000 ohms. The relay is set so that, for the external fault, the voltage measured across the impedance is less than the pickup, and the internal fault is above the pickup. This scheme is fast and secure, but costly, because of the need for dedicated CTs and additional wiring and testing to validate the scheme.

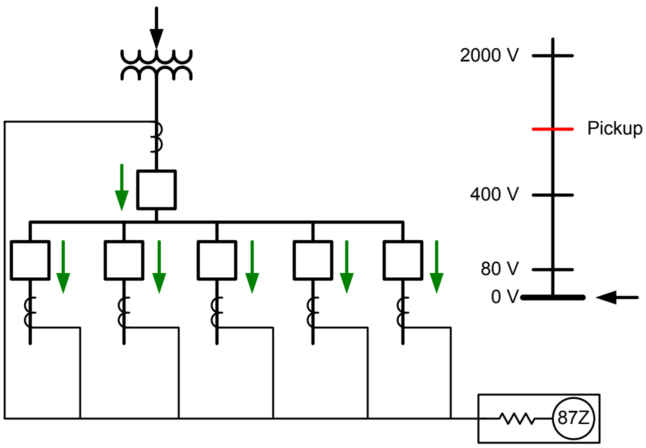

Fig. 2. High-impedance bus differential scheme

B. Low-Impedance Bus Differential Protection

A low-impedance bus differential scheme is fast and secure and does not require dedicated CTs. Typically, relay settings are slightly more complex than in a high-impedance differential scheme because each input has an independent CT ratio and connection. Like the high-impedance scheme, this scheme requires additional commissioning testing.

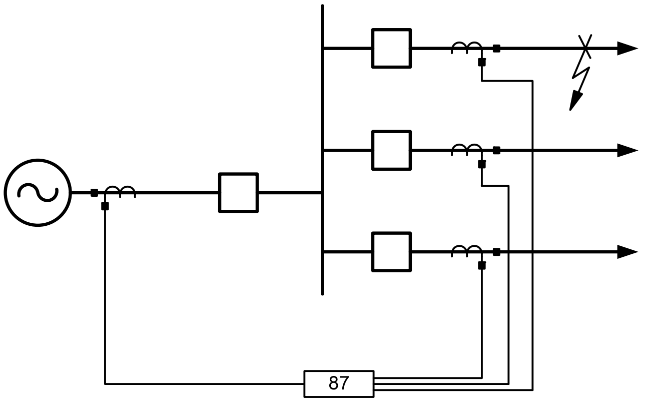

Fig. 3. Low-impedance bus differential scheme

C. Fast Bus Trip Schemes

In this protection scheme, the feeder relays and main relay communicate to signal the location of the fault. Then the relay coordination can be maintained without long time delays.

For a fault on the feeder, the feeder relay sends a “block” signal to the main relay. The main relay has only a short time delay to look for a block signal. If no block signal is received, the main breaker is tripped to clear the fault.

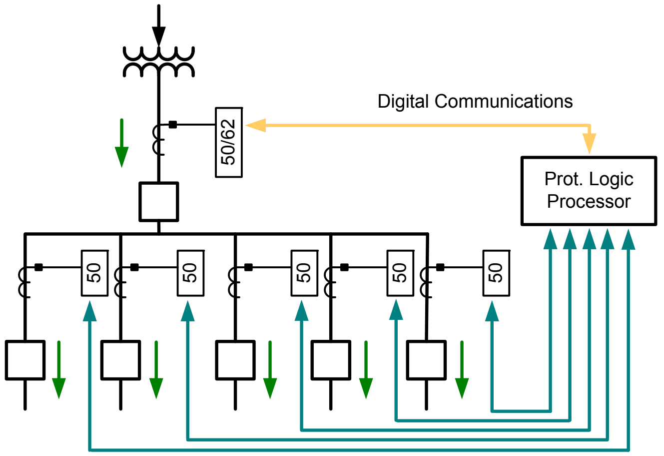

Fig. 4. Fast bus trip scheme

D. Enable Instantaneous Element During Maintenance

In order to improve safety while working near energized equipment, protection engineers have implemented an instantaneous setting used when workers are within the hazard zone. The presence of workers can be indicated with a pushbutton on the relay, with a separate switch, or via remote communication. While activated, this change in setting disables the time coordination and allows the breaker to trip without any delay. This scheme can be added to new or old installations without much expense. This special protection scheme is only activated when workers are in the proximity of the energized circuit(s).

E. Arc-Flash Detection

The purpose of detecting the arc flash is to minimize the time needed to trip the circuit breaker and interrupt the fault. Arc detection in the protective relay minimizes trip time, cost, and complexity. Enabling arc detection in the relay makes use of the current monitoring and protection already in the circuit.

Arc-detection sensors provide a clear measurement of an arc flash. The light emitted during an arc-flash event is significantly brighter than the normal substation light background. The light surge is available from the initiation of the flash and is easily detected using proven technology. The most common sensors are lens-point sensors and bare fiber-optic sensors.

The light is channeled from the sensor to the detector located in the protective relay. Monitoring the system integrity is accomplished using a fiber-optic loop. In the case of the lens sensors, each lens has an input and an output connection. The input is connected to a transmitter in the relay, and the output is connected to a detector in the relay. This loop connection allows periodic testing of the system by injecting light from the transmitter through the loop and back to the detector. This loop connection system works with either the lens sensor or the bare fiber sensor.

The bare fiber sensor consists of a high-quality plastic fiber-optic cable without a jacket (see Fig. 5). The clear fiber cable becomes a lens, bringing in light from the area. Using a bare fiber sensor makes detection in large areas possible using only one sensor. The cable is constructed of a 1-millimeter plastic material that can withstand a 25-millimeter bending radius without damage. The cable can be cut to length in the field and fit to the application without excess cable.

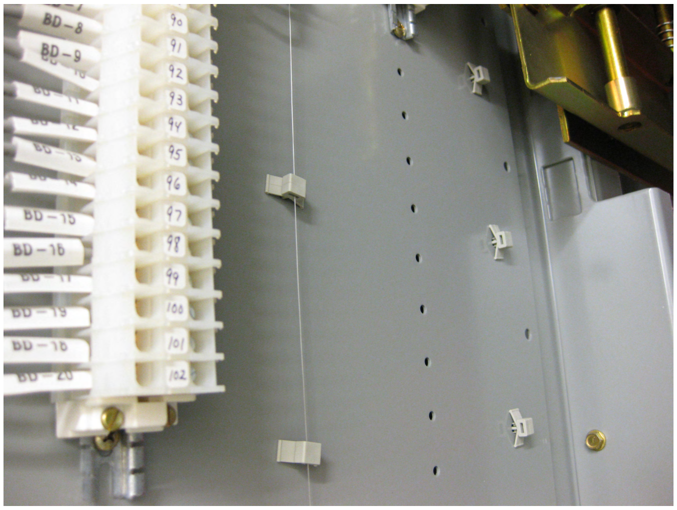

Fig. 5. Bare fiber-optic cable

Fig. 6. Lens sensor

Arc-detection systems typically use a combination of lens and bare fiber sensors returning to a single relay. Proper installation of the sensors and relays provides logical detection and trip points in any system.

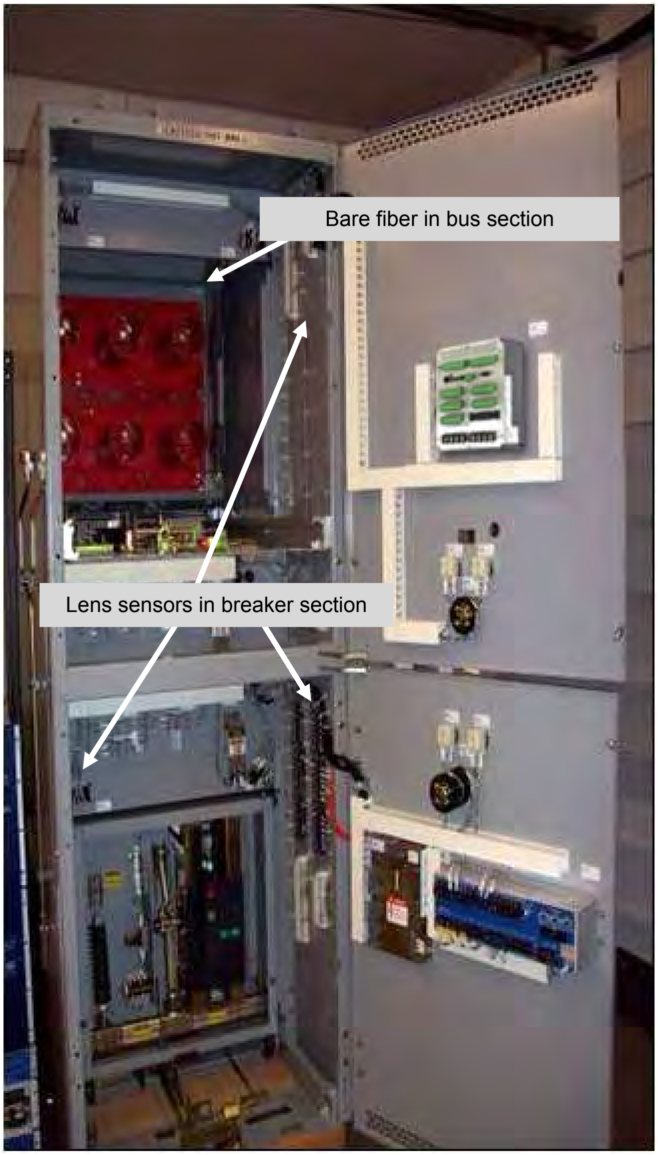

Fig. 7. Install sensors in bus breaker input and output sections

Sensors should be located where arc detection for the specific sensor would trip the corresponding upstream circuit breaker. Using more than one sensor provides 100 percent coverage even during 1-millisecond testing intervals.

Fig. 8. Lens sensor installed above breaker

Installation of sensors varies depending on the switchgear manufacturer, type of gear, and number of sections. Multiple sensor inputs provide coverage and sectioning options.

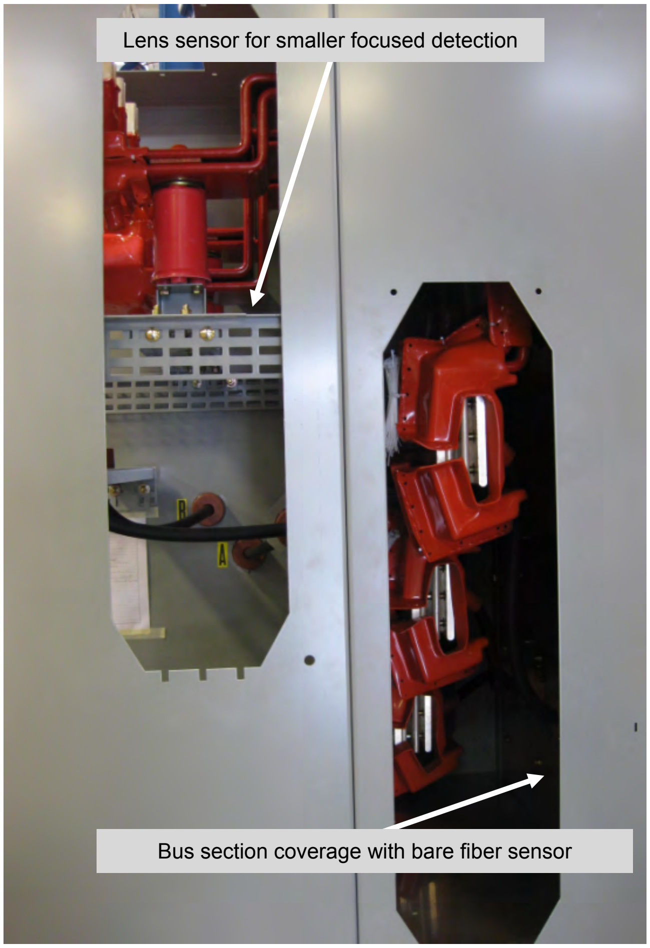

Fig. 9. Typical installation locations for arc sensors

One bare fiber sensor can provide excellent coverage of the entire bus section. Using lens sensors allows better control in small, confined spaces.

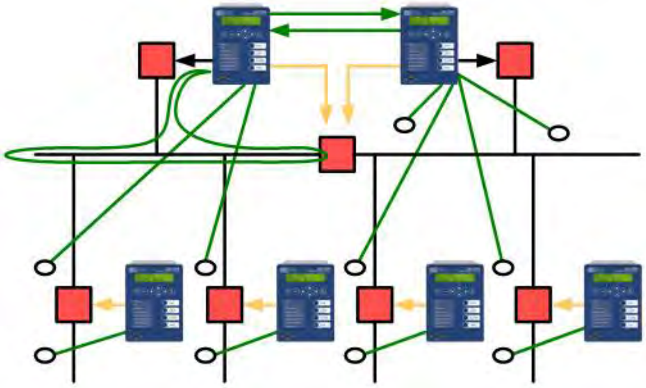

Fig. 10. Typical system with sensors and relay-to-relay communication

One obstacle in using light sensors is the need to measure and adjust for changing ambient light levels. Measuring light and current in the protective relay can make use of the analog measurements and event reporting capabilities in the relay.

By monitoring the incoming light as an analog signal, the user is able to view and set the normal light levels for the application. The event reporting also provides a troubleshooting tool with time-tagged events, including arc-sensor light levels.

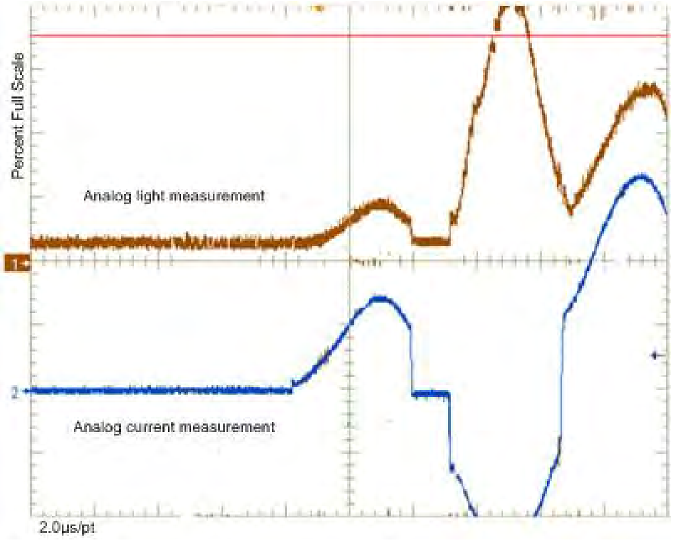

Fig. 11. Analog light measurement plotted with current

Tracking the arc-light intensity provides the detail needed to reach the root cause of an event.

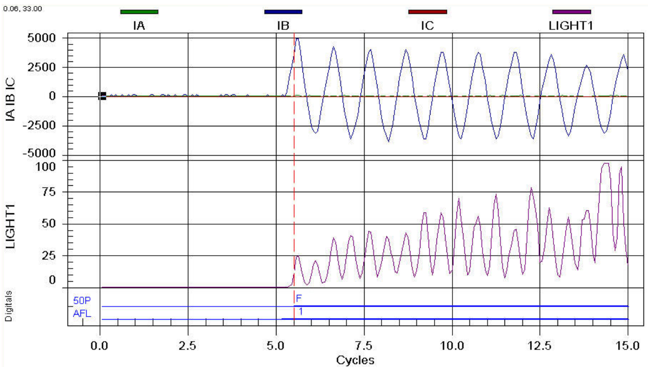

Fig. 12. Current and light event report

The added advantage of processing the arc-flash detection in the protective relay is the ability to use a true overcurrent measurement as a supervising element to improve security.

In order to reach the fastest trip times, some arc-detection systems use a current setting level below the normal expected load to enable the arc-flash detector as the trip mechanism. Using current in this manner removes any time lag, determining if a fault exists but sacrifices security and makes the system dependent on light detection alone. Superior security can be obtained using a high-speed overcurrent element in conjunction with the light sensor, without sacrificing trip speeds.

In the system presented in this paper, a true high-speed overcurrent element is used in parallel with the arc-flash detector. The current used to trigger a trip is derived by sampling the feeder current and using a fast detection algorithm to signal that a fault has occurred. This fault is then compared with the trip levels of the arc-detection sensors to determine if an arc-flash trip is warranted. Many standard overcurrent elements have response times between 6 and 20 milliseconds. This delay is unacceptable for arc-flash detection supervision. To avoid introducing additional delay, the high-speed overcurrent protection must act as quickly as the arc detection. The combination of fast overcurrent and flash detection must be present at the same instant; the combined security is much higher than either system alone.

VIII. RECALCULATING ARC-FLASH ENERGY

Adding arc-flash sensors reduces the total fault clearing time. The time reduction has a dramatic effect on arc-flash energy.

When Schemes 5 and 6 from Table I are implemented, significant reduction in arc-flash energy is observed.

For the 23.6 kA current, the bus relay trip time is:

$$2.5 \text{ ms} + 5/60 \text{ s} = 0.0858 \text{ s}$$

The breaker time of five cycles was added to obtain the total trip time.

For this system at 23.6 kA, the new incident energy is:

$$E = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.0858}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 13.4 \text{ J/cm}^2$$

$$5.0 \text{ J/cm}^2 = 1.2 \text{ cal/cm}^2$$

For the 23.6 kA current, the new arc-flash energy at the bus is:

$$E = 26.5 \bullet \frac{1.2}{5} = 3.2 \text{ cal/cm}^2$$

The new flash boundary of this system is:

$$D_b = \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.0858}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}}$$

$$D_b = 2502 \text{ mm} = 2.5 \text{ m}$$

TABLE I
COMPARISON OF PROTECTION SCHEMES

Scheme Number	Protection Scheme Description	Advantages	Discussion
	Reduce coordination intervals of existing time-overcurrent relays	Existing hardware, existing technology.	Adds cost of coordination study, trip times are still likely to be high (0.5 to 2 s, depending on coordination issues), only marginal improvement can be achieved.
1	High-impedance bus differential	Fast (less than 1.5 cycles) and secure for any fault type, easy to set.	Requires additional relay, dedicated CTs, cost to purchase CTs, wiring installation. Testing more complex. Trip time 0.107 s.
2	Low-impedance bus differential	Fast (less than 1.5 cycles) and secure for any fault type.	Requires additional relays, cost to wire CTs. Settings, testing more complex. Trip time 0.107 s.
3	Fast bus trip	Use of existing main and feeder overcurrent relays. Faster than time-overcurrent (typically 3 to 5 cycles), secure, communications channel monitors integrity of scheme. Relatively low cost to install fiber and transceivers.	Settings more complex. CTs on bus side of breaker would result in delayed tripping for faults in the feeder breaker. Trip time 0.17 s. Energy 6.4 cal/cm^2. Boundary 5.1 m.
4	Enable instantaneous overcurrent protection during maintenance	Use of existing main and feeder overcurrent relays. Fast (less than 1.5 cycles). Low cost to install control switch, wiring.	Lose selectivity during maintenance periods, could overtrip. Introduces change in maintenance procedures. Trip time 0.12 s. Energy 4.5 cal/cm^2. Boundary 3.5 m.
5	Addition of arc-flash detection to fast bus trip	Low cost, easy to retrofit, fastest detection principle, continuous self-testing, secure with two separate detections.	Trip time reduced from 0.17 to 0.0858 s. Energy reduced from 6.4 to 3.2 cal/cm^2. Boundary reduced from 5.1 to 2.5 m.
6	Addition of arc-flash detection to instantaneous trip	Low cost, easy to retrofit, fastest detection principle, continuous self-testing, secure with two separate detections.	Trip time reduced from 0.12 to 0.0858 s. Energy reduced from 4.5 to 3.2 cal/cm^2. Boundary reduced from 3.5 to 2.5 m.

On many systems, especially at industrial facilities, high fault currents, low-ratio CTs, and high system X/R ratios conspire to cause CT saturation during faults with dc offset current.

Microprocessor relays typically use analog and digital filtering to obtain phasors that eliminate dc and harmonic components. This is superior for most applications, but the ideal filter for an instantaneous overcurrent element must also detect bipolar peaks for high-current faults during extreme CT saturation. Thus, it is important to apply overcurrent elements that respond to the fundamental in the absence of saturation but respond to peak currents during saturation [7].

IX. TESTING THE RELAY

One major obstacle in the implementation of arc-flash detection has been the testing of the relay. Some manufacturers have suggested using a camera flash to verify the light detection circuit. Although this does verify the continuity of the circuit, it does not validate the overcurrent function or timing. As discussed in this paper, use of both the overcurrent and light detection provides superior security. The testing of the arc flash and overcurrent for this system was accomplished using a standard relay test set with an additional arc-test unit.

The arc-test unit operates in either of two modes. The first uses the time source from the test set to generate a light pulse. The light pulse is directed through a fiber-optic lead attached to the light sensor being tested.

The light test signal can be observed as an analog signal in the relay. The test set, on command, implements a series of step increases in current. When the overcurrent signal is initiated, the test set synchronizes the overcurrent with the synchronized light test signal.

The second test mode is used when no time signal is available. The arc-test unit synchronizes an output contact with the light strobe. This contact is connected between a current source and the relay CTs.

The final step in the test sequence allows the test set to measure the total time delay from the overcurrent and flash pulse until the relay contacts close. This type test verifies not only the proper functionality of the arc-flash relay but also provides the actual total trip delay from the relay. The trip time found during testing should be used when calculating the arc-flash hazard information. Relying on unsupported claims of fast trip times can result in incorrect hazard analysis and unanticipated risk to workers.

X. CONCLUSION

Arc-flash hazards present a clear danger to personnel. Worker safety should always be at the forefront of designs, processes, and procedures. Several means exist to reduce the likelihood of injury from an arc flash. The results seen by the addition of arc-flash detectors working in parallel with a high-speed overcurrent element are striking. Arc-flash trip times are reduced by 28.5 percent from the previous fastest tripping scheme. The incident energy and boundary distance are both reduced by 50 percent to 3.2 cal/cm^2 and 2.5 meters, respectively.

Clearly, the addition of arc-flash detection improves the safety of the installation. When comparing the cost of installation, arc-detection systems are relatively inexpensive to install and are easy to set up using analog measurements. Arc-detection systems can be designed into new switchgear or retrofitted into existing gear.

Security of the system is very high, due to the parallel action of two separate detection systems—overcurrent and light. Overcurrent detection must be at high-speed levels so no delay is added to the light detection trip time. Misoperations due to nonarc-flash sources are eliminated. Security is further enhanced by the self-testing of each sensor loop. The self-test ensures continuity and function. It provides a system health indicator without exposing personnel to testing hazards.

Event reports that include analog values of light provide clear data for root cause analysis of any trip event. This eliminates the guesswork in determining the light source and intensity causing any trip.

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XII. BIOGRAPHIES

Mark Zeller received his B.S. in Electrical Engineering from the University of Idaho in 1985. He has broad experience in industrial power system maintenance, operations, and protection. Upon graduating, he worked over 15 years in the pulp and paper industry, working in engineering and maintenance with responsibility for power system protection and engineering. Prior to joining Schweitzer Engineering Laboratories, Inc. in 2003, he was employed by Fluor to provide engineering and consulting services. He has been a member of IEEE since 1985.

Gary W. Scheer received his B.S. in Electrical Engineering from Montana State University in 1977. He worked for the Montana Power Company and the MPC subsidiary, The Tetragenics Company, before joining Schweitzer Engineering Laboratories, Inc. (SEL) in 1990 as a development engineer. He has served as vice president of the research and development division and of the automation and engineering services division of SEL. Mr. Scheer is now a senior marketing engineer in the marketing division for automation and communications products. His biography appears in Who's Who in America. He holds two patents related to teleprotection. He is a registered professional engineer and member of the IEEE and the ISA.

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