Arc-Flash Protection for Low- and Medium-Voltage Panels

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ARC-FLASH PROTECTION FOR LOW- AND MEDIUM-VOLTAGE PANELS

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Abstract—This paper presents a new, reliable solution using arc-flash light detection supervised using overcurrent protection to reduce the risk of an arc flash in low- and medium-voltage panels and switchgear equipment, thereby eliminating false trips from lighting and providing the fastest detection and tripping possible. The paper also presents the advantages of fast overcurrent detection combined with arc-flash measurement to produce a sensitive, fast, and secure tripping scheme.

Index Terms—Protective relay, medium-voltage panel, low-voltage panel, arc flash, electric arc, personnel safety.

I. INTRODUCTION

One of the greatest concerns of a company today is the safety of its personnel, especially substation operators and maintenance electricians. Simple daily tasks performed in a substation, such as the insertion of a circuit breaker, can produce an arc flash. This event can result in irreversible effects on the health of the operator, including serious burns, inhalation of hot, toxic gases, high levels of noise, flying melted parts and materials, and pressure waves that can propel the operator through the air for several meters, knocking the operator against equipment inside the substation.

Studies conducted in the United States show that 50 percent of the people in burn care units have arc-flash injuries and one or two out of five do not survive these injuries [1].

An arc flash is a dangerous condition associated with the release of energy caused by an electric arc that moves at high speeds (about 100 meters per second) and reaches high temperatures. It can completely destroy metal panels and equipment and cause serious physical injury, occasionally fatal, to people in the affected area. Some important definitions of arc flash and related issues can be found in IEEE 1584-2002 IEEE Guide for Performing Arc-Flash Hazard Calculations [2]. Similar definitions are found in *NFPA 70E: Standard for Electrical Safety in the Workplace*® [3].

Because they release large amounts of energy and heat over a very short period of time, arc-flash events have become the focus of studies to improve safety for operations and maintenance personnel and minimize damage to switchgear panels and equipment.

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 concludes that arc time has a linear effect on incident energy. Therefore, reducing fault clearing times proportionately reduces an arc flash [4] [5].

There are several procedures for protecting personnel, including the use of special clothing, arc-resistant switchgear, and remote controls via HMI (human-machine interface) panels. However, a movement has recently emerged toward the greater use of protective relays that detect the formation of an arc flash and reduce fault clearing time, because the three methods cited above do not prevent the destruction caused by the arc but only minimize the effects of an explosion.

The following list highlights the most common arc-flash hazard reduction methods:

- Avoid the hazard area.
- Install arc-resistant switchgear.
- Add current-limiting devices.
- Reduce the relay time-coordination settings.
- Improve protection schemes: low- and high-impedance bus differential protection and fast bus trip schemes using overcurrent relays and communications.
- Enable instantaneous elements during maintenance.

All of these methods are clearly examined in [4] and [5].

The adoption of protective measures, such as arc-resistant switchgear, does not resolve the problem of the release of toxic gases and does not dispense with the need for special clothing if maintenance is performed by thermal imaging.

Using protective relays for arc-flash detection has proven to be very effective, because in addition to protecting personnel, it can also prevent explosions and the destruction of the panel. Reducing fault clearing times proportionately reduces arc flash. Because it is impossible to prevent 100 percent of arc flashes from forming, the arc-flash detection relay provides an effective and reliable way to reduce the amount of energy released during the event, which, in turn, reduces equipment damage and harm to individuals.

Recent technological advances have made arc-flash detection relays economically viable for installation in various types of industrial panels used in both low- and medium-voltage distribution centers.

Table I details the available types of arc-flash protection and their consequences for switchgear equipment and the operator.

TABLE I
TYPES OF ARC-FLASH PROTECTION AND CONSEQUENCES

Type of Arc-Flash Protection	Consequences	
	Operator	**Equipment**
Personal protective equipment (PPE) and/or special clothing	Personal protection	Total destruction
Arc-resistant switchgear	Better protection (during normal operation)	Partial destruction
Remote operation	Safe, good protection	Total destruction
Arc-flash detection relay	Enhanced protection	Enhanced protection

Furthermore, considering the time required to replace a medium-voltage panel after its destruction or the immeasurable loss of a human life, the installation of arc detectors has become mandatory in electric substations, in the same way that safety belts are indispensable in automobiles.

II. ARC-FLASH HAZARD EXAMPLE

This paper uses the IEEE 1584 model for calculating arc-flash hazards [2]. The example system shown in Fig. 1 is used to help analyze the arc-flash hazard. Details can be found in [4] and [5].

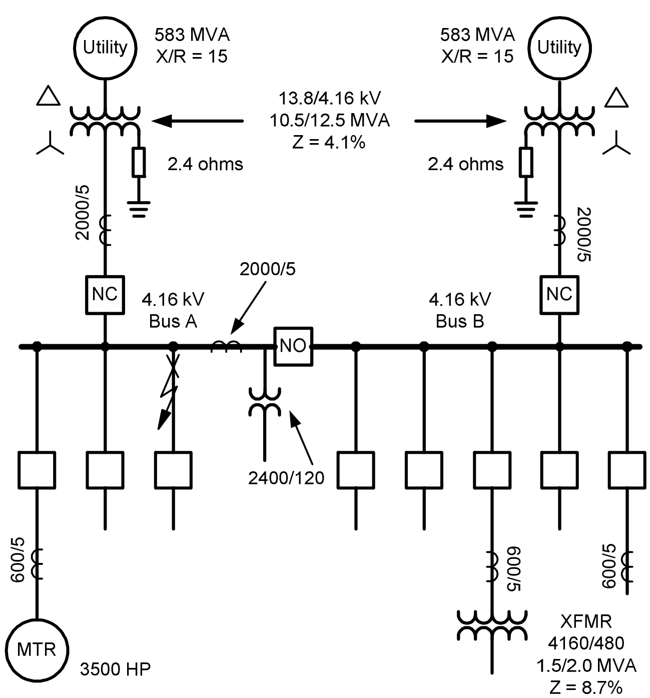

Fig. 1 Example System

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 (1) to make the conversion to a percent impedance, based on the transformer MVA and kV.

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

where:

$\%Z$ = utility impedance as a percentage, based on transformer base

kV_u = utility voltage base

kV_t = transformer voltage base

MVA_u = utility fault MVA

MVA_t = transformer MVA base

$\frac{X}{R}$ = utility $\frac{X}{R}$ ratio

The impedance is shown in (2).

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

Since the example switchgear has no cable impedance, only the transformer impedance of 4.1 percent needs to added. Assuming the transformer impedance is all inductive, the total impedance to the bus is shown in (3).

$$\begin{aligned} \%Z_{total} &= 0.13 + j1.8 + j4.1 \\ &= 0.13 + j5.9 \\ &= 5.9\% \angle 89^\circ \end{aligned} \quad (3)$$

Calculate the fault current with (4) and (5).

$$I_f = \frac{MVA_t \bullet 57735}{kV_t \bullet \%Z_{total}} \quad (4)$$

$$I_f = \frac{10.5 \bullet 57735}{4.16 \bullet 5.9} = 24.7 \text{ kA} \quad (5)$$

where:

I_f = maximum bus fault current

kV_t = transformer voltage base

MVA_t = transformer MVA base

$\%Z_{total}$ = total impedance on transformer base to bus as a percentage

B. Determine the Arc-Fault Currents

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

Equations (6) and (7) are used to calculate the arcing current.

$$\mathrm{Log}I_a = 0.00402 + 0.983 \bullet \mathrm{Log}I_{bf} \quad (6)$$

$$\begin{aligned} I_a &= 10^{\mathrm{Log}I_a} \\ \mathrm{Log}I_a &= 0.00402 + 0.983 \bullet \mathrm{Log}(24.7) = 1.373 \\ I_a &= 10^{1.373} = 23.6 \text{ kA} \end{aligned} \quad (7)$$

where:

I_{bf} = maximum bus fault current in kA

I_a = maximum arcing current in kA

85 percent of this value is also needed to see how the lower fault current impacts trip times, which may, in fact, increase energy. The 85 percent value is 20 kA.

C. Determine the Protective Relay Operate Times

Relay coordination for this system was extracted from the time-coordination curves. The breaker time of 5 cycles was added to obtain the total trip time. The bus relay trip time for the 23.6 kA current is shown in (8).

$$0.69 + \frac{5}{60} = 0.77 \text{ s} \tag{8}$$

The bus relay trip time for the 20.0 kA current is shown in (9).

$$0.88 + \frac{5}{60} = 0.96 \text{ s} \tag{9}$$

D. Document 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 system grounding, are taken into account.

E. Determine the Incident Energy

The empirically derived model presented in IEEE 1584-2002 provides two equations to calculate the incident arc-flash energy. The first is normalized incident energy, and the second is incident energy with specific parameters.

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 shown in (10) and (11).

$$\text{Log}E_n = K_1 + K_2 + 1.081 \bullet \text{Log}I_a + 0.0011 \bullet G \tag{10}$$

$$E_n = 10^{\text{Log}E_n} \tag{11}$$

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 normalized incident energy for the 23.6 kA arc current in this example is shown in (12).

$$\begin{aligned} \text{Log}E_n &= -0.555 + 1.081 \bullet \text{Log}(23.6) + 0.0011 \bullet 102 \\ \text{Log}E_n &= 1.0413 \\ E_n &= 10^{1.0413} = 11 \text{ J/cm}^2 \end{aligned} \tag{12}$$

Incident energy for the 20.0 kA arc current in this example is shown in (13).

$$E = 4.184 \bullet C_f \bullet E_n \bullet \left(\frac{t}{0.2}\right) \bullet \left(\frac{610^x}{D^x}\right) \tag{13}$$

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

Incident energy for this system at 23.6 kA is shown in (14).

$$E = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 120 \text{ J/cm}^2 \tag{14}$$

Incident energy at 20.0 kA is shown in (15).

$$E = 4.184 \bullet 1.0 \bullet 9.2 \bullet \left(\frac{0.96}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 125 \text{ J/cm}^2 \tag{15}$$

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

Convert arc energy into cal/cm^2 using the conversion shown in (16).

$$5.0 \text{ J/cm}^2 = 1.2 \text{ cal/cm}^2 \tag{16}$$

Arc-flash energy at the bus for the 23.6 kA current is shown in (17).

$$E = 120 \bullet \frac{1.2}{5} = 29 \text{ cal/cm}^2 \tag{17}$$

F. Determine the Flash-Protection Boundary

The flash boundary is calculated from (18).

$$D_b = \left[4.184 \bullet C_f \bullet E_n \bullet \left(\frac{t}{0.2}\right) \bullet \left(\frac{610^x}{E_b}\right)\right]^{\frac{1}{x}} \tag{18}$$

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 seconds

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

x = distance exponent = 0.973 for 5.0 kV switchgear

E_n = normalized incident energy in J/cm^2

The flash boundary for this system is shown in (19).

$$\begin{aligned} D_b &= \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} \\ D_b &= 23867 \text{ mm} = 24 \text{ m} \end{aligned} \tag{19}$$

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

III. NEW RELIABLE ARC-FLASH PROTECTION PHILOSOPHY

An arc-flash protection system should be extremely fast, safe, and reliable. This means that the system should act instantaneously, providing high-speed detection of the arc inside the switchgear and tripping the circuit breaker in a few milliseconds to extinguish the arc. However, the protection system must not act when there is no arc flash inside the panel.

Adopting a philosophy that combines the detection of light inside the switchgear (which indicates the formation of an arc flash) with the detection of significant increases in load current nominal values (which confirms the presence of a short circuit between live parts inside the switchgear) eliminates false trips from lighting and provides the fastest detection and tripping possible.

To ensure and improve the reliability of this philosophy, the main circuit protective relay is used with additional light sensor units that are placed at strategic points in low- or medium-voltage panels or switchgear and interconnected by fiber-optic cables to this relay, eliminating the need for other components inside these cubicles.

By using one piece of equipment to provide both protective relay and arc-flash detection, this philosophy provides the following additional advantages:

- There is no need for additional current transformers (CTs) or connections in a series of current circuits to supply the inputs of the arc-flash detection device.
- Event reports provide analysis of the arc-flash event, verifying the appropriate operation of the arc-flash detector by oscillographic records of light intensity metering, arc-detector element pickup signals, and current values present during the event.
- Sequence of events (SOE) reports include pickup of the arc-flash detection element.
- An Ethernet interface enables communications with the supervisory and control system and viewing of information from the arc-flash detector (e.g., alarm, trip), as well as the operation of any other protection functions related to the relay.
- Trip/alarm messages can be sent via IEC 61850 GOOSE (Generic Object-Oriented Substation Event) messages to other equipment connected to the Ethernet network.
- A single software program is used to configure the arc-flash detector and protective relay.
- A single software program is used for settings, event acquisitions, data logs, and parameter and settings changes in a local and remote manner.
- The equipment offers a self-checking function with an alarm contact to communicate an internal failure, providing high system reliability (watchdog).
- There is a reduction in spare parts and equipment training time, because the main relay performs all functions.

The system uses three or four sensors in each cubicle, each one linked by fiber-optic cable to the main protective relay, which serves as the master unit. The relay is easier to integrate with the supervisory and control system, enables remote settings and configuration, and has high-speed pickup (approximately 2 milliseconds), excellent safety against false trips (the presence of light is not enough; both light and current must be present), and lower cost.

The following list summarizes the main features of the arc-flash protection system:

- Elimination of additional CTs in the panel.
- Information on light intensity, current measurement, trip element pickup, and current values provided by event reports (oscillography) and SOE.
- Integration with other IEDs (intelligent electronic devices).
- GOOSE message exchange.
- Single software.
- Remote access.
- Single unit for arc-flash detection and protection functions.
- Operation time of approximately 2 milliseconds.
- Safety: use of light plus current to activate the system operation.
- Self-testing of optical circuit, capable of generating alarms.

IV. ARC-FLASH PROTECTION SYSTEM COMPONENTS

The arc-flash protection system is illustrated in Fig. 2. It is composed of a master unit (main protective relay), point light sensors (see Fig. 3), and area light sensors.

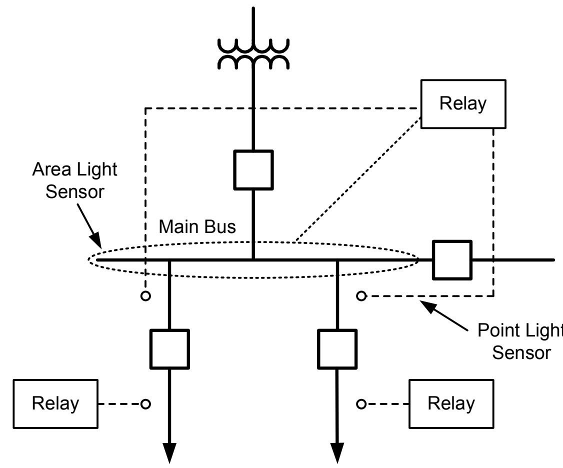

Fig. 2 Protective Relay With Point Light and Area Light Sensors

Fig. 3 Point Light Sensor

Point light sensors are placed at the specific points that have the greatest risk of arc flash, such as movable panel parts (e.g., insertion/removal of a circuit breaker). Regional sensors are recommended for covering a larger area and are commonly placed in the main bus compartment of the panel.

A typical protective relay for feeder or panel inputs can use up to four sensors.

A. Point Light Sensors

An arc-flash formation generates light that is captured by the optical lenses of the point light sensors (appropriately located in the panel) and transmitted over a 1,000 micrometer plastic fiber-optic cable to the optical detector installed in the protective relay. These sensors are normally installed at connection points inside each cubicle (e.g., in the circuit breaker insertion compartments and at cable connections and potential transformer [PT] connections). Point light sensors do not have electronic components and are easily affixed to the panel and replaced in the event of an arc flash.

B. Area Light Sensors

Another option for the detection of an arc flash uses a bare 1,000 micrometer plastic fiber-optic cable that captures the light emitted during an arc-flash event. These area light sensors cover a larger area in the panel and can be installed along the entire length of the panel main bus.

C. Protective Relay

The main protective relay used for this arc-flash protection system is a multifunctional device for applications in low- and medium-voltage feeders.

In addition to the arc-flash detection function, the relay has many other features, including the following protection functions:

- High-speed phase instantaneous overcurrent for arc-flash detection (50PAF)
- High-speed neutral instantaneous overcurrent for arc-flash detection (50NAF)
- Phase instantaneous and time-overcurrent elements (50/51)
- Residual instantaneous and time-overcurrent elements (50/51G)
- Neutral or ground instantaneous and time-overcurrent elements (50/51N [or GS])
- Negative-sequence instantaneous and time-overcurrent elements (50/51Q [46])
- Thermal element (49)
- Over-/underfrequency and rate of change of frequency elements (81)
- Phase-to-ground or phase-to-phase undervoltage and overvoltage elements (27/59)
- Power factor (55)
- Loss of potential (60)
- Negative-sequence overvoltage element (reverse phase) (59Q [47])
- Zero-sequence overvoltage element, when three four-wire connection PTs are used (59N)
- Blocking (86)
- Circuit breaker failure (50/62BF)
- Autoreclosing (four shots) (79)
- Synchronism check (25)

Metered quantities in the relay include currents; voltages; three-phase apparent, real, and reactive power; three-phase power factor; three-phase real and reactive energy; demand; frequency; and resistance temperature detector temperatures.

Monitoring capabilities of the relay include the following:

- Sequence of events with storage of the most recent 1,024 events and load profile reports.
- Messages on the front displays and target light-emitting diodes (LEDs) with event information, including the interruption of optical circuits.
- Event reports (oscillography) with information on light intensity, current measurement, and arc-flash detection element pickup.

The main protective relay can have up to 21 input/outputs when equipped with arc-flash detection or a maximum of 37 input/outputs when equipped with an additional module. It is easy to perform system tests using relay pushbuttons and logic equations. For example, test logic can be created to intentionally block the arc detector at the request of the operator.

The relay has logic to send the trip signal to the circuit breaker closest to the detected arc flash. This is necessary because one relay has four distinct inputs from sensors that can be installed in different points of a cubicle or even in adjacent cubicles. An example is four cable output compartments monitored by only one relay. The relay trips the circuit breaker where the arc-flash sensor was activated.

The trip order issued by the arc-flash detector can be inserted in the circuit breaker failure scheme. The relay blocks the closing of the circuit breaker until the light sensors detect normal operating conditions (i.e., light intensity insufficient to activate the trip circuit based on arc-flash detection).

Multiple serial ports, an Ethernet port, and various communications protocols are included in the relay. The relay makes it easy to transmit information from the arc-flash detector (alarm, trip, etc.) over a communications network, because the relay is already part of the supervisory system. It has the ability to send trip and alarm messages via IEC 61850 GOOSE messages to other equipment on the Ethernet network.

The relay continuously monitors light sensor circuits and can send an alarm to the supervisory system in case of any interruption in these circuits, easing the job of maintenance personnel. It uses a single software program for local and remote parameterization and offers local and remote engineering access for event acquisition, data logs, and settings and parameter changes.

V. ARC-FLASH PROTECTION SYSTEM OPERATION PRINCIPLE

A. Introduction

The purpose of detecting an 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 current monitoring and protection already in the circuit.

The arc-flash protection system operation principle combines a variation of light intensity (captured by as many as four independent optical sensors) with an increase of phase and neutral currents measured by the protective relay (exceeding the phase and neutral currents previously set).

The additional 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.

High-speed overcurrent elements (50PAF and 50NAF) are used to obtain faster trip times. These elements are separate from those based on short-circuit currents. 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.

From this point, the operator uses the protective relay settings to define the actions to be taken after an arc flash is detected, such as issuing a trip command to the circuit breaker or sending remote alarms in order to extinguish the arc flash as fast as possible.

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 analog measurements and event reporting capabilities in the relay.

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

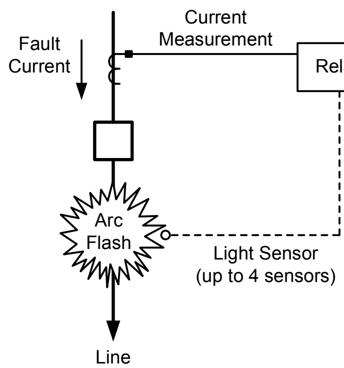

Fig. 4 Arc-Flash Protection System Operation Principle

In Fig. 5, the line marked IB represents overcurrent in the Phase B channel of the relay. The line marked LS(1) represents the variation in the intensity of current on Optical Sensor 1 of Relay LS(1). The vertical dashed line represents the exact instant at which the high-speed overcurrent element, 50AF, asserted. The variation of the TOL1 line shows the instant at which the light level reached the previously set level. The time required to eliminate the fault depends upon the circuit breaker tripping time.

In addition, an IEC 61850 GOOSE message can be sent or relay-to-relay digital communications can be used to coordinate with the panel input relay, if the signal remains active for a previously set time delay.

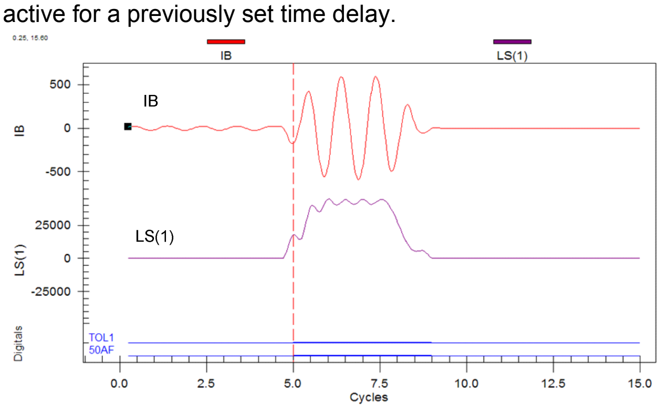

Fig. 5 Oscillographic Record of a Protective Relay With Arc-Flash Detection Function

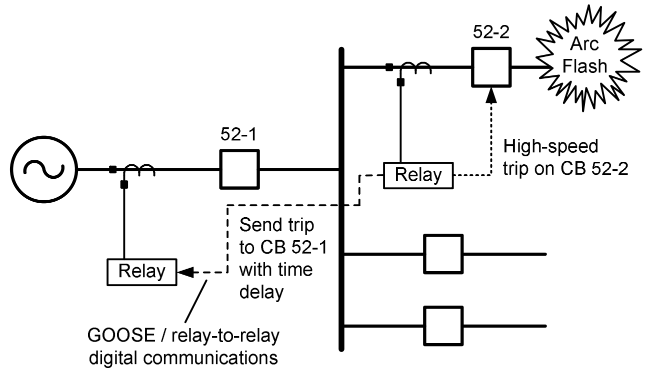

Fig. 6 Use of Relay-to-Relay Digital Communications for Protection Coordination

B. Self-Testing

An optical loop technique performs self-testing of the arc-flash detection system. An LED transmitter in the protective relay emits light pulses at regular intervals. The pulses are monitored on the optical circuit (loopback tests) by an optical detector and reflected in the lenses of the light sensors. Continuous monitoring of this optical loop allows the relay to send alarms via contact, display, serial, or Ethernet communications, if the circuit is interrupted. Fig. 7 illustrates this optical loop.

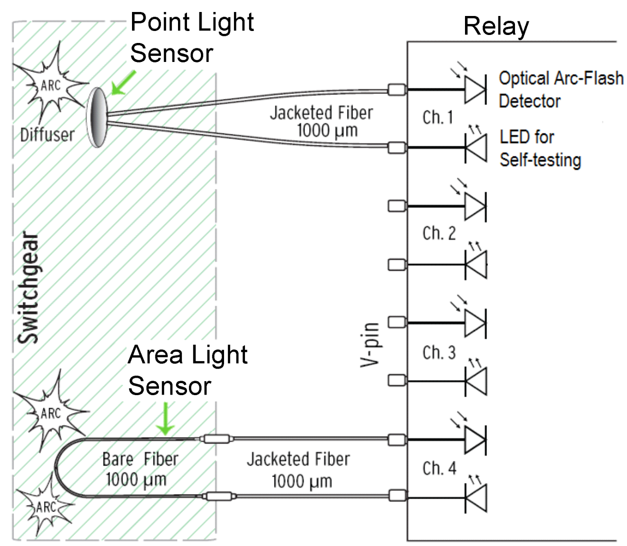

Fig. 7 Self-Testing Scheme of the Arc-Flash Detection System With Point Light and Area Light Sensors

VI. RECALCULATING ARC-FLASH ENERGY

Adding arc-flash sensors reduces the total fault clearing time. Time reduction has a dramatic effect on arc-flash energy, causing a significant reduction in arc-flash energy.

The bus relay trip time for the 23.6 kA current is shown in (20).

$$2.5\text{ ms} + \frac{5}{60}\text{ s} = 0.0858\text{ s} \qquad (20)$$

The breaker time of 5 cycles was added to obtain the total trip time.

New incident energy for this system at 23.6 kA is shown in (21) and (22).

$$E = 4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.0858}{0.2}\right) \cdot \left(\frac{610^{0.973}}{910^{0.973}}\right) = 13.4 \text{ J/cm}^2 \quad (21)$$

$$5.0 \text{ J/cm}^2 = 1.2 \text{ cal/cm}^2 \quad (22)$$

New arc-flash energy at the bus for the 23.6 kA current is shown in (23).

$$E = 26.5 \cdot \frac{1.2}{5} = 3.2 \text{ cal/cm}^2 \quad (23)$$

The new flash boundary of this system is shown in (24).

$$D_b = \left[4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.0858}{0.2}\right) \cdot \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} \quad (24)$$

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

VII. BENEFITS OF USING ARC-FLASH PROTECTION INTEGRATED WITH MAIN RELAYS

The primary benefit of the system proposed in this paper is that the reduction of fault clearing times proportionately reduces arc flash. In addition, system advantages include:

- Flexibility
  - When installing in existing panels, a retrofit of the existing main protection is recommended to obtain other advantages from high-technology protective relays (e.g., oscillography, SOEs, network integration).
  - For a panel retrofit or modernization of industrial substations, the entire conventional protection system can be replaced, and the arc-flash detection system should be included in this concept as a whole.
  - When installing new panels, the main protective relay can be defined as the master unit for the detection of an arc flash.
- Reliability
  - Using only one device for arc-flash detection and protection functions reduces the number of components in the switchgear.
  - The individual components of the arc-flash protection system present low failure rates. In addition, the system as a whole ensures operation only when there is a combination of light intensity and current. Therefore, if only light is detected inside the cubicle or only fault current is detected in the circuit, the arc-flash protection system is not activated.
  - The self-testing features of the protective relay and optical loop of the arc-flash detection system provide alarms if problems occur in the fibers/sensors.
- Equipment optimization. There is no need for additional CTs or connections in series of current circuits to supply additional equipment inputs, if the arc detector is installed outside the protective relay.
- Software optimization. Using one type of software to configure the arc detector and protective relay functions makes it easy for the maintenance team that routinely parameterizes microprocessor-based protective relays.
- Optimization of spare parts. This solution reduces the number of spare parts, which, in this case, would be only the main relay.

VIII. CONCLUSIONS

Some large industries already consider the arc-flash protection system presented in this paper as the most effective protection system for the safety of personnel, instruments, and equipment. The philosophy of the high-speed arc-flash protection system (detection in approximately 2 milliseconds) allows for integration in a highly reliable network and optimization of panel assembly and equipment.

IX. REFERENCES

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X. VITAE

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