# Application of Existing Technologies to Reduce Arc-Flash Hazards

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## I. INTRODUCTION

Protective relay engineers have long been concerned with protecting power systems and all of the equipment associated with those systems. We routinely apply relays to limit damage to apparatus (e.g., transmission and distribution lines, power transformers, buses, generators, motors, etc.) and protect against, or reduce, the impact of electrical disturbances on the larger power system (e.g., shedding load for frequency or voltage variations).

Safety for personnel has always been a concern, but in the past several years there is a heightened awareness of the importance of safety around electrical apparatus, as reflected in recent regulations and standards [1] [2].

In particular, industry and utilities alike recognize that arc-flash events can cause dangerous and potentially fatal levels of heat, ultraviolet radiation, blast pressure, flying shrapnel, and deafening sound waves. The existing standards mainly deal with the heat energy from the arc flash.

The energy produced by an arc-flash event is proportional to voltage, current, and the duration of the event (V•I•t). Design engineers have a few options to reduce system voltage or fault currents (e.g., grounding practices and application of current-limiting fuses), but the best and most direct ways to reduce arc-flash hazards are to reduce fault-clearing times and use wireless communications to reduce the need for technicians to be in harms way. In most cases, clearing times are reduced via more complete use of microprocessor relays features and other technologies already available. Similarly, digital relay communications and secure wireless communications devices allow engineers and technicians to converse with relays from a safe distance.

In this paper, we include some important industry definitions of arc flash and ways of measuring arc-flash hazards. We then examine the use of existing technologies, including digital relays and communications capabilities, to implement reduced trip times using instantaneous overcurrent relays, a fast bus-trip scheme, and differential schemes. We use a typical industrial switchgear lineup as an example of how to implement these schemes. Finally, we quantify the levels to which we can reduce arc-flash energy and its impact on safety.

## II. DEFINITIONS

What is an arc flash? How do we measure the energy so as to quantify improvement? Some important definitions of arc flash and related issues can be found in IEEE 1584-2002, "IEEE Guide for Performing Arc-Flash Hazard Calculations." Similar definitions are found in NFPA 70E, "Standard for Electrical Safety in the Workplace, 2004 Edition."

> *Arc-Flash Hazard. A dangerous condition associated with the release of energy caused by an electric arc.*
>
> *Flash Hazard Analysis. A method to determine the risk of personal injury as a result of exposure to incident energy from an electrical arc flash.*
>
> *Flash-Protection Boundary. An approach limit at a distance from live parts that are insulated or exposed within which a person could receive a second-degree burn.*
>
> *Working Distance. The dimension between the possible arc point and the head and the body of the worker positioned in place to perform the assigned task* [1].

## III. MEASURING ARC FLASH AND THE EFFECTS OF ARC FLASH

There are several methods for calculating incident energy due to an arc-flash event. These include a table-based method in NFPA 70E-2004, a theory-based model for applications over 15 kV (Lee method), empirically derived models based on a curve-fitting program, and a physical model-based method with some verification testing.

Within the last few years, IEEE 1584 was published, and an empirically derived model based on statistical analysis was developed as part of this effort [1]. IEEE 1584 includes several spreadsheets to assist the engineer in arc-flash studies. We will use this method for our analysis in this paper.

Incident energy is typically quantified in cal/cm$^2$ or Joules/cm$^2$. The incident energy determines the personal protective equipment (PPE) required to provide adequate protection based on recommendations in NFPA 70E. Incident energy calculations also provide the basis for the flash-protection boundary.

### *A. Protection Considerations for Arc Flash*

IEEE 1584-2002 concluded that arc time has a linear effect on incident energy, i.e., reducing fault-clearing times proportionately reduces arc flash.

Also, IEEE 1584-2002 states that the system X/R ratio had "little or no effect" on arc current and incident energy and was, thus, neglected. All of the formulas for arc current and incident energy calculations assume a 200 ms arc duration and use symmetrical fault current.

For the analysis in this paper, no "weight" factor was added due to asymmetrical current, but it seems possible that faster clearing times (< 100 ms) might increase incident energy due to higher dc offset currents. Further study, beyond the scope of this paper, would be required to analyze this issue.

## *B. Steps in Calculating Arc-Flash Energy and Its Effects*

### *1) Collect the System Data and Modes of Operation*

In short, we need an accurate one-line diagram including system source, line, and transformer impedances. We also need to know the modes of operation, if additional feeders and generators may be in service, and how this impacts fault currents and trip times. The goal is to establish the conditions that produce the maximum fault currents.

### *2) Determine the Bolted Fault Currents*

Next, we calculate the maximum three-phase fault current based on short-circuit programs, fault studies, or the method shown in Section IV.

### *3) Determine the Arc-Fault Currents*

The arc-fault current is typically slightly less than bolted-fault current due to arc impedance.

### *4) Determine the Protective Relay/Device Operate Times*

One subtle aspect of calculating arc-flash incident energy is that a lower fault current (e.g., further downstream fault) may not decrease the energy if the protection used is an inverse time-current characteristic (fuse or 51 device). The lower fault current could (and often does) result in increased energy because of the increased trip times. So, the incident energy analysis is typically performed at 100% and 85% of maximum arcing current.

Also, if no intentional time delay is used, the operate time for "instantaneous" relaying is still taken into account. Thus we must always consider breaker operate times.

### *5) Document System Voltages, Equipment Class, and Working Distances*

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

### *6) Determine the Incident Energy*

Use one of the methods discussed earlier to calculate incident energy. IEEE 1584-2002 includes the equations and reference spreadsheets that can be used for this task.

### *7) Determine the Flash-Protection Boundary*

Based on the incident energy, a flash boundary can be calculated.

## *C. How Arc-Flash Energy Affects Personal Protective Equipment (PPE)*

NFPA 70E defines five levels of arc hazard. Table I shows the hazard/risk category levels and the calculated incident energy at the working distance. The table lists typical clothing and layer counts for the torso. In short, this is the level of clothing that should be worn to limit incident energy damage to a second-degree burn. Put another way, this guide is designed to protect the worker from heat to prevent a second-degree burn.

TABLE I
PERSONAL PROTECTIVE EQUIPMENT (PPE) TO LIMIT BURNS

| **Hazard/Risk Category** | **Clothing Description (Typical clothing layers in parentheses)** | **Requiring Minimum Arc Rating of PPE cal/cm$^2$** |
|---|---|---|
| 0 | | N/A |
| 1 | Fire retardant (FR) shirt and pants or FR coverall (1) | 4 |
| 2 | Cotton undergarments plus FR shirt and pants (1 or 2) | 8 |
| 3 | Cotton undergarments plus FR shirt and pants, plus FR coverall, or plus two FR coveralls (2 or 3) | 25 |
| 4 | Cotton undergarments plus FR shirt and pants plus multilayer flash suit (3 or more) | 40 |

[3]

# IV. EXAMPLE SYSTEM TO ANALYZE ARC FLASH

## *A. Steps to Calculate Arc Flash on an Example System*

The system shown in Fig. 1 is used to help analyze these issues.

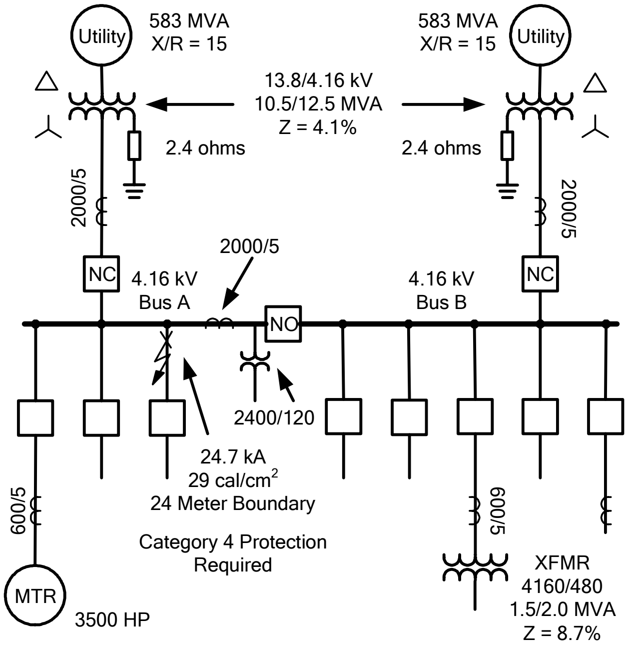

Fig. 1. Example System

### *1) Determine the Bolted Fault Currents*

The first step in calculating an arc-flash number is to calculate the maximum available three-phase fault current. The utility may give a number based on fault MVA and an X/R ratio. As shown in (2), the utility has given the available source fault MVA as 583 and the X/R ratio as 15.

To convert this to a percent impedance based on the transformer MVA and kV, we use (1):

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

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 conversion gives the following result:

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

The example shows switchgear and has no cable impedance to add to the total impedance to the bus. We must add the transformer impedance, which is listed as 4.1%. If we assume that the transformer impedance is all inductive, then the total impedance to the bus is:

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

To calculate the fault current, we use (3):

$$I_f=\frac{MVA_t\bullet 57735}{kV_t\bullet\%Z_{total}} \tag{3}$$

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 in percent

The fault current for this example is as follows:

$$I_f=\frac{10.5\bullet 57735}{4.16\bullet 5.9}=24.7\,kA$$

*2) Determine the Arc-Fault Currents*

After calculating the maximum three-phase fault current, we calculate arcing current. The arc-fault current is typically lower than the bolted-fault current due to the arc impedance. In this example, the arcing fault current is 23.6 kA.

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

$$LogI_a=0.00402+0.983\bullet LogI_{bf} \tag{4}$$

$$I_a=10^{LogI_a}$$

Where:

$I_{bf}$ = Maximum bus fault current in kA
$I_a$ = Maximum arcing current in kA

The arcing current for this example is as follows:

$$LogI_a=0.00402+0.983\bullet Log(24.7)=1.373$$

$$I_a=10^{1.373}=23.6\ kA$$

We also want 85% of this value to see how the lower fault current impacts trip times (which may in fact increase energy). The 85% value is 20 kA.

*3) Determine the Protective Relay/Device Operate Times*

The relay coordination for this system is shown in Fig. 2. 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:

$$0.69 + 5/60 = 0.77\ s$$

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

$$0.88 + 5/60 = 0.96\ s$$

*4) 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 cable. Also included are spreadsheets, which perform calculations based on selected parameters.

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

*5) 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 mm and an arc duration of 0.2 s. The equation for this example is:

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

$$E_n=10^{LogE_n}$$

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

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

$$LogE_n=-0.555+1.081\bullet Log(23.6)+0.0011\bullet 102=1.0413$$

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

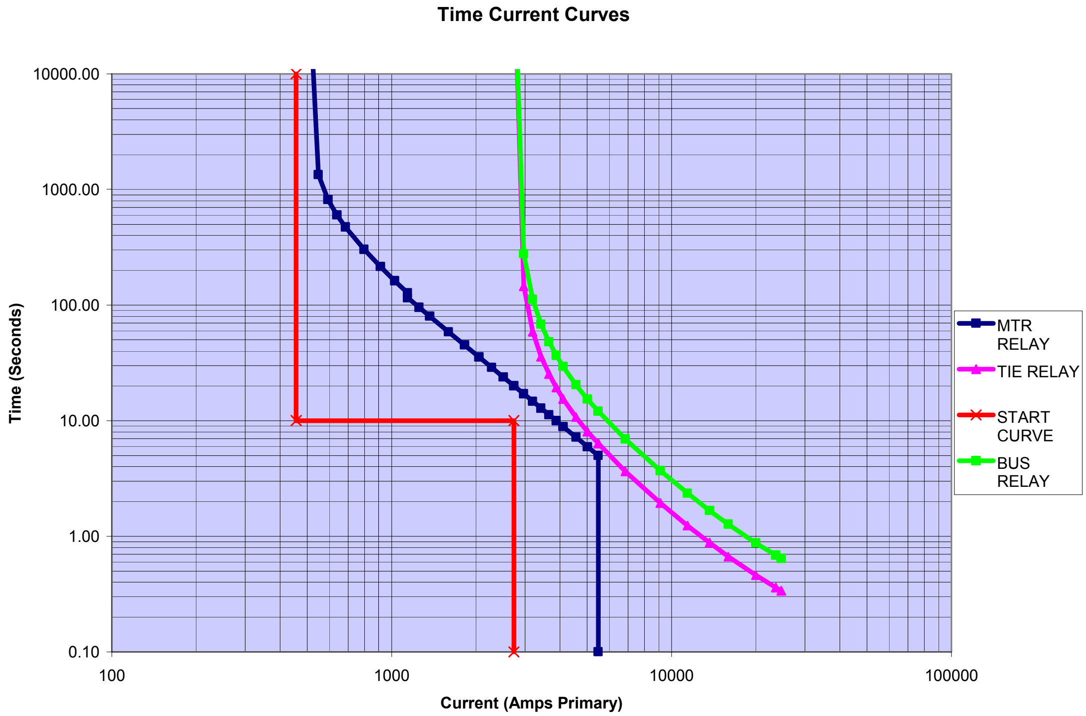

Fig. 2. Example System Relay Coordination

The normalized incident energy for the 20 kA arc current in this example is as follows:

$$\text{Log}E_n = -0.555 + 1.081 \bullet \text{Log}(20) + 0.0011 \bullet 102 = 0.9636$$

$$E_n = 10^{0.9636} = 9.2 \ \text{J/cm}^2$$

Next, we vary the parameters to calculate incident energy for our specific example system. For 5 kV switchgear, we use a working distance of 910 mm and then we calculate incident energy for different operate times (0.77 s and 0.96 s):

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

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, the incident energy is:

$$E = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 120 \ \text{J/cm}^2 \ @ \ 23.6 \ \text{kA}$$

$$E = 4.184 \bullet 1.0 \bullet 9.2 \bullet \left(\frac{0.96}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 125 \ \text{J/cm}^2 \ @ \ 20.0 \ \text{kA}$$

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

Next, we convert the arc energy into cal/cm$^2$ using the conversion:

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

Thus the arc-flash energy at the bus is:

$$E = 120 \bullet \frac{1.2}{5} = 29 \ \text{cal/cm}^2 \ @ \ 23.6 \ \text{kA}$$

### *6) Determine the Flash-Protection Boundary*

The flash boundary is calculated from (7):

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

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:

$$D_b = \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.77}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} = 23867 \ \text{mm} = 24 \ \text{meters}$$

This indicates that within 24 meters of the arc flash, any unprotected person could sustain second-degree burns from the fault incident energy. From this we also see that a worker must use Level 4 PPE to perform live work on this switchgear.

## V. WHAT CAN BE DONE TO REDUCE ARC FLASH

Nearly all distribution, utility or industrial, uses fuse and/or time-overcurrent protection. Using common practices and coordination techniques, trip times are higher closest to the source transformer or switchgear. In short, the hazard is the greatest where personnel are most likely to be in or near the switchgear.

As discussed earlier, the energy produced by an arc-flash event is proportional to Energy = V•I•t. By performing arc-flash analysis on each system, it is often possible to reduce time-coordination intervals to achieve lower trip times and thus, lower incident energy.

### *A. Nonrelaying Approaches*

On low-voltage systems (<600 V), some users apply current-limiting fuses. Current-limiting fuses are designed to operate rapidly so that the current never reaches its bolted short-circuit level. As a result, it is more difficult to calculate incident energy, but significant testing has been performed to obtain arc-flash data [1] [5].

Other ways to reduce arc flash include applying faster breakers or designing "arc-resistant" switchgear such that arc blast goes upward or away from personnel should a fault occur. In addition, research and development is being performed to use light-sensing technology to detect arcs.

### *B. Relaying Approaches*

#### *1) Reduce Coordination Intervals of Existing Time-Overcurrent Relays*

Fig. 3 shows a typical coordination of feeder relays. Most engineers and many software programs use a 0.3-s minimum coordination interval (CI) between tripping characteristics of series-overcurrent devices. If coordination intervals are longer than 0.3 s, tightening up these settings is a direct and simple way of reducing tripping times. We do not recommend a margin less than 0.3 s, unless very specific testing and analysis is performed.

Note that setting an instantaneous overcurrent at B is desired (80% reach or 125% of maximum fault current at A), but coordination is not possible if there is no difference in the fault current at A and B.

Fig. 4 shows fault current and relay-operate times based on fault location. We can see that fault current is highest at the source. If the distance between coordinating devices is low, the effect is that the "delta Ts" continue to add. Thus, we end up with the highest fault currents and longest trip times closest to the source, where personnel are most likely to be working.

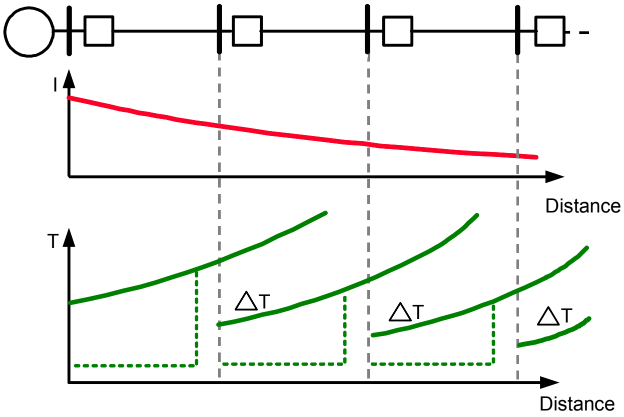

Fig. 4. Fault Current and Operate Time as a Function of Electrical Distance From Source

Thus, we can attempt to improve coordination, which has the advantages of using existing relays and no electrical design changes. The disadvantages are the cost of the coordination study and only a small decrease in trip time may be achieved.

#### *2) 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 2000 ohms.

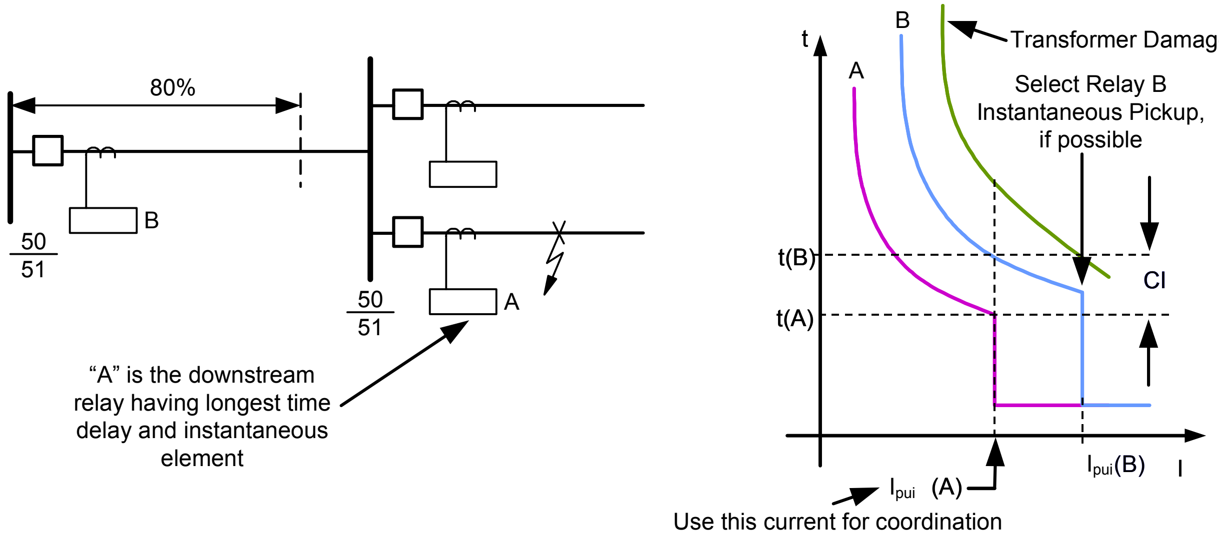

Fig. 3. Time Current Coordination

The relay is set such 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 very costly because of the need for the dedicated CTs and the additional wiring and testing required to validate the scheme.

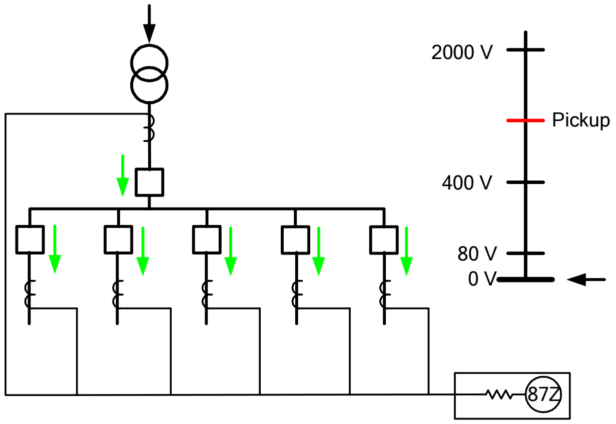

Fig. 5. High-Impedance Bus Differential Scheme

### *3) Low-Impedance Bus Differential*

A low-impedance bus differential scheme is fast and secure and does not require dedicated CTs (i.e., additional relays, meters, transducers, etc., can be connected to the same set of CTs).

Relay settings are typically slightly more complex than a high-impedance differential scheme because each input has an independent CT ratio and connection. Like the high-impedance scheme, this scheme requires some additional commissioning testing.

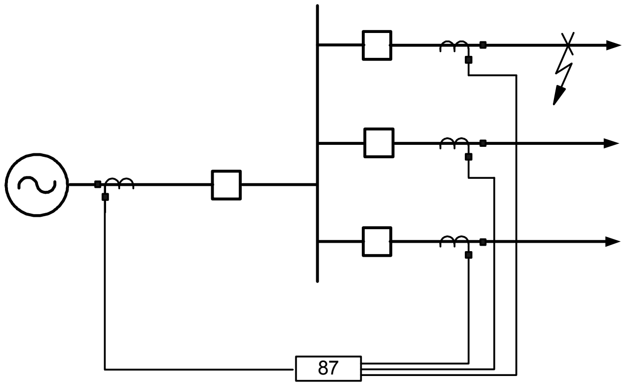

Fig. 6. Low-Impedance Bus Differential

### *4) Fast Bus Trip Schemes Using Overcurrent Relays and Communications*

Scheme operation:

- Feeder relays send "block" signal to low-side main breaker for feeder faults.
- Main breaker set to trip with short (2- to 3-cycle) delay to allow time to receive block signal.
- Maintains sensitivity and security even when CTs approach saturation.
- Can be applied with nondirectional or directional overcurrent elements.

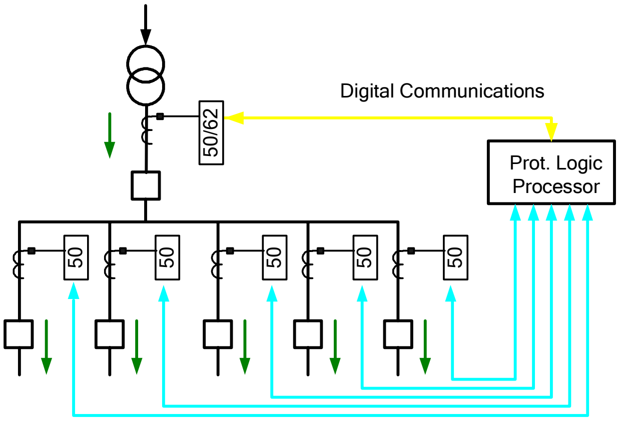

Fig. 7. Fast Bus Trip Scheme

One consideration is that if a fault occurs in one of the feeder breakers, the feeder relay on the faulted line would block the fast-tripping element. Thus the scheme would perceive this as a feeder fault and block the fast-trip scheme. If we take no other measures, time-delayed tripping would occur.

### *5) Enable Instantaneous Element During Maintenance*

Perhaps the best and simplest solution is to apply a control solution, whereby, operators enable an instantaneous element whenever live work is being performed. It would require adding a control switch or pushbutton, cabling, and associated logic. This could be added to new or old installations for a relatively low cost.

Like any lock-out tag-out procedure, this could be added to operations and maintenance plans for switchgear or electrical equipment. Just as workers are expected to wear hard-hats and safety goggles, they would be required to enable fast tripping on the bus relays.

During maintenance periods, there is a risk of over-tripping, but statistically, it is a small risk. For example, if we assume that 80 hours per year of live work is performed, the probability of overtripping during maintenance is 80/(24•365) = 0.91% per year. This seems to be a small risk when considering the safety of personnel.

On many systems, especially at industrial facilities, high-fault currents, low-ratio CTs, and high-system X/R ratios conspire to 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 [4].

TABLE II
SUMMARY OF SCHEME ADVANTAGES AND DISADVANTAGES TO REDUCE ARC-FLASH HAZARD

| Scheme Number | Protection Scheme Description | Advantages | Disadvantages |
|---|---|---|---|
| 1 | Reduce coordination intervals of existing time-overcurrent relays | Existing hardware, existing technology. | Cost of coordination study, trip times are still likely to be high (0.5–2 s, depending on coordination issues), only marginal improvement can be achieved. |
| 2 | High-impedance bus differential | Fast (less than 1.5 cycles) and secure for any fault type, easy to set. | Requires additional relay, dedicated CTs, $$$$$ to purchase CTs, wiring installation. Testing more complex. |
| 3 | Low-impedance bus differential | Fast (less than 1.5 cycles) and secure for any fault type. | Requires additional relays, $$$$ to wire CTs. Settings, testing more complex. |
| 4 | Fast bus trip | Use of existing main and feeder overcurrent relays. Faster than TOC (typically 3–5 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. |
| 5 | 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 over trip. Introduces change in maintenance procedures. |

### C. *Arc-Flash Recalculation*

When Schemes 4 and 5 from Table II are implemented, significant reduction in arc-flash energy is observed.

#### *1) Incident Energy Recalculation for Fast Bus Trip (Scheme 4)*

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

$$5/60 + 5/60 = 0.17 \text{ s}$$

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

For this system, the new incident energy is:

$$E = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.17}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 26.5 \text{ J/cm}^2 \text{ @ } 23.6 \text{ kA}$$

It is desired to convert the arc energy into cal/cm$^2$ using the conversion:

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

Thus the new arc-flash energy at the bus is:

$$E = 26.5 \bullet \frac{1.2}{5} = 6.4 \text{ cal/cm}^2 \text{ @ } 23.6 \text{ kA}$$

For this system, the new flash boundary is:

$$D_b = \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.17}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} = 5053 \text{ mm} = 5.1 \text{ meters}$$

#### *2) Incident Energy Recalculation With Instantaneous Trip Element (Scheme 5) Enabled*

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

$$2/60 + 5/60 = 0.12 \text{ s}$$

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

For this system, the new incident energy is:

$$E = 4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.12}{0.2}\right) \bullet \left(\frac{610^{0.973}}{910^{0.973}}\right) = 18.7 \text{ J/cm}^2 \text{ @ } 23.6 \text{ kA}$$

It is desired to convert the arc energy into cal/cm$^2$ using the conversion:

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

Thus the new arc-flash energy at the bus is:

$$E = 18.7 \bullet \frac{1.2}{5} = 4.5 \text{ cal/cm}^2 \text{ @ } 23.6 \text{ kA}$$

For this system, the new flash boundary is:

$$D_b = \left[4.184 \bullet 1.0 \bullet 11 \bullet \left(\frac{0.12}{0.2}\right) \bullet \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} = 3532 \text{ mm} = 3.5 \text{ meters}$$

#### *3) Benefits of Reducing Trip Times on Example System*

We can see from the data that applying faster tripping has reduced the arc-flash incident energy significantly. For either a fast bus trip scheme, adding instantaneous elements, or combining schemes, we now require Level 2 PPE (compared to Level 4), and flash boundary distances are about 5 meters or less (compared to 24).

## VI. CONCLUSIONS

An arc-flash event occurs whenever a fault occurs. The attention given to the safety of personnel continues to increase. Conducting arc-flash studies allows engineers to determine personal protective equipment required and flash boundaries.

Implementing protection schemes to reduce trip times increases safety and could reduce injuries or even save lives.

Differential schemes can be, and often are, applied on distribution buses. However, they are much more expensive to install and test.

Protective systems already require overcurrent protection on feeder and bus breakers. The incremental cost of adding communications equipment and relay logic is small and benefits are great. On new installations and protection upgrades, always apply fast-tripping solutions.

On new and existing systems, consider adding controls to enable instantaneous tripping when personnel are in close proximity to energized equipment. The cost of implementation is small compared to the benefits of reduced trip times and reduced arc-flash hazards.

If a maintenance procedure can require a worker to wear safety goggles and a hard hat, or to place a warning tag on energized equipment, then it seems logical that a pushbutton or control switch to enable instantaneous tripping can be added as well.

Finally, whenever possible, use secure wireless communications to operate devices from a safe distance.

## VII. REFERENCES

[1] IEEE Standard 1584-2002, IEEE Guide for Performing Arc-Flash Hazard Calculations.

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## VIII. BIOGRAPHIES

**Jim Buff** received a B.S. degree in Electrical Engineering from the University of Missouri-Rolla in 1986. He currently holds a registered PE license in the state of Missouri. Before joining Schweitzer Engineering Laboratories, Inc., in 1999, Jim worked in the utility industry for 13 years setting and testing power plant and substation protective relays. Jim has experience with generator and motor protective relaying. Jim is a field application engineer located in Valparaiso, Indiana.

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