©PHOTODISC

REDUCING ARC-FLASH HAZARDS

Applying existing technologies

BY JIM BUFF & KARL ZIMMERMAN

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) 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 $(V \times I \times t)$. 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 harm's way. In most cases, clearing times are reduced via more complete use of microprocessor relays features and other already available technologies. Similarly, digital relay communications and secure wireless communications devices allow engineers and technicians to converse with relays from a safe distance.

In this article, 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.

Definitions

What is an arc flash? How do we measure the energy so as to quantify improvement? Some important definitions of

Digital Object Identifier 10.1109/MIAS.2008.918501

1077-2618/08/$25.00©2008 IEEE

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 the National Fire Protection Association (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]

USE SECURE WIRELESS COMMUNICATIONS TO OPERATE DEVICES FROM A SAFE DISTANCE.

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 1584-2002 was published, and an empirically derived model based on statistical analysis was developed as part of this effort [1]. IEEE 1584-2002 includes several spreadsheets to assist the engineer in arc-flash studies. We will use this method for our analysis in this article.

Incident energy is typically quantified in cal/cm^2 or J/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.

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

Steps in Calculating Arc-Flash Energy and Its Effects

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.

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 the "Example System to Analyze Arc Flash" section.

Determine the Arc-Fault Currents

The arc-fault current is typically slightly less than bolted-fault current because of arc impedance.

Determine the Protective Relay or 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.

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.

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.

Determine the Flash-Protection Boundary

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

How Arc-Flash Energy Affects PPE

NFPA 70E defines five levels of arc hazard. Table 1 shows the hazard or 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. In other words, this guide is designed to protect the worker from heat to prevent a second-degree burn.

Example System to Analyze Arc Flash

Steps to Calculate Arc Flash on an Example System

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

SAFETY FOR PERSONNEL HAS ALWAYS BEEN A CONCERN.

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 million volt-ampere 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.

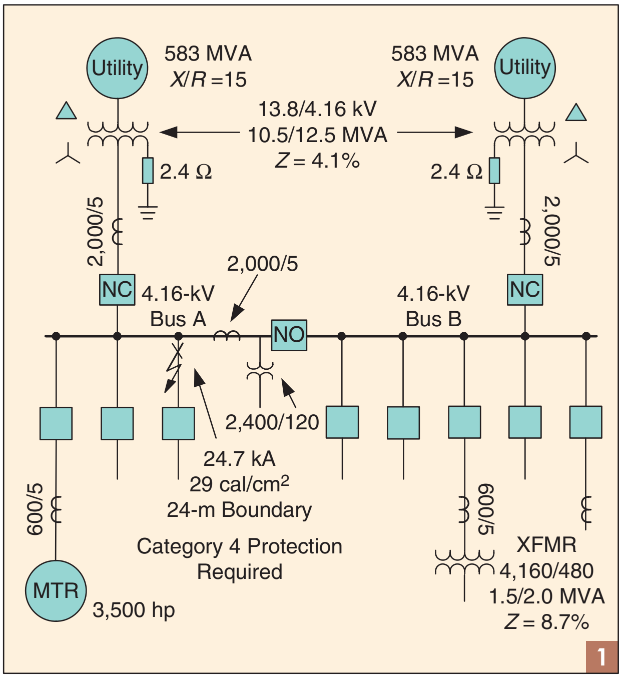
To convert this to a percent impedance based on the transformer MVA and kV, we use

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

where $\%Z$ is 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; and X/R, utility X/R ratio.

The conversion gives the following result:

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



Example system.

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

To calculate the fault current, we use

$$I_f = \frac{MVA_t \cdot 57,735}{kV_t \cdot \%Z_{total}} \quad (3)$$

where I_f is maximum bus fault current; kV_t, transformer voltage base; MVA_t, transformer MVA base; and $\%Z$, total impedance on transformer base to bus in percent.

The fault current for this example is as follows:

$$I_f = \frac{10.5 \cdot 57,735}{4.16 \cdot 5.9} = 24.7 \text{ kA}.$$

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 because of the arc impedance. In this example, the arcing fault current is 23.6 kA.

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

$$\begin{aligned}\mathrm{Log}\, I_a &= 0.00402 + 0.983 \cdot \mathrm{Log} I_{bf}\\ I_a &= 10^{\mathrm{Log} I_a}, \quad (4)\end{aligned}$$

TABLE 1. PPE TO LIMIT BURNS [3].

Hazard or 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 (one)	4
2	Cotton undergarments and FR shirt and pants (one or two)	8
3	Cotton undergarments plus FR shirt and pants, and FR coverall, or plus two FR coveralls (two or three)	25
4	Cotton undergarments and FR shirt and pants and multilayer flash suit (three or more)	40

where I_{bf} is maximum bus fault current in kA and I_a, maximum arcing current in kA.

The arcing current for this example is as follows:

$$\begin{aligned}\text{Log}\, I_a &= 0.00402 + 0.983 \cdot \text{Log}(24.7)\\ &= 1.373\\ I_a &= 10^{1.373}\\ &= 23.6\ \text{kA}.\end{aligned}$$

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.

ON NEW INSTALLATIONS AND PROTECTION UPGRADES, ALWAYS APPLY FAST-TRIPPING SOLUTIONS.

The normalized incident energy for the 20-kA arc current in this example is

$$\begin{aligned}\text{Log}\, E_n &= -0.555 + 1.081 \cdot \text{Log}(20)\\ &\quad + 0.0011 \cdot 102\\ &= 0.9636\\ E_n &= 10^{0.9636}\\ &= 9.2\ \text{J/cm}^2.\end{aligned}$$

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 calculate incident energy for different operate times (0.77 and 0.96 s):

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

where E is 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; and x, distance exponent = 0.973 for 5.0-kV switchgear.

For this system, the incident energy is as follows:

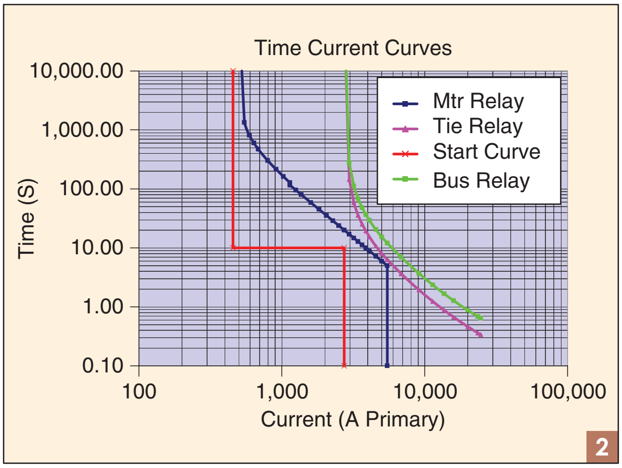
$$\begin{aligned}E &= 4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.77}{0.2}\right) \cdot \left(\frac{610^{0.973}}{910^{0.973}}\right)\\ &= 120\ \text{J/cm}^2\ @\ 23.6\ \text{kA}\\ E &= 4.184 \cdot 1.0 \cdot 9.2 \cdot \left(\frac{0.96}{0.2}\right) \cdot \left(\frac{610^{0.973}}{910^{0.973}}\right)\\ &= 125\ \text{J/cm}^2\ @\ 20.0\ \text{kA}.\end{aligned}$$

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

Next, we convert the arc energy into cal/cm^2 using the following conversion: 5.0 J/cm^2 = 1.2 cal/cm^2.

Determine the Protective Relay or Device Operate Times

The relay coordination for this system is shown in Figure 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.



Example system relay coordination.

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. Spreadsheets are also included, 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.

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 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

$$\begin{aligned}\text{Log}\, E_n &= K_1 + K_2 + 1.081 \cdot \text{Log} I_a + 0.0011 \cdot G\\ E_n &= 10^{\text{Log}E_n},\end{aligned} \qquad (5)$$

where E_n is 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

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

Thus, the arc-flash energy at the bus is

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

Determine the Flash-Protection Boundary

The flash boundary is calculated from

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

where E_b is 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

$$\begin{aligned} D_b &= \left[4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.77}{0.2}\right) \cdot \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} \\ &= 23{,}867 \text{ mm} \\ &= 24 \text{ m}. \end{aligned}$$

This indicates that within 24 m 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.

What Can Be Done to Reduce Arc Flash

Nearly all distribution systems, utility or industrial, use fuse 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 = $V \times I \times t$. 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.

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], [4].

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.

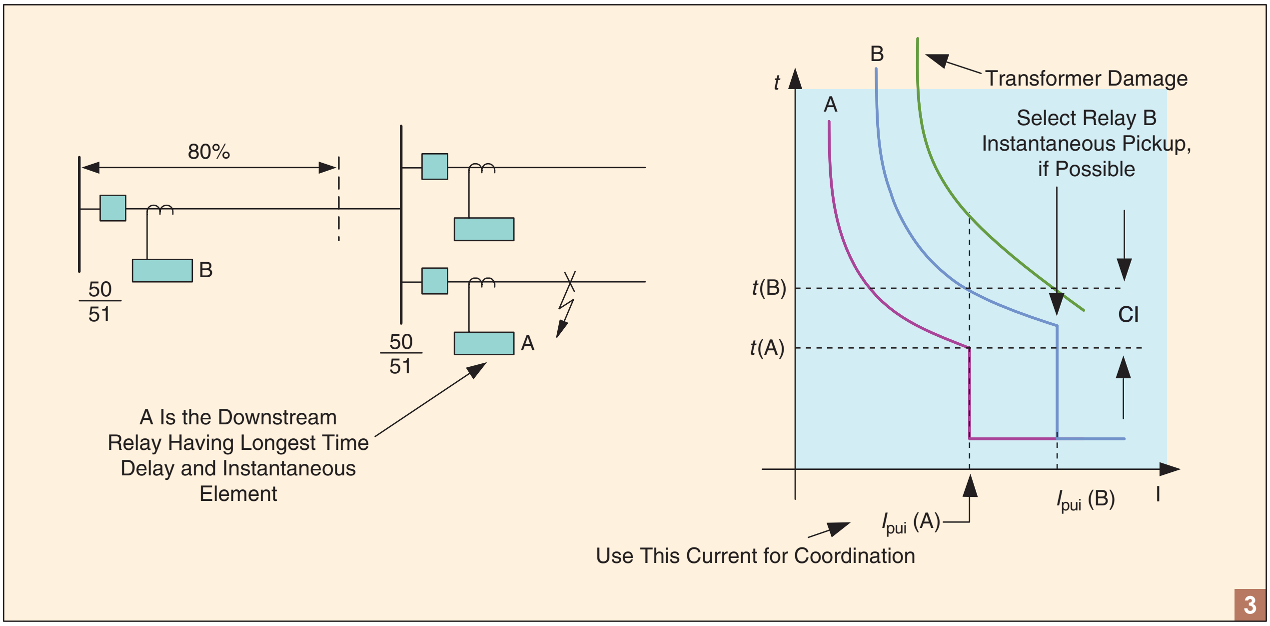
Relaying Approaches

Reduce Coordination Intervals of Existing Time-Overcurrent Relays

Figure 3 shows a typical coordination of feeder relays. Most engineers and many software programs use a 0.3-s minimum coordination interval 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 of 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.

Figure 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



Time current coordination.

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.

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

High-Impedance Bus Differential Protection

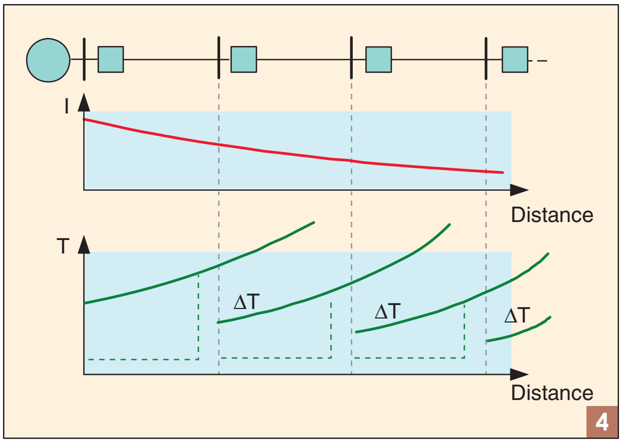
Dedicated current transformers (CTs) are required for this scheme because all of the CT inputs are paralleled and then connected to a high-impedance input in the relay. The relay measures the voltage across its internal impedance, which is typically about 2,000 Ω.

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.

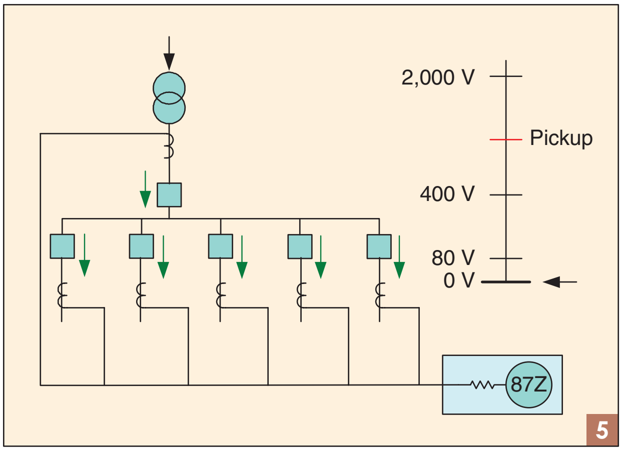
This scheme is fast and secure but very costly because of the need for the dedicated CTs and the additional wiring and testing required to validate the scheme (Figure 5).

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).



Fault current and operate time as a function of electrical distance from source.



High-impedance bus differential scheme.

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 (Figure 6).

Fast Bus Trip Schemes Using Overcurrent Relays and Communications

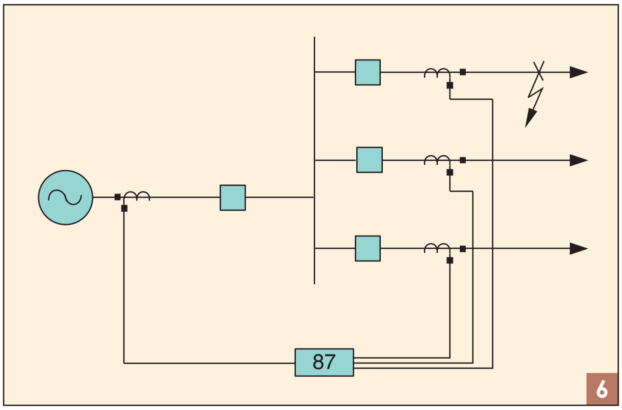
Scheme operation includes the following steps:

- feeder relays send block signal to low-side main breaker for feeder faults
- main breaker set to trip with short (two to three cycles) 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 (Figure 7).

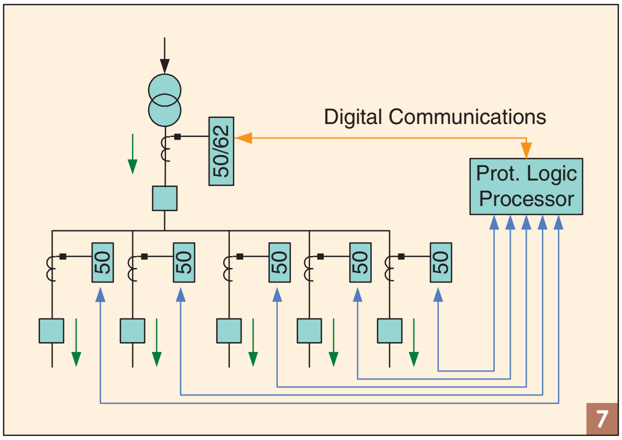
One consideration is that if a fault occurs in one of the feeder breakers, the feeder relay on the faulted line would block the fast-tripping element. Thus, the scheme would perceive this as a feeder fault and block the fast-trip scheme. If we take no other measures, time-delayed tripping would occur.

Enable Instantaneous Element During Maintenance

Perhaps the best and simplest solution is to apply a control solution where the operators enable an instantaneous



Low-impedance bus differential.



Fast bus trip scheme.

element whenever live work is being performed. It would require adding a control switch or push button, 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 overtripping, but statistically, it is a small risk. For example, if we assume that 80 h per year of live work is performed, the probability of overtripping during maintenance is $80/(24 \times 365) = 0.91\%$ 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 [5].

IMPLEMENTING PROTECTION SCHEMES TO REDUCE TRIP TIMES INCREASES SAFETY AND COULD REDUCE INJURIES OR EVEN SAVE LIVES.

Arc-Flash Recalculation

When schemes 4 and 5 from Table 2 are implemented, significant reduction in arc-flash energy is observed.

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

For this system, the new incident energy is

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

Arc energy can be converted into cal/cm^2 using the following conversion: $5.0 \ \text{J/cm}^2 = 1.2 \ \text{cal/cm}^2$.

TABLE 2. 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, cost to purchase and wire CTs; testing more complex
3	Low-impedance bus differential	Fast (less than 1.5 cycles) and secure for any fault type	Requires additional relays, cost to wire CTs; settings and testing more complex
4	Fast bus trip	Use of existing main and feeder overcurrent relays; faster than time-overcurrent relays (typically three to five 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 and wiring	Lose selectivity during maintenance periods, could over trip; introduces change in maintenance procedures

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

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

For this system, the new flash boundary is calculated as

$$D_b = \left[4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.17}{0.2}\right) \times \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} = 5,053\ \text{mm} = 5.1\ \text{m}.$$

CONSIDER ADDING CONTROLS TO ENABLE INSTANTANEOUS TRIPPING WHEN PERSONNEL ARE IN CLOSE PROXIMITY TO ENERGIZED EQUIPMENT.

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

For the 23.6-kA current, the feeder relay trip time is as follows: 2/60 + 5/60 = 0.12 s. The breaker time of five cycles was added to obtain the total trip time.

For this system, the new incident energy is calculated as

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

It is desired to convert the arc energy into cal/cm^2 using the following conversion: $5.0\ \text{J/cm}^2 = 1.2\ \text{cal/cm}^2$.

Thus, the new arc-flash energy at the bus is as follows:

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

For this system, the new flash boundary is

$$D_b = \left[4.184 \cdot 1.0 \cdot 11 \cdot \left(\frac{0.12}{0.2}\right) \cdot \left(\frac{610^{0.973}}{5}\right)\right]^{\frac{1}{0.973}} = 3,532\ \text{mm} = 3.5\ \text{m}.$$

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 a fast bus trip scheme, adding instantaneous elements, or combining schemes, we now require level 2 PPE (compared with level 4), and flash boundary distances are about 5 m or less (compared with 24).

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 PPE 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 with 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 push button or control switch to enable instantaneous tripping can also be added.

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

References

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

[2] *Standard for Electrical Safety in the Workplace*, NFPA Standard 70E, 2004.

[3] *Standard for Electrical Safety in the Workplace*, NFPA Standard 70E, 2004, Table 130.7(C)(11).

[4] W. A. Brown and R. Shapiro, "A comparison of arc-flash incident energy reduction techniques using low-voltage power circuit breakers," 1-4244-0336-7/06, Tech. Rep. 2006.

[5] G. Benmouyal and S. E. Zocholl, "The impact of high fault current and CT rating limits on overcurrent protection," in *29th Annu. Western Protective Relay Conf.*, Spokane, WA, 2002, p. 11.

Jim Buff (jim_buff@selinc.com) and Karl Zimmerman (karl_zimmerman@selinc.com) are with Schweitzer Engineering Laboratories, Inc. They are Members of the IEEE.

This article was presented at the 2007 Pulp & Paper Industry Conference as "Application of Existing Technologies to Reduce Arc Flash Hazards."