Methods in reducing hazardous areas in large industrial facilities

INDUSTRIAL AND COMMERCIAL FACILITIES HAVE RECOGNIZED THAT arc-flash prevention is a part of a complete safety program. Quantification of the arc-flash hazard level and labeling procedures are a major portion of this effort.

When calculating incident energy, the engineer must deal with two main issues in addition to the burn hazard: blast pressure effect on the human body and worker comfort or mobility with multilayer flash suits and associated flame-resistant (FR) protective equipment. For work tasks where calculated incident energy levels are above 40 cal/cm², it is desirable to reduce the exposure to the worker to reduce the burn injury. This can be achieved with either a change to the work method or by engineering design.

This article will discuss various methods that have been used to reduce the incident energy levels from above 40 cal/cm² to levels below 40 cal/cm². Specific solutions implemented at a large chemical manufacturing facility are presented. The solutions include equipment upgrades, overcurrent protection modifications, changes to work methods, and worker training which increase the effectiveness of an already robust safety program.
In addition, design changes that could be considered to keep incident energy below 40 cal/cm² for expansions or additions to the power system are discussed.

**Background**

NFPA 70E-2004 [1] defines flash hazard as “a dangerous condition associated with the release of energy caused by an electric arc.” Flash-hazard analysis is defined as a study investigating a worker’s potential exposure to arc-flash energy, conducted for the purpose of injury prevention, and the determination of safe work practices along with appropriate levels of personal protective equipment (PPE).

**Problem Description**

The key word in these NFPA definitions is energy. Industry initially focused upon the heat portion of the total energy release of the arc-flash event. Engineers developed equations for calculating incident energy, which is defined as:

The amount of energy impressed on a surface, a certain distance from the source, generated during an electric arc event. One of the units used to measure incident energy is calories per centimeter squared (cal/cm²).

The incident energy equations described in NFPA 70E-2004 and IEEE 1584-2002 [2] calculate heat energy. Flash-hazard analysis determines the heat energy released from an arc-flash event under worst-case conditions. NFPA 70E requires that a flash hazard analysis be performed when there is potential for a worker to be exposed to live circuits operating at greater than 50 V.

**Examples of Dangerous Areas**

The incident energy from an arc-flash event impressed upon a worker is mostly dependent upon

- available fault current at the arcing terminals
- protective device clearing time for the arcing fault
- the distance of the worker to the arcing terminals.

Incident energy is affected to a lesser extent by

- operating voltage
- gap length
- type of system grounding.

Figure 1 is a partial single-line diagram of a chemical plant. The 480-V main bus transformer secondary circuit is consistently at Hazard Risk Category 4 (from 25.1 to 40 cal/cm²) or Dangerous (>40 cal/cm²). The transformer primary fuse would clear the arcing fault on the line side of the main secondary circuit breaker. Clearing times are usually greater than 1 s, and fault current at this location is the greatest magnitude in the circuit.

Overcurrent protection for critical loads, such as fire protection circuits or pump circuits, would be selected to achieve continuity of service with less emphasis on equipment protection. Longer clearing times would allow higher magnitudes of incident energy.

---

*Single line diagram.*
As one approaches the utility-connection point, device clearing times become greater so that overcurrent coordination can be achieved with downstream devices. This is the case for an industrial plant or mill whose electrical circuit is effectively coordinated and equipment adequately protected. The combination of higher magnitudes of fault current and longer clearing times often cause incident energy to be classified Hazard Risk Category 4 (from 25.1 to 40 cal/cm²) or Dangerous (>40 cal/cm²).

The Arc-Flash Hazard
Industry is now addressing the impact to the worker of other energies transformed from electrical energy through the arc-flash event (see Figure 2). These energies include electrical, thermal, acoustic, radiation, chemical, and mechanical that may cause
- excessive noise
- intense heat
- flying debris or shrapnel, projected molten copper
- expanding toxic vapor cloud
- explosions of flammable gases, vapors, or combustible dusts
- pressure waves.

Heat and Burns
Clothing manufacturers have engineered PPE systems capable of limiting a burn injury to the onset of a second-degree burn when the wearer is subjected to an arc-flash event with incident energy as high as 100 cal/cm². Thus, “barrier protection” emerged as a key strategy to mitigate the burn hazard associated with an arc-flash event.

Pressure Wave
The arc-blast pressure is related to available fault current and distance from the arc and not to the arc clearing time. This force is significant and can cause falls and injuries to the worker that are more serious than burn injuries. Research which studies the trauma from pressure waves is supported in part by Grant R01 OH04136-01 the U.S. Centers for Disease Control and Prevention National Institute of Occupational Safety and Health. The trauma from pressure waves may not be readily diagnosed in triage because of the absence of external wounds. Resulting brain injury, tissue damage to lungs, ears, bowel, and concussions may not be accompanied by electrical contact evidence or burns.

Barrier protection in the form of arc-flash suits has proven effective for reducing the burn injury. Barrier protection when applied to switchgear can reduce the risk and impact of electrical burns and pressure waves. Enclosures containing primary elements are compartmentalized and grounded for maximum isolation. All live parts (where possible) are fully insulated reducing the possibility of an arcing fault to occur. All primary elements such as breakers, PTs, CPTs, etc. have disconnect means with isolating shutters.

Workers exposed to an arc-flash event may suffer from injuries including burns, cardiac arrest, amputation, memory loss, hearing loss, fracture, cataract, and blast trauma. For example, NFPA 70E-2004 requires hearing protection as part of PPE where incident energy exceeds 4 cal/cm².

The Flash Suit Issue
NFPA 70E-2004 defines a flash suit as a complete FR clothing and equipment system that covers the entire body, except for the hands and feet. This includes pants, jacket, and beekeeper-type hood fitted with a face shield.

NFPA 70E-2004 Table 130.7(C)(10) requires a flash suit hood for Hazard/Risk Categories 3 and 4. This requirement occurs when the calculated incident energy for the work task is greater than 8 cal/cm².

NFPA 70E-2004 Table 130.7(C)(10) requires an arc-rated face shield or flash suit hood for Hazard/Risk Category 2. The face shield must have a minimum arc rating of 8 cal/cm², with wrap-around guarding to protect not only the face, but also the forehead, ears, and neck. This requirement occurs when the calculated incident energy for the work task is greater than 4 and less than 8 cal/cm².

Face shields are normally available with arc ratings of 10–17 cal/cm². A flash suit hood is usually required above 10 cal/cm².

Heat Stress
Flash suit hoods cover the entire head and make breathing more difficult than normal (without a hood). Hoods with ventilation are available and improve worker comfort when compared to a nonventilated hood because of
- improved ease of breathing
- cooling effect of fresh air stream
- reduced claustrophobic feeling
- reduction in fogging of visor and worker's safety eyewear.

Generally, at incident energy levels above 8 cal/cm², a double layer of fabric is used for both the flash suit hood and FR clothing. When wearing two layers, there is an increased risk of heat stress.

Heat stress can be minimized by reducing the time PPE has to be worn. Work activity should be planned such that potential arc-flash exposure time duration is identified and minimized.
Pressure Wave
Most flash suits and flash suit hoods are designed for the main purpose of skin burn protection and, therefore, provide limited protection from the blast pressure wave hazards, which include:

- excessive noise
- flying debris or shrapnel
- projected molten copper.

Reduced Visibility and Dexterity
The typical green tint in the flash suit visor is capable of causing distortion of colors. The colors most affected are white, yellow, red, and blue. These four colors are commonly used to provide phase marking on electrical conductors.

Multiple layers of fabric in flash suits and flash suit hoods also reduce worker dexterity, reduce the range of motion, and decrease the ease of movement. All of these could potentially cause problems while a work task is being performed.

Energy Reduction Solutions
An arc-flash hazard evaluation for an industrial power system will generally uncover locations in the power system where the incident energy levels are high. This is considered to be levels above 40 cal/cm².

Design Changes
Incident energy is directly proportional to fault clearing time. It is desirable to clear the arcing fault as fast as possible while maintaining overcurrent coordination. Time reduction can be achieved by the following design changes. The first two changes listed are the easiest and least costly methods.

Reduce Existing Pickup Settings
In some cases, the arcing fault current magnitude may not be large enough to operate the overcurrent protective device in its short delay or instantaneous trip time. If possible, the short delay or instantaneous pickup should be reduced to allow for more sensitive sensing of the calculated arcing current that flows through the protective device. Changing the sensing element from long delay to short delay or instantaneous can make a significant difference in incident energy levels. Care must be taken with the choice of the reduced pickup setting to ensure that overcurrent coordination is maintained and nuisance tripping on load energization inrush will not occur.

Reduce Existing Time Delay Settings
If a protective device operates in its long time region, the time curve is normally an inverse type that has increased time delay as fault current decreases. Arcing fault magnitude is approximately 50% of the bolted fault current magnitude. Long delay trip time greater than 2 s may occur for arcing faults. It is generally recognized that the reaction time required to move away from an arc-flash hazard is 2 s. Based on the work task, if there is a good possibility that the worker can move away from the arc-flash area, then a maximum clearing time of 2 s may be used for incident energy calculations.

When reviewing existing coordination studies, there are usually areas found where coordination between two devices can be eliminated which will allow the time delay setting for the upstream device to be reduced. Two areas where removal of the coordination interval can be considered are between the main and tie protective devices or between primary and secondary protective devices on transformers.

Enable Instantaneous Functions
This design change can be easy and low cost, however there is a loss of coordination with any downstream overcurrent protective device for faults above the pickup setting of the adjusted device.

Implement Zone Interlocking Protection
This feature provides fast trip time for faults between the main and feeder circuit breakers. In some cases this feature may already exist in the switchgear but may not be implemented.

Change to a Faster Fuse Curve Shape
There is usually a range of current where the clearing time of an expulsion fuse is faster than the current limiting fuse when comparing the same fuse rating in amps. When the calculated arcing current appears in this range, changing from a current limiting fuse to an expulsion fuse will reduce the incident energy. Changing fuse types is not always possible. Each application requires an engineering study.

Reduce Fault Current
Incident energy can also be reduced by lowering the arcing fault current. The reduction of incident energy will depend on the trip time that results at the reduced current. A protective device with a definite time characteristic is best suited for this incident energy reduction technique. Note that for most inverse time current curve characteristic shapes, reduced arcing currents will result in increased trip time and increased incident energy. Fault levels can be reduced by one of the following design changes, both of which require a significant amount of cost and engineering effort:

- installation of current limiting reactor
- use of multiple transformers instead of one large transformer.

Overcurrent Upgrades
Incident energy can be reduced by clearing the arcing fault faster using any of the following overcurrent protective device upgrades.

Retrofit with an Instantaneous or a Short Delay Function
An instantaneous function can be used for devices in series at the same voltage level as long as loss of coordination has been considered and evaluated. For example, the
instantaneous overcurrent protection pickup on the primary of transformers is chosen to be higher than the asymmetrical fault level on the secondary side to avoid nuisance tripping on through faults.

A retrofit with a short delay function can provide the combination of improved coordination and lower incident energy. The short delay time is chosen to coordinate with downstream protective devices and to override any transient condition such as magnetizing inrush current.

**Reduce Fuse Ampere Rating**

There are cases where the fuse is oversized for the circuit loading and a reduction in fuse ampere rating will result in faster fault clearing time. Fuse trip time in current limiting mode is a half cycle or less. The largest reduction in clearing time will occur if the existing fuse does not operate in its current limiting mode and the new reduced ampere fuse will operate in its current limiting mode.

**Change to a Fuse with Better Current Limiting Characteristics**

When fault current is greater than the current limiting threshold, a current limiting fuse is considered to operate in less than a half cycle. For the same fuse ampere rating, there may be a fuse type that requires less fault current to reach the current limiting threshold. Changing to a different fuse type has been accomplished with good success in power systems that have bus plug switches feeding production floor equipment.

**Retrofit with Current Limiting Circuit Breakers**

This is an option that is not widely used because of the cost of this retrofit.

**Addition of Current Limiting or Expulsion Fuses**

Adding a fuse to an existing power system can decrease fault clearing time. Existing nonfused primary disconnect switches for transformers are locations where this retrofit may apply. Each application needs to be studied to determine the cost and benefit of the retrofit.

**Add Differential Protection**

Differential protection provides for fast clearing times when the fault is in the differential zone. Unless the current transformers suitable for differential protection already exist in the equipment, this retrofit may require a major cost and engineering effort.

**Work Method Modifications**

Incident energy can be reduced by changes to work methods such as the following.

**Use of a Temporary “Faster” Trip Time While Work Is Being Performed**

A lockout tagout procedure can include the reduction of protective device tripping time. The reduced time settings must be returned to the normal time settings after the work is completed. This can be easily accomplished with relays that have “group settings” where one of the groups is not currently used. A lockable switch could be used to enable the faster setting. For applications where the existing relay does not have a group setting available, it is possible to retrofit to a lockable switch that controls a relay with a faster trip setting. A separate contact in the lockable switch could be used to monitor the switch condition and alarm if the switch is not returned to normal after the work task is completed.

**Change Location of Work**

In many cases, the incident energy on the primary side of a transformer is much lower than the incident energy on the secondary side. This occurs for two reasons: An arcing fault on the low-voltage side of a transformer is generally a higher magnitude than an arcing fault on the high-voltage side. The high-voltage protective device usually is a fuse or a relay with an instantaneous trip that clears a primary side fault in a few cycles. For example, the application of temporary grounds on primary side of transformer instead of load side can take advantage of the lower arc-flash hazard level that typically occurs on the primary side.

**Working at a Greater Distance**

In some cases, working distance can be increased with the use of live line tools. In other cases, the working distance may be greater because of the task. For example, the depth of a circuit breaker can be added to the worker distance during the task of racking the breaker in or out of a cell.

**Eliminating Switching Conditions That Increase Fault Levels**

Mechanical or electrical interlocks can be used to prevent switching conditions such as parallel operation of transformers.

**New Product Implementation**

**Maintenance Switch**

Some low-voltage circuit breakers with digital trip systems are available with a safety feature in the form of a lockable switch which changes the trip unit to a faster trip time for the purposes of maintenance, testing or troubleshooting. The faster trip time will reduce incident energy and the PPE required for the work task. The lockable switch can be part of a lockout tag out procedure. Once the work task has been completed, the switch can be returned to normal overcurrent settings that provide optimal protection and coordination.

**Remote Racking Device**

These devices are presently available for some equipment. Awareness of the arc-flash hazard is accelerating the development of these devices to work with an increasing number of equipment types from various manufacturers.
Industry Example

Description of Electrical Infrastructure

The Willow Island power distribution system is a primary selective radial bus system. The main switchyard is powered from a single utility line at 138 kV to a single primary 138-kV oil circuit breaker. Three-pole, gang-operated air switches are used for isolating both the primary oil circuit breaker and the two main switchyard transformers. The two main 15/20-MVA switchyard transformers have a secondary voltage of 13.8 kV. Transformer T1 utilizes two 13.8-kV oil circuit breakers and underground feeders to provide power to the east bus of the facilities 13.8-kV switchgear room. Transformer T2 utilizes a single 13.8-kV vacuum breaker and overhead line to provide power to the west bus of the switchgear room. Either transformer can maintain the entire plant load. The switchgear room is located approximately 3,500 ft from the main switchyard.

The 13.8-kV switchgear room consists of a combination of both oil circuit breakers and vacuum breakers. A normally open tie breaker is used to isolate the east and west bus. The tie breaker is utilized to allow isolation of incoming feeders and switchyard transformers for maintenance and testing purposes. Each switchgear bus line up has a resistor bank and zigzag grounding transformer for a resistance grounding scheme. Grounding relays are set to immediately trip a detected ground fault.

Feeder breakers from both the east and west bus in the switchgear room provide power to yardswitch line-ups that are strategically located in unit substation areas of the facility. All feeders from the switchgear room are distributed to the yardswitch line-ups utilizing an underground duct bank system. Each yardswitch line up has a normally open tie switch that will allow either the east bus or west bus feeder breakers to power the entire yardswitch arrangement. Utilization of these tie switches allow for the isolation of either the east or west switchgear room bus for maintenance and testing. In addition to the incoming switches and tie switch, fused switches at each yardswitch feed individual unit substations through underground duct banks.

There are a total of 19 unit substations that are located at the various utility and production facilities at the site. Two of the unit substation secondary voltages are 2,300

<table>
<thead>
<tr>
<th>Bus Name</th>
<th>Protective Device</th>
<th>Reason for Dangerous classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 kV ICL</td>
<td>Primary OCB</td>
<td>Device is a 138 kV ICL OCB</td>
</tr>
<tr>
<td>943 MCC Bus</td>
<td>943 MCC Main</td>
<td>Brkr Inst. is set at 9X (&gt; arc current)</td>
</tr>
<tr>
<td>Fdr 9515 Bus</td>
<td>951-5 Feeder</td>
<td>Brkr Inst. is set at 8X (&gt; arc current)</td>
</tr>
<tr>
<td>Island MCC</td>
<td>Island Sub Fuse</td>
<td>MCC not equipped with a Main Breaker</td>
</tr>
<tr>
<td>Sub 821E</td>
<td>Sub 821E Fuse</td>
<td>Device is a primary fuse</td>
</tr>
<tr>
<td>Sub 822</td>
<td>Sub 822 Main</td>
<td>Min STDPU is (&gt; arc current)</td>
</tr>
<tr>
<td>Sub 831</td>
<td>Sub 831 Main</td>
<td>STDPU set at 4X (&gt; arc current)</td>
</tr>
<tr>
<td>Sub 951E</td>
<td>951E Net Fuse</td>
<td>Device is a 1,200-A network protector</td>
</tr>
<tr>
<td>Sub 951W</td>
<td>951W Net Fuse</td>
<td>Device is a 1,200-A network protector</td>
</tr>
<tr>
<td>Sub 972</td>
<td>Feeder H972 PH</td>
<td>Device is an upstream feeder relay</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bus Name</th>
<th>Protective Device</th>
<th>Arcing (kA)</th>
<th>Arc-Flash Boundary (in)</th>
<th>Incident Energy (cal/cm²)</th>
<th>Required Protective Clothing Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 kV ICL</td>
<td>Primary OCB PH</td>
<td>24.85</td>
<td>585</td>
<td>1262</td>
<td>Dangerous</td>
</tr>
<tr>
<td>943 MCC Bus</td>
<td>943 MCC Main</td>
<td>6.58</td>
<td>15</td>
<td>0.92</td>
<td>Class 0</td>
</tr>
<tr>
<td>Fdr 9515 Bus</td>
<td>951-5 Feeder</td>
<td>6.18</td>
<td>19</td>
<td>1.28</td>
<td>Class 0</td>
</tr>
<tr>
<td>Island MCC</td>
<td>Island MCC Main</td>
<td>5.14</td>
<td>37</td>
<td>3.88</td>
<td>Class 1</td>
</tr>
<tr>
<td>Sub 821E</td>
<td>821E Main Bkr</td>
<td>11.68</td>
<td>93</td>
<td>17.5</td>
<td>Class 3</td>
</tr>
<tr>
<td>Sub 822</td>
<td>Sub 822 Main</td>
<td>15.81</td>
<td>86</td>
<td>15.5</td>
<td>Class 3</td>
</tr>
<tr>
<td>Sub 831</td>
<td>Sub 831 Main</td>
<td>15.13</td>
<td>114</td>
<td>24.6</td>
<td>Class 3</td>
</tr>
<tr>
<td>Sub 951E</td>
<td>951E Main Bkr</td>
<td>6.30</td>
<td>70</td>
<td>11</td>
<td>Class 3</td>
</tr>
<tr>
<td>Sub 951W</td>
<td>951W Main Bkr</td>
<td>6.70</td>
<td>62</td>
<td>9.1</td>
<td>Class 3</td>
</tr>
<tr>
<td>Sub 972</td>
<td>Fdr H972 PH</td>
<td>6.06</td>
<td>90</td>
<td>16.8</td>
<td>Class 3</td>
</tr>
</tbody>
</table>
and 7,200 V, respectively. The remaining unit substation secondary voltages are 480 V. All of the unit substations were originally ungrounded delta secondary configurations. The site is presently migrating to high-resistance grounded secondary unit substations with the installation of HRG detection systems at each substation.

The Willow Island site electrical distribution system equipment spans an age of over 50 years. This equipment includes both oil-filled and vacuum-type medium-voltage breakers, induction disk and solid-state protective relaying, dry-type and oil-filled unit substation transformers, low-voltage distribution breakers with both oil dash pot and solid-state tripping units, and unit substations with both ungrounded and high-resistance grounded secondary. This large span of technology presents unique opportunities and challenges for the reliability, maintenance, and safe operation of this system.

**Description of Electrical Safety Program**

Willow Island electrical maintenance personnel consist of both qualified electricians and instrument and electrical (I&E) technicians. Qualified contract electricians are also utilized at the site. Maintenance personnel have completed extensive training schools and testing in order to qualify for general plant electrical work. On-site refresher training is also given to the site’s maintenance personnel. Plant personnel also attend training seminars specific to particular equipment. On-the-job training has been given to a select number of maintenance personnel to qualify them to perform tasks in the medium-voltage distribution equipment locations and the site’s main switchyard. Local utility personnel are contracted for all overhead line maintenance and testing. All contract electricians are required to be licensed.

Job-specific safety training for electrical maintenance personnel consists of electrical shock hazards, arc-flash incident energy and arc-blast hazards. All maintenance personnel are required to also complete monthly site safety training. A two-day certified training course was initially presented to all plant electrical personnel that pertained to OSHA and NFPA electrical safety standards. The course included present regulations, protective measures, OSHA electrical safety related work practices, lockout/tagout, and NFPA 70E-2004 electrical safety requirements for employee workplaces. A follow-up safety course pertaining to the determination of arc-flash hazards values and the interpretation and use of NFPA 70E-2004 tables was also presented to plant electrical personnel. The tables of NFPA 70E-2004 were used to determine the hazard risk category and required PPE for a particular task.

A recently completed site short-circuit and coordination study presented the opportunity to also perform a detailed arc-flash hazard analysis study. The analysis determined incident energy levels, arc-flash boundaries, and required PPE for 158 bus locations. This included all bus locations to the 480-V level. Labels were installed with values listing the arc-flash boundary, incident energy, and hazard risk category at all bus locations that were included in the arc-flash study. Placards were also placed in all switchgear and motor control center locations to define the required PPE for a particular risk category listed on each label.

Safety training was given to all site electrical personnel and maintenance supervisors to introduce them to the results of the arc-flash study. The training course reviewed the differences of the NFPA 70E-2004 tables relating to arc-flash risk categories pertaining to a particular task and the calculated values of the arc-flash study that determined the risk categories for the various bus locations.

To meet the requirements of the risk categories listed on the arc-flash study labels, electrical personnel are each issued work uniforms that meet the minimum requirements for a Hazard Risk Category 2. Personnel are also issued individual arc-flash rated face shields with hardhat, 1,000-V gloves, and insulated 1,000-V tools. Flash suits are provided for incident energy levels above 8 cal/cm² (Hazard Risk Categories 3 and 4). Contractors are required to familiarize their employees on arc-flash hazards and to provide the necessary PPE. Written electrical work procedures used in combination with periodic safety training and issued PPE minimizes the risks involved in performing the assigned work.

**Incident Energy Reduction Examples**

Short circuit, protective device coordination, and arc-flash hazard analysis studies were conducted for the industrial electrical distribution system described above.

The scope of the studies started at the 138-kV incoming line, through the two 15-MVA, 138-kV–13.8-kV transformers T1 and T2, the 13.8-kV main switchgear and distribution system, down to and including the 480-V substations and motor control centers. The arc-flash hazard analysis required energy and arc-flash boundary calculations for approximately 160 locations.
The arc-flash analysis calculations were completed for two study cases. Study Case 1 utilized device settings that were either derived during the coordination study or existing device settings that were not included in the scope of the coordination study. Study Case 2 was conducted using device settings that were revised in an attempt to reduce the incident energy magnitudes obtained in Study Case 1. Study Case 2 also incorporated device and system changes recommended in the study report.

Of the approximately 160 locations included in Study Case 1 arc-flash analysis, 21 locations received “Dangerous” (\(\geq 40 \text{ cal/cm}^2\)) classifications at all locations. A sample listing of the NFPA 70E defined dangerous locations is given in Table 1 following the recommendations with an abbreviated reason for the “Dangerous” classification.

Reducing device settings could not eliminate the “Dangerous” classifications at all locations. Eleven bus locations remained classified as “Dangerous” (\(\geq 40 \text{ cal/cm}^2\)) by the arc-flash calculations of Study Case 2 due to protective device and system design constraints. Changing the upstream protective device type and/or modifying the system design eliminated the “Dangerous” classification of these locations.

The following is a sample listing of recommendations for device and system changes that would alleviate some of the dangerous classification results of Study Case 2.

1) To reduce the arc-flash hazard at the Island motor control center (MCC), a main breaker would need to be installed in the MCC. The use of a lower ampere fuse on the primary of the upstream transformer is not practical since the existing fuse is rated 65 A and the transformer full load current rating is 60 A.

2) Sub 822 Main: The Sub 822 main breaker trip unit is an electromechanical type (long delay and short delay) trip unit that has the short time delay pick-up (STDPU) and short time delay (STD) set on the minimum available settings of 4X and Min, respectively. Therefore, it is not possible to reduce the arc-flash hazard class through decreased settings with the existing trip unit. However, if the main breaker trip unit was replaced with a solid-state-type trip unit, the arc-flash hazardous class could be reduced to Class 3 (<25 cal/cm²).

3) Sub 942 Main: The Sub 942 main breaker trip unit is an early vintage solid-state-type trip unit which has the STDPU set at the minimum available setting of 4X (12,800 A = 4 X sensor rating of 3,200 A) and STD set on the next to the lowest available setting of 0.3 s. Since 85% of the arcing current value is 13,022 A, which is within the tolerance range of the STDPU, a lower STDPU setting is needed in order to reduce the hazard class. However, this is not possible with the existing 3,200-A sensor and existing trip unit, which has a minimum available STDPU setting of 4X. Therefore, if the existing 3,200-A sensors were to be replaced with 2,400-A sensors, or the trip unit is replaced with one having a minimum STDPU of 3X (9,600 A), the arc-flash hazard class could be reduced to Class 3 (<25 cal/cm²).

4) Substations 821E, 821W, 951E, 951W, 972, and 973 presently have network protectors as main protective devices. The only overcurrent-sensing device contained within the network protector is a fusible link having a time-current characteristic that reacts very slowly to fault currents. The arc-flash energy at these locations could be reduced significantly through the use of a main circuit breaker having a modern solid-state trip unit. Figure 3 shows the network protector replacement breaker and solid-state trip unit.

Table 2 below compares the hazard risk classification results to those listed in Table 1. Improvements were achieved by incorporating device setting changes beyond those recommended in the initial protective coordination study and by upgrading protective devices and modifying the power distribution design.

Conclusions

In the past, a coordination study involved choosing the best combination of protection and coordination for a power system. With the increased emphasis on safety in the workplace, an arc-flash hazard analysis is now required.

The easiest way to reduce incident energy in an existing electrical system is to review and modify the overcurrent protection settings. Both the pickup (sensitivity) and the time delay should be evaluated.

If incident energy levels can be reduced to a lower hazard level class, there are overall benefits of improved safety. Depending on the FR PPE available at the work location, a reduction in incident energy may result in a requirement for reduced layers of PPE fabric that would result in reduced heat stress, greater worker comfort and ease of movement.

Acknowledgments

The authors thank John Rankin for his comments. The authors also would like to acknowledge Kenny Shillingburg and John Carter for their contributions in completing the arc-flash study and developing the network circuit breaker replacement.

References


Michael Hodder is with Eaton Electrical Services & Systems in Mississauga, Ontario. William Vilbek (williamvilbek@eaton.com) and Floyd Croyd are with Eaton Electrical in Warrendale, Pennsylvania. David McCue is with Cytic Industries in Willow Island, West Virginia. Vilbek is a Senior Member of the IEEE. Hodder, Croyd, and McCue are Members of the IEEE. This article first appeared at the 2005 IEEE/IAS Pulp and Paper Industry Committee Conference.