Arc Flash Prevention

How implementing the right mitigation strategies helps to reduce risk

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ARC FLASH PROTECTION CANNOT BE LEFT TO CHANCE

Why the most successful electrical safety strategies are proactive and purposeful

By Ellen Parson, Editor-in-Chief, *EC&M*

Five employees working at a hydroelectric generating plant in Colorado were injured during an arc flash incident. A worker at a bowling alley in Arizona suffered severe injuries when a breaker panel exploded. Two technicians working on electrical equipment in a refinery were injured in Pennsylvania after an arc blast. The chief engineer at a New York hotel, who was performing maintenance on an electrical panel when an arc flash occurred, suffered second- and third-degree burns to more than 63% of his body. These are just a few examples of the news briefs we've run on *EC&M* online. Fortunately, none of these particular accidents ended in a fatality, but the fact remains: Arc flash incidents can and do kill.

According to statistics from the Electrical Safety Foundation International, there were 160 electrical fatalities in 2018, an 18% increase over the previous year and the highest number since 2011. The construction industry accounted for 54% of all fatal electrical injuries, and contact with/exposure to electric current accounted for 3% of all fatalities in 2018.

At *EC&M,* we continue to provide a comprehensive content approach to the topic of electrical safety, offering readers a variety of valuable information sources that apply to their specific needs. Whether that's running case studies to demonstrate the real-life consequences of carelessness, shortcuts, or failure to follow proper safety procedures in the workplace that end in arc flash accidents, technical articles on how to simplify arc flash calculations and apply them in the field, or detailed analysis on the importance of why customers need incident energy/arc flash audits performed at their facilities, *EC&M* reinforces the importance of safety on a daily, weekly, and monthly basis.

Being stringent when it comes to safety, especially when it comes to arc flash prevention strategies, is a key component in reducing the number of electrical injuries and deaths evidenced in the statistics mentioned earlier. Another step in spreading the safety awareness message is through custom publishing products. The editors of *EC&M* along with sponsor ABB are pleased to bring you this compilation of articles in an effort to inform and educate electrical professionals on arc flash prevention best practices. By selecting a handful of popular pieces that examine how to reduce incidents, this e-book offers insight into improving overall outcomes in different applications. By establishing a proactive and purposeful safety plan, electrical professionals can make a difference in reducing electrical hazards in the workplace, which ultimately saves money, downtime, and, most importantly, lives.

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THREE KEY SAFEGUARDS AGAINST ARC FLASH INJURY

How electrical inspections, preventive maintenance, and training come together to bolster a facility's electrical safety culture.

By Richard Paese and Frank Ceci

Two-thirds of workers injured by arc flash did not conduct an arc flash analysis, according to the "Occupational Injuries from Electrical Shock and Arc Flash Events" study published by the National Fire Protection Association (NFPA) in March 2015. Compare that result with this risk analysis from the Workplace Safety Awareness Council: 30,000 arc flash incidents annually lead to 2,000 burn center admissions for severe burns. At an average hospitalization of 19 days, costing $18,000 a day, those burns total more than half a billion dollars in medical expenses alone. That's not counting damage to equipment, productivity, or quality of the worker's life. So why do so many serious arc flash burns still occur? Because the same known causes turn up over and over in investigations, including:

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- Failure to verify de-energization,
- Failure to conduct a proper risk assessment or hazard analysis, and
- Failure to wear protective gear properly, even when the risk is known.

These examples all indicate that a facility has failed to establish a culture of safety.

A culture of safety, when it comes to the power distribution equipment in a facility, depends on a clear and visible commitment to safety. The effects of arc flash incidents can be catastrophic, but sadly, the human capacity for believing "it won't happen to me" means that safety can be taken for granted. A culture of safety needs more positive reinforcement to truly influence behavior. How a business treats electrical equipment is how its employees will treat electrical equipment.

THE EFFECTS OF ARC FLASH INCIDENTS CAN BE CATASTROPHIC, BUT SADLY, THE HUMAN CAPACITY FOR BELIEVING "IT WON'T HAPPEN TO ME" MEANS THAT SAFETY CAN BE TAKEN FOR GRANTED.

Superb minds have devoted countless hours to standards that help businesses protect against these incidents. To be fair, it's unreasonable to expect those standards to be a core competency for every business; that would be wasteful. But when management brings in an expert to care for and monitor power distribution assets, the company demonstrates due diligence clearly to employees while reinforcing a culture of safety. Following are three key safeguards you can implement to prevent arc flash injuries.

1. INSPECTIONS AND ANALYSIS

When a new facility is constructed, an accredited third party should perform acceptance testing, along with any additional commissioning of the facility. This provides clear baseline data for safe operations. This objective data should be readily available to decision makers and maintenance personnel. It should be regularly updated, and facility operations processes should make the parameters for safe operations clear to everyone involved.

Going forward, an expert should be brought in for predictive inspections and performance tests to uncover any deviations from the expected life cycle of components. Testing should expose the effects of deteriorating insulation or other causes of faults, as well as ensure the proper operation of the circuit breakers and protective relays that are designed to protect facilities and personnel. Management's staunch commitment to verifying the safe, efficient operation of electrical distribution equipment sends a strong signal to everyone.

If an arc flash hazard analysis has not been performed, the facility should have one conducted immediately. Arc flash labels should be prominently displayed, and procedures indicated by the hazard analysis — both for normal operations and maintenance

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— should be clearly communicated and regularly reviewed. Since a significant portion of arc flash incidents involve non-electrical workers (as much as 50%, according to one report in the IEEE *Industry Applications* magazine), facilities should take the utmost care to include all parties possibly exposed to risk in mandated training. A culture of safety depends on viewing these requirements not just as business needs or compliance needs, but as the best practices of a proactive employer.

There's another place where inspection is key to maintaining a safety culture (and compliance), and that's regular inspection of personal protective equipment (PPE). Making this step a highly visible priority goes a long way to turning training into an unbreakable habit, ensuring employees keep proper PPE on when called for.

2. PREVENTIVE MAINTENANCE

The value of inspections leads naturally to preventive maintenance. Given that deteriorating insulation is a leading cause of arc flashes, a maintenance schedule that stays ahead of deterioration is key.

Maintenance and testing of overcurrent protection devices now need to be documented, and compliance with NFPA 70E now includes maintenance of all electrical equipment — not just overcurrent protection — to manufacturer standard or consensus standards. This requires knowledge of the equipment standards and precise recordkeeping.

From a safety culture viewpoint, the issue is how maintenance and testing is done. Is attention to maintenance just checking a box, or is it a proactive exercise in caring for business assets and the well-being of employees? Mandated maintenance does not guarantee a proactive culture of safety. Diligent and visible attention to preventive maintenance and recordkeeping reinforces that safety is valued and a necessary component of the working day.

A recent update to NFPA 70E requires that mandated arc flash risk assessments also document the regular performance of proper maintenance. An employee needs to know the maintenance status of the equipment to select the proper PPE (when required).

3. TRAINING

Documented training is a staple of compliance — and for good reason. As noted earlier, anyone exposed to arc flash risk — not just employees qualified to work on equipment, but all those working around energized electrical equipment — must receive safety training. Compliance requires a minimum of documented safety training at three-year intervals.

Three years is a long time. Employees may change, standards may be updated, and equipment/procedures may be upgraded. Training courses provided by responsible, credible experts are necessary, but so is regularly checking in with employees on their safety knowledge. If training isn't mandated for another year and a half — but employees voice a clear need or demonstrate reluctance or confusion — training should be arranged to meet that need.

NOT BECAUSE YOU COMPLY, BUT BECAUSE YOU CARE

Testing and predictive inspections proactively identify risks so they can be safely eliminated. In addition, qualified maintenance and certified training reinforce a culture of safety that ensures proper procedures remain an operational priority. With the risk of arc flash injury so high, caring for the well-being of employees is simply the right thing to do.

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ARC FLASH RISK ASSESSMENT CONSIDERATIONS

A new emphasis on an old requirement

By Tommy Northcott, P.E.

The addition of the term "risk assessment" was a change made in the 2015 revision of NFPA 70E, and additional emphasis was added to the risk assessment requirements in the 2018 revision. Prior to 2015, NFPA 70E revisions referenced a hazard assessment, which seemed to imply that severity was the only critical element of the evaluation.

The change from hazard to risk brings in the idea of evaluating both probability and severity of electrical hazards as well as keeping the NFPA 70E consistent with recent changes found in similar standards that address risks and hazards. An arc flash hazard should be evaluated according to: 1) how likely it is that an arc flash incident is to occur; and 2) if one does occur, how severe could it be? The result of this arc flash risk assessment will help guide electrical professionals in determining the appropriate hazard mitigation methods to use.

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WHEN IS AN ARC FLASH RISK ASSESSMENT REQUIRED?

The 2018 edition of NFPA 70E requires an arc flash risk assessment be performed during the job safety planning process before starting any work that involves exposure to electrical hazards. Energized Electrical Work Permits are required to include the results of the arc flash risk assessment associated with the task to be performed. The bottom line is any task that involves potential for a worker to be exposed to electrical hazards must have an arc flash risk assessment performed.

Not all tasks that involve potential electrical hazard exposure will include a potential for an arc flash hazard, but this should be determined through the arc flash risk assessment. Even in the case where an arc flash risk assessment results in no likelihood of an arc flash event, the process is still required, and the results must be documented. The general purpose is to identify arc flash hazards, estimate the likelihood of occurrence and the potential severity of injury or damage to health, and determine if additional protective measures are required to mitigate the hazard.

WHAT DOES AN ARC FLASH RISK ASSESSMENT INVOLVE?

Likelihood and probability — 130.5 of NFPA 70E puts forth the requirements for conducting an arc flash risk assessment. The first step is to estimate the likelihood of occurrence and the potential severity of injury or damage to health. This estimation should consider the design of the electrical equipment and associated overcurrent protective devices, including its operating time, and should include the status of maintenance and operational capability. One example to consider is a panel that looks brand new and in excellent condition would likely have less probability of posing an arc flash hazard than a panel that is old, corroded, and is missing blank covers that leave the bus exposed. Likewise, an older motor control center that has never had any preventive maintenance performed on it may have a greater risk than one that is part of a mature, effective electrical equipment maintenance program.

Hierarchy of risk control methods — If the likelihood and severity indicate that there is risk of an arc flash incident, the next step is to determine additional protective measures needed to mitigate the arc flash risk. Additional protective measures should be selected and implemented according to the hierarchy of risk control. The hierarchy of risk control methods were only included as an Informational Note in the 2015 edition of NFPA 70E but are now part of the specific requirements in the 2018 edition [110.1(H)]. This hierarchy is being adopted by similar standards and is explained in more detail in ANSI/AIHA Z10, American National Standard for Occupational Health and Safety Management System. The expectation is that workers should follow a specific priority of options when determining the best way to mitigate the hazard. The prioritized order is as follows:

(1) Elimination
(2) Substitution
(3) Engineering controls
(4) Awareness
(5) Administrative controls
(6) Personal protective equipment (PPE)

The overall idea is to start with mitigations that avoid exposure to the hazard. If these are not feasible, continue down the priority list with the final option of using PPE to protect workers during their time of exposure to an arc flash hazard.

Arc flash boundary — After determining appropriate risk control methods, any applicable safety-related work practices must be identified and associated with each method, including the arc flash boundary and the PPE that is required for anyone who is inside the boundary. The arc flash boundary is the distance at which the incident energy equals 1.2 cal/cm^2. The preferred

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method for determining the arc flash boundary is through calculations associated with an incident energy analysis. In lieu of the analysis, it is permitted to be determined by Table 130.7(C)(15)(a) or Table 130.7(C)(15)(b) when the requirements of these tables apply.

Arc flash PPE — Knowing that there is a potential for an arc flash event to occur, the next requirement is to determine what arc flash PPE is required within the arc flash boundary. The required minimum rating of arc flash PPE can be determined either by the incident energy analysis method in accordance with 130.5(G) or the arc flash PPE category method in accordance with 130.7(C)(15). From the perspective of clearly understanding the severity of the hazard, the incident energy analysis method is always the preferred method. However, the incident energy analysis method requires data collection, system modeling, and calculations, all of which take time. In lieu of this method being finalized, NFPA 70E allows the use of Table 130.7(C)(15)(a) or Table 130.7(C)(15)(b) to determine required PPE when the requirements of these tables apply.

Documentation — Arc flash risk assessment results are required to be documented. Documentation can take many forms, depending on the level of risk and the complexity of the mitigating actions. Low-risk tasks may simply be documented as part of the job planning document while higher risk tasks may have a separate arc flash risk assessment document. If the arc flash risk analysis involves performing an incident energy analysis, documentation may include labeling equipment with incident energy analysis results. As stated in 130.6(H), electrical equipment that is likely to require examination, adjustment, servicing, or maintenance while energized is required to be marked with a label containing the nominal system voltage, arc flash boundary distance, and an indication of the minimum PPE required within the arc flash boundary.

KEY TAKEAWAYS

Any task that has the potential to involve an electrical hazard must include an arc flash risk assessment from inception. The overall goal of the assessment is to encourage a deliberate thought process that allows qualified electrical workers opportunity to determine feasible means to avoid exposure to an arc flash hazard. If the assessment determines that the potential arc flash hazard exposure cannot be avoided, the assessment process facilitates a logical method for determining preferred means to protect the workers from arc flash hazards. While this process may seem tedious at times, the habits that are developed through following this process consistently may indeed prevent unimaginable pain and suffering caused by experiencing an arc flash event with insufficient protection.

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HOW DOES THE NEW IEEE 1584 STANDARD AFFECT ME?

Understanding how this version incorporates additional details of equipment configuration can result in more accurate incident energy calculations.

By Mitch Costley, P.E., Ph.D.

If you are responsible for facility electrical operations, you may have heard of the recent updates to IEEE 1584 "IEEE Guide for Performing Arc-Flash Hazard Calculations." The previous major edition of the standard was released in 2002. A lot has changed in this 16-year span, which led to many revisions in the 2018 version of the guide.

Understanding what changed, why it changed, and how that bears out for incident energy calculations will help to clarify the impact on operations and maintenance. Here are some of the most significant changes discussed in this article:

- Arc flash model updates — Arcing current and incident energy calculations were updated based on the latest research, so they will be different, even if the electrical system has not changed.
- Bus configuration — The orientation of the buses inside the equipment now has a significant impact on the incident energy and must be considered.
- Enclosure size — If the equipment has an enclosure, the box dimensions have an impact on incident energy and must be considered.
- 125kVA transformer exception — The exemption for systems downstream of a 125kVA transformer has been removed.

As an example of how arc flash assessments can change under the 2018 guide, an existing laboratory facility was used as a test case and is presented here. In this discussion, low-voltage systems under 600V will primarily be considered, although some may also pertain to higher-voltage systems.

BACKGROUND

The 2002 version of IEEE 1584 represented a broad industry consensus on how to calculate the heat energy that electrical workers may be exposed to during an arc flash. Although not perfect, it provided a better measure of AC arc flash hazards than those available before and — quoting from the introduction to the new IEEE 1584 document — "has been used with success throughout industry." Through further research and testing, it was identified that the incident energy given by the 2002 model was too low or too high for some equipment conditions. The 2018 version provides a greatly refined model that incorporates more details of equipment configuration, resulting in more accurate incident energy calculations in many cases.

ARC FLASH MODEL UPDATES

One of the most significant updates in the new 1584 is the introduction of new equations for arcing current, arc flash boundary, and incident energy. The past 16 years of experiments have yielded a volume of data on arcing current and incident energy that is matched better by the new equations. Therefore, arcing

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currents will be different when calculated using the 2018 method compared to the 2002 method, even with the same system parameters and available short-circuit current.

The same goes for incident energy. The next time you update your arc flash hazard assessment, prepare to see different incident energy values than before, even if the system configuration has not changed at all. Despite the breadth of these changes, many of the changes in incident energy may be small, and, depending on your facility's PPE standard, may require no change in the minimum PPE for energized work. The magnitude of the change is heavily influenced by the construction of the electrical equipment, as described next.

BUS CONFIGURATION

Two new required inputs to the model are the configuration of conductors inside the equipment and the size of the enclosure. IEEE 1584-2018 describes five different conductor configurations:

- VCB: vertical conductors inside a metal enclosure
- VCBB: vertical conductors terminated in an insulating barrier inside a metal enclosure
- HCB: horizontal conductors inside a metal enclosure
- VOA: vertical conductors in open air
- HOA: horizontal conductors in open air

Most low-voltage work on energized panelboards (**Photo 1**), switchboards, motor control centers (MCCs), or switches would be considered inside an enclosure (VCB, VCBB, or HCB). An example of an open-air installation would be pole-mounted overhead conductors.

It is possible to encounter different conductor configurations within the same equipment, depending on the work task. IEEE 1584-2018 Annex C provides some guidance on the selection of conductor configuration. For example, within an MCC, the electrode configuration could be VCB or VCBB, depending on the fault location. For low-voltage draw-out switchgear, a fault on

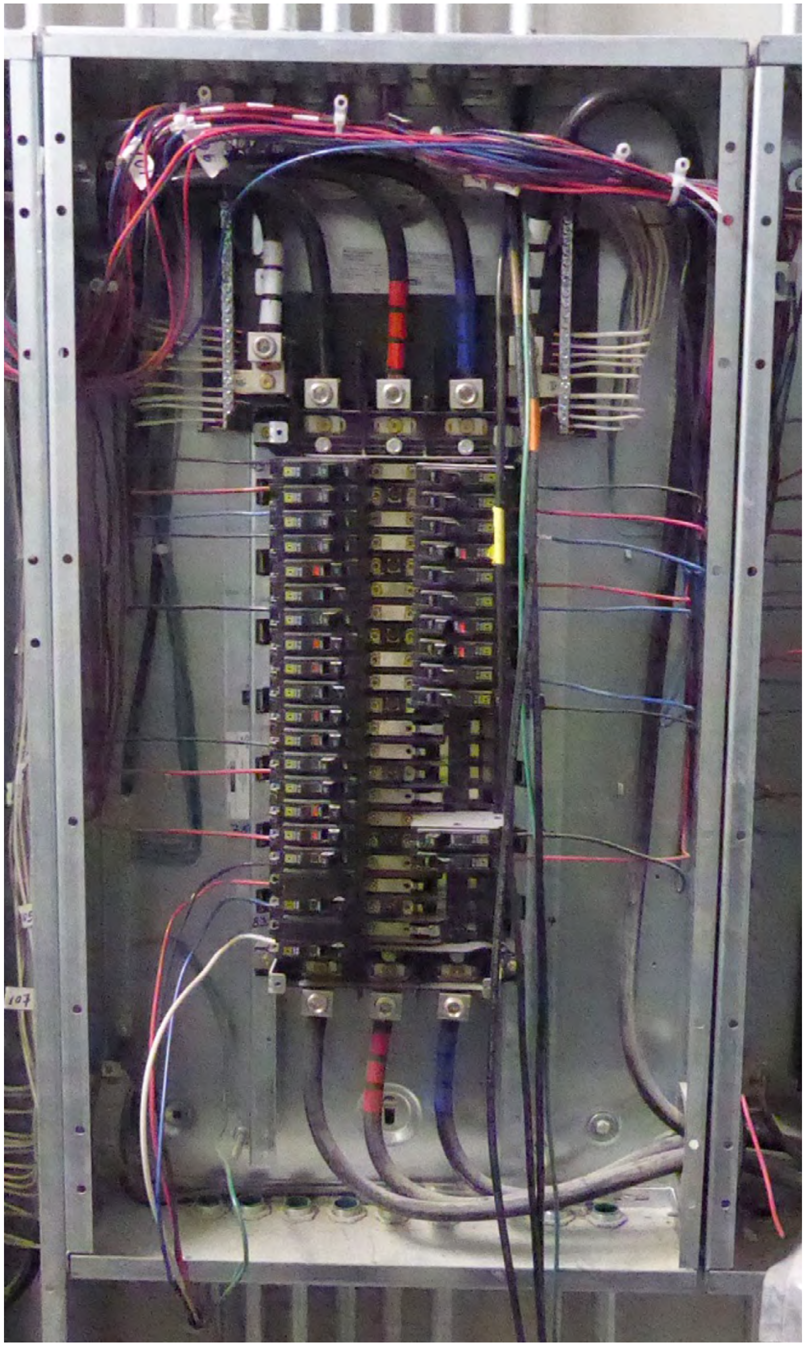

Photo 1. Phase conductors terminate down into the panel's main lugs. As outlined in the new version of IEEE 1584, this would be best modeled as a VCBB conductor configuration.

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the bus studs with a breaker racked out may correspond to the HCB mode (**Photo 2**).

Much higher incident energy may be predicted by the 1584-2018 calculations using the HCB conductor configuration compared to the 1584-2002 calculations — all else being equal. This is based on experiments that indicate horizontal electrodes direct more of the heat toward the open front of the enclosure than vertical electrodes. Therefore, facilities that regularly perform "hot work" on switchgear or switchboard systems (such as racking in drawout breakers on a hot bus) may want to consider updating their arc flash studies, since it is possible that incident energy is presently under-represented.

ENCLOSURE SIZE

As previously mentioned, the size of the equipment enclosure must also be considered in the new model. Research has indicated that the walls of an enclosure reflect radiation from the arc back at the front of the box, resulting in higher incident energy compared to arcs in open air. Generally, the larger the enclosure, the lower the incident energy (all else being equal), since the heat is less concentrated over the incident surface. For "shallow" enclosures less than 20 inches in height and width and less than 8 inches in depth, this trend is reversed. Note that, unlike the choice of bus configuration, the selection of enclosure size does not affect the calculation of arcing current — only the incident energy.

Field data gathering efforts for arc flash studies seldom include measurements of box dimensions. Including this in future field data requests could benefit the accuracy of the study, but if this information

Photo 2. These draw-out circuit breaker compartments (as seen from the rear of a switchgear cabinet under construction) house connections that run horizontally from the circuit breaker stabs to the switchgear bus. Within the breaker cell, an operator would be exposed to conductors in the HCB configuration.

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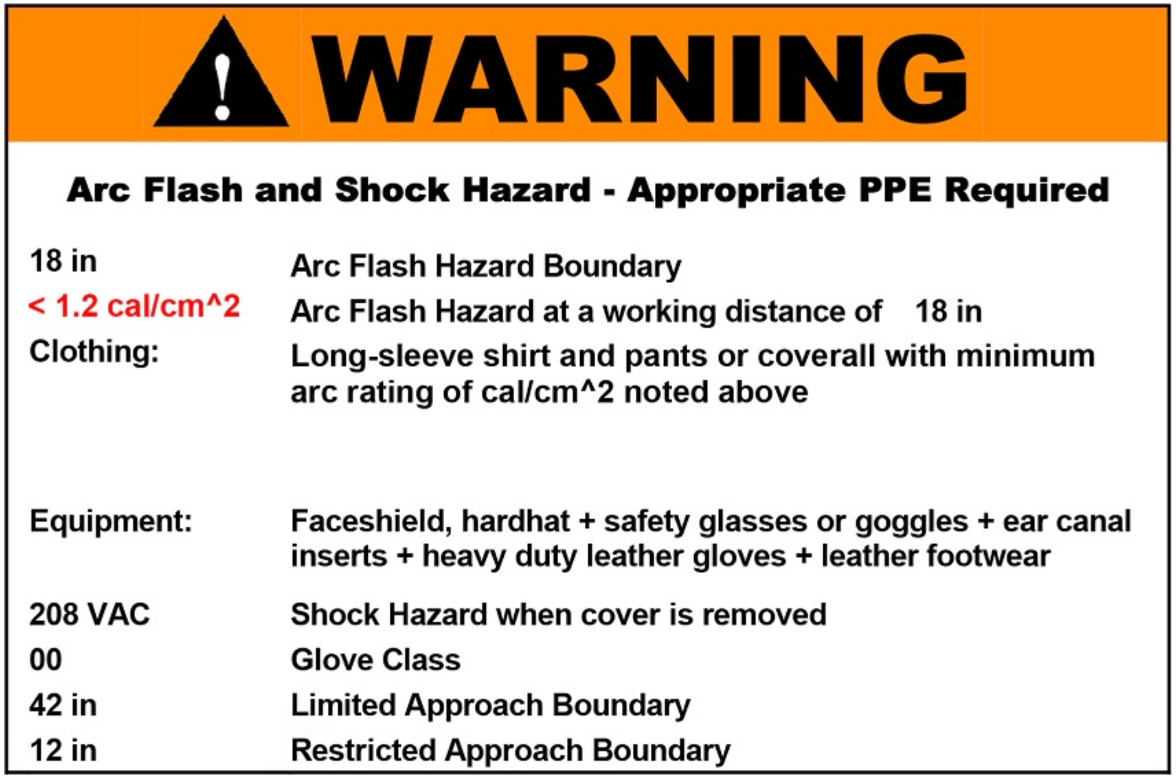
is not available, appropriate assumptions based on the guide must be made. Table 8 in IEEE 1584-2018 contains typical enclosure sizes and bus gaps for various types of equipment. Selecting the minimum enclosure dimensions corresponding to the equipment type per Table 8 should yield a conservative result (for any "shallow" enclosures, the maximum size would yield the conservative result).

125KVA TRANSFORMER EXCEPTION

IEEE 1584-2002 stated that equipment rated 240V and below and downstream of a transformer rated less than 125kVA need not be considered in the study. Since the incident energy was not calculated for this equipment, it was often assumed to be less than 1.2 cal/cm².

The 2018 version no longer includes this exception in light of research demonstrating that arcs can be sustained at 240V under some conditions. Instead, a new statement has been added, which reads: "Sustainable arcs are possible but less likely in 3-phase systems operating at 240V nominal or less with an available short-circuit current less than 2,000A." Therefore, equipment downstream of 480-208V transformers rated under 112.5kVA may now need to be considered as part of the arc flash study, depending on the available fault current. Furthermore, the low fault current — and hence low arcing current — on these systems often drives long interrupting times for molded-case circuit breakers, which can result in incident energy much higher than 1.2 cal/cm².



Under the previous IEEE 1584 guidelines, a panel on the secondary of a 112.5 kVA,480-208V transformer would not need to be considered for incident energy calculations.Many times, the incident energy at the arc flash boundary would be labeled as 1.2 cal/cm² or below. IEEE 1584-2018 now requires that this incident energy be calculated if the available fault current is greater than 2kA.

TEST CASE: 133-BUS LABORATORY BUILDING

Newcomb & Boyd conducted a study on a laboratory facility with 133 buses to compare the results using the IEEE 1584-2002 and 1584-2018 methodologies. The building is served by two medium-voltage network transformers through a 480V switchboard with a main-tie-main configuration. There are three MCCs in the building for mechanical loads. Lighting and plug/process loads are served by two busway

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risers, which are tapped off on each level with 150kVA, 480-208V transformers to serve the 208Y/120V panels on each floor. Several other 480V panels are tapped off the busway risers to serve miscellaneous loads.

For the 2018 model, conductor configuration had to be selected for each bus. Based on the guidance of Annex C, the VCBB configuration was initially selected for all MCCs, panelboards, enclosed circuit breakers, and disconnects. Further study found the VCBB electrode configuration to result in higher incident energy for all but five panelboards. For these panelboards, the VCB configuration resulted in a lower arcing current and longer interrupting time, producing a higher incident energy than the VCBB configuration. Per Annex C, certain faults within a panelboard are consistent with VCB, so VCB was selected for these five buses. For the MCCs, the VCBB configuration resulted in higher incident energy than VCB, so VCBB was selected.

Since certain faults in switchgear or switchboard draw-out compartments correspond to the HCB configuration, HCB was selected for the service main compartment. This resulted in an incident energy that was 40% higher than that calculated from the 2002 method. The incident energy was also twice what was calculated assuming the conductors were in the VCB configuration, which indicates the importance of selecting an appropriate configuration.

Enclosure sizes were selected based on Table 8 in the 2018 guide. Because larger enclosures typically result in lower incident energy, the minimum enclosure size corresponding to the equipment class was selected to obtain a conservative result. No equipment in the study could be definitively classified as "shallow."

The incident energy calculation results with the two methods were closely compared. One of the more significant deviations occurred on a 208V panelboard that would not have been considered in the incident energy calculations under the 2002 guide. The incident energy as calculated with the 2018 model was 11.6 cal/cm^2, which would require significantly greater PPE to protect against if the panel was worked hot. The other 132 buses in the system exhibited a 22% decrease in incident energy (on average). Using common breakpoints for PPE category (1.2, 4, 8, 25, and 40 cal/cm^2), a total of five buses went up in PPE category (higher-rated PPE), and a total of nine buses went down in PPE category. The change in incident energy for all the other buses in the system was not significant enough to trigger a shift in category using the above breakpoints.

DEPENDING ON THE TYPE OF EQUIPMENT INVOLVED, THE PPE NEEDED TO PROTECT FROM ENERGIZED WORK HAZARDS MAY CHANGE GREATLY WITH THE NEW GUIDANCE.

This is just one example of one building, and time and experience may offer more insight into how the new 1584 may affect the study results at different types of facilities. Depending on the type of equipment involved, the PPE needed to protect from energized work hazards may change greatly with the new guidance. Regardless, NFPA 70E and OSHA continue to preclude most energized work, except where de-energizing results in a greater hazard or if it is infeasible for the work to be performed. Establishing an electrically safe work condition is the safest way to work on electrical equipment.

Dr. Costley is an electrical engineer with Newcomb & Boyd, an engineering & consulting firm located in Atlanta, where he provides design and consulting services to clients in institutional, government, military, and commercial fields. He is experienced in short circuit, selective coordination, and arc flash studies as well as engineering forensics and custom testing. He can be reached at MCostley@newcomb-boyd.com.

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HOW TO CHOOSE THE RIGHT ARC FLASH PPE

Knowing and understanding this might just save your life.

By Tommy Northcott, P.E.

Most electrical workers today recognize that, in recent years, a major emphasis has been placed on arc flash hazard recognition. Depending on the maturity of your company's electrical safety program, your personal experience may vary greatly from your peers in the industry. However, a scenario exists that is still far too common for electrical workers.

The scenario might go something like this: Your company finally recognized that you need to be protected from this arc flash hazard "thing." The company hired some engineering firm to come collect drawings and information on the system, and then they ran out and put arc flash hazard stickers on all the equipment. The next thing you know, your supervisor dumps a pile of arc flash personal protective equipment (PPE) in your lap and tells you it is a requirement for you to wear it. What do you do now? The following article will try to help you answer that question.

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ARE ALL ARC FLASH PPE ITEMS APPLICABLE FOR ALL SCENARIOS?

The answer to this question is, "absolutely not!" When an arc flash analysis has been performed and stickers have been placed on your equipment, these stickers will include incident energy levels or arc flash PPE categories on them. The incident energy level should be listed in cal/cm². This means that the highest energy level that this equipment will produce in an arc flash event will not exceed the posted cal/cm² rating. Your arc flash PPE should contain a tag that has an arc thermal protective value (ATPV) rating (also listed in cal/cm²). The ATPV rating means that the rated PPE will protect the wearer from arc flash energies up to that ATPV value. The arc flash PPE is only effective for equipment that has incident energy levels that are lower than the ATPV rating of the PPE. This is a fundamental understanding that all electrical workers should have.

HOW CAN YOU BE SURE YOU ARE WEARING THE CORRECT PPE FOR THE TASK AT HAND?

Following these two steps can help you determine if you are wearing the correct PPE for the task you're performing:

Step 1: Identify the hazard that you need to protect yourself from.

For the sake of this discussion, we are going to limit the hazards to electrical-specific hazards: electric shock and arc flash. With respect to shock hazards, note that arc flash PPE does not typically provide shock protection. If a potential shock hazard exists, then shock PPE must be considered in addition to the PPE discussed in this article (as well as fall protection, confined spaces, etc.).

Let's assume you know there's an arc flash hazard associated with the task you are about to perform. How do you determine the severity of the arc flash hazard? The severity is defined by the incident energy level. If there is a sticker on the equipment from an arc flash analysis, then the sticker will tell you the incident energy or the minimum level of PPE required. If there is no sticker, then you must reference NFPA 70E Table 130.7(C)(15)(A), Tables a and b. Based on this information, you should be able to verify the minimum level of PPE required.

If the sticker says it has an incident energy level of 4.6 cal/cm² — and all your arc flash PPE items are individually rated for 8 cal/cm² — then you can rest assured you have sufficiently rated PPE. If you have site-specific PPE categories or levels, then reference your company's electrical safety program documentation to confirm the minimum ATPV ratings for each level or category.

It's important to note that companies can have unique category ratings based on their PPE program. Don't assume the Category 2 PPE from a past employer is properly rated for Category 2 hazards at a new employer. Verify that the ATPV ratings for the new PPE categories line up with the protection rating of any existing PPE.

Step 2: Ensure you're protected from head to toe.

Arc flash PPE is more than just free shirts and pants that your company makes you wear to work. Depending on the exposure level, there are several other requirements to ensure you are completely protected when exposed to an arc flash event. Let's start with your head and work our way down to your toes.

Head protection — A hardhat is required for all levels of arc flash incident energies. The hardhat should be electrically rated and within the manufacturer's recommended lifecycle date. Also, when using the NFPA 70E table method, for energy levels of 4 cal/cm² and greater, you must wear either an arc-rated balaclava or arc-rated hood.

Face protection — Your face will need to be protected from two dangers: severe heat (molten copper, flames, plasma,

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etc.) and tremendous amounts of light energy from infrared to ultraviolet. You will need to wear an arc flash face shield with balaclava or arc flash hood to block the light exposure.

However, these face shields and hoods are not designed to protect you from the potential of projectiles. Therefore, you must also wear safety glasses under the hood or a face shield to fully protect your eyes.

Hearing protection — Hearing protection is required for all arc flash hazard levels. The sound created from an arc blast can reach up to 140 dB, which is comparable to hearing a military jet aircraft take off from 50 ft away. The recommended practice is to use ear canal inserts. A common question is: Will ear plugs melt in an arc flash? The reality is that ear plugs should never be exposed to an arc flash because they will either be under the balaclava or inside the arc-rated hood. However, the scientific answer is that the most common styles of ear plugs can withstand direct exposure to significant incident energies before showing signs of melting. But let's not test that ourselves — keep yourself and your earplugs covered.

Torso, arm, and leg protection — Your arms, legs, and torso should be covered by some combination of long sleeve shirt, pants, or coveralls. Your shirt sleeves should be rolled down. All buttons should be buttoned, and all zippers closed. Your shirt should be tucked into your pants. Not only should no skin be exposed, but there also should be no exposed non-arc rated materials. All the outer layers must be individually rated greater than the potential incident energy exposure.

Hand protection — You should always wear gloves that provide the appropriate level of arc flash protection. According to the NFPA 70E Table 130.7(C)(15)(c) Note (d), the combination of rubber insulating gloves with leather protectors satisfies the arc flash protection requirement.

Foot protection — Leather footwear will provide the protection needed for your feet. Tests have shown that even with steel toe leather boots, the leather provides sufficient protection to avoid any temperature increase inside the boot during an arc flash event. Keep in mind, however, that shoes should be completely leather and not a combination of leather and synthetic materials like many of the current popular safety shoes.

For all items of PPE, visually inspect them to make sure there are no holes, tears, or any other damage that may compromise the item's ability to withstand the hazard to which you will be exposed. With everything on, make sure there is no exposed skin or exposed non-arc rated materials. Also, ensure everything fits properly. It is best if the clothing is not too loose or too tight. A slight air gap between the shirt and your skin adds an extra buffer between you and the heat to which you could potentially be exposed. Also, keep in mind that if the task requires fall protection, you should be using an arc-rated harness and lanyards. Anything worn on the outside of your arc flash PPE should also be arc rated.

In a nut shell, the questions you should ask and answer for yourself are:

- First, is there a way to accomplish this task without being exposed to an arc flash event?
- If not, what are all the potential arc flash hazards and their severity?
- Is the arc-rated PPE an appropriate level for my needed protection?
- Does the arc flash PPE provide complete head-to-toe coverage?

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WHY DO YOU NEED AN INCIDENT ENERGY/ARC FLASH ANALYSIS?

The reasons are numerous, but safety is the top priority.

By Ryan Downey, P.E.

Protecting workers' lives is a priority. If a serious incident occurs, the emotional and financial effects can be devastating. For most countries, including the United States, electrical safety is mandated and regulated by the law. OSHA 1910.132 requires employers to assess the workplace to determine if hazards are or are likely to be present. OSHA references the National Electrical Code (NEC), NFPA 70E – *Standard for Electrical Safety in the Workplace,* and IEEE standards for compliance. Additionally, these standards, as well as the National Electrical Safety Code (NESC), which is specifically enforced for electric utilities, require an arc flash assessment to be performed. IEEE 1584 – *Guide for Performing Arc Flash Hazard Calculations,* provides a procedure for performing the arc flash hazard/incident energy calculations.

WHAT CAUSES AN ARC FLASH EVENT?

An arc flash is a rapid release of energy due to an electrical arcing fault. This could be due to a fault that is phase-to-phase, phase-to-ground, or phase-to-neutral. Sometimes, a worker can cause an arc flash by using inadequate safety practices, working on energized equipment, or intentionally using unsafe tools. For example, while working on energized equipment, a worker drops an uninsulated tool in the equipment that causes a phase-to-phase or phase-to-ground fault that escalates into an arc flash event.

Other things that may increase the risk of an arc flash event are related to the environment, such as moisture building up on the energized equipment, which can increase the conductivity and cause an arc. Faulty equipment that isn't working properly, is defective, or allows exposure to foreign objects can also pose an arc flash risk. As **Fig. 1** shows, when you start to combine these individual risks, you increase the chances of an arc flash event.

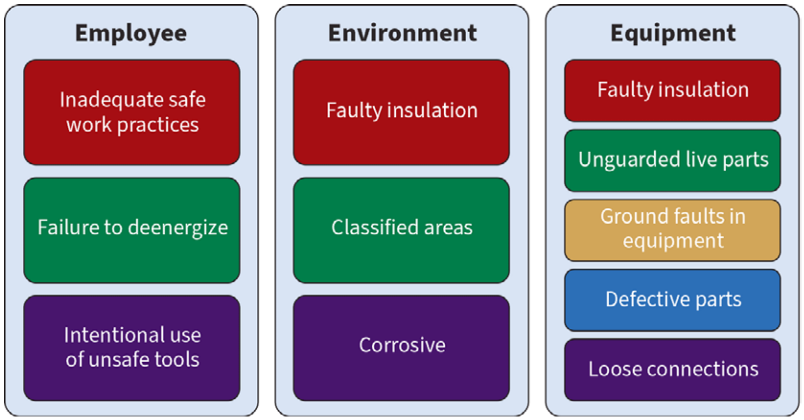

Fig. 1. Three key factors come into play with an arc flash event.

In addition, maintenance of electrical equipment is crucial because the risk of an arc flash occurring or equipment having exposed energized conductors or circuit parts can be dramatically reduced by adhering to sound maintenance practices and procedures.

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NON-COMPLIANCE

A common occurrence that can happen relating to non-compliance is the misuse of personal protective equipment (PPE) tables contained in NFPA 70E. Something often overlooked is that NFPA 70E requires the available fault current and clearing time of the protective devices to be known, which typically isn't the case. Furthermore, NFPA 70E states that an incident energy analysis must be performed for the following conditions:

- The worker's task(s) are not listed in the tables.
- Power systems with greater than the estimated maximum available fault current.
- Power systems with longer than the maximum clearing times.
- Tasks with less than the minimum working distance.

When the NFPA 70E tables are used instead of an incident energy analysis, some things to consider include:

- Notes in the tables that have specific requirements for the PPE are generally ignored.
- The short-circuit current is assumed.
- The protective device clearing time is assumed.

In addition, maintenance of the protective devices is not considered when the tables are used. This can affect the incident energy in the event a sticky breaker or other protective device isn't opening when it should, so the clearing time of the device would be inaccurate. It's also important to note that the tables and the arc flash calculations are not intended to work together. Therefore, NFPA 70E did away with the PPE values and identifies PPE with actual incident energy values for the analysis.

Insufficient training can also be a problem because workers need to know the correct use of PPE, they need to be able to recognize electrical hazards, and they need to understand safe work practices. This training is required and specified by OSHA, NFPA 70E, and the NEC.

INADEQUATE EQUIPMENT MAINTENANCE

For the arc flash hazard analysis to be valid, Sec. 130.5 in NFPA 70E requires the consideration of maintenance. As a case example, consider the following situation:

- A low-voltage power circuit breaker has not been operated or maintained for several years.
- The lubrication has become sticky or hardened.
- The circuit breaker could take additional time to clear a fault condition.

Two flash hazard analyses will be performed using a 20,000A short circuit with the worker 18 in. from the arc:

- Based on what the system is supposed to do [0.083 sec (5 cycles)].
- Due to a sticky mechanism, the breaker now has an unintentional time delay of 0.5 sec (30 cycles).

E_{MB} = maximum 20-in. cubic box incident energy, cal/cm^2

D_B = distance from arc electrodes, inches (for distances 18 in. and greater)

t_A = arc duration (seconds)

F = short circuit current, kA (for the range of 16kA to 50kA)

All calculations are based on formulas in NFPA 70E-2018, Annex D (D.3.3).

(1) D_B = 18 in.

(2) t_A = 0.083 sec (5 cycles)

(3) F = 20kA

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$$E_{MB} = 1038.7D_B^{-1.4738}t_A \times [0.0093F^2 - 0.3453F + 5.9675]$$

$$E_{MB} = 1038.7 \times 0.0141 \times 0.083\ [0.0093 \times 400 - 0.3453 \times 20 + 5.9675]$$

$$E_{MB} = 1.4636 \times [2.7815]$$

$$E_{MB} = 3.5\ \text{cal/cm}^2$$

Per Sec. 130.5 of NFPA 70E, arc-rated FR clothing and other PPE to be selected based on this incident energy level exposure. Thus, the FR clothing and PPE must have an arc rating of at least 3.5 cal/cm².

Now, let's run through the same calculation considering the sticky breaker scenario:

(1) D_B = 18 in.

(2) t_A = 0.5 sec (30 cycles)

(3) F = 20kA

$$E_{MB} = 1038.7D_B^{-1.4738}t_A \times [0.0093F^2 - 0.3453F + 5.9675]$$

$$E_{MB} = 1038.7 \times 0.0141 \times 0.05\ [0.0093 \times 400 - 0.3453 \times 20 + 5.9675]$$

$$E_{MB} = 7.3179 \times [2.7815]$$

$$E_{MB} = 20.4\ \text{cal/cm}^2$$

Therefore, the FR clothing and PPE must have an arc rating of at least 20.4 cal/cm².

ARC FLASH LABELS

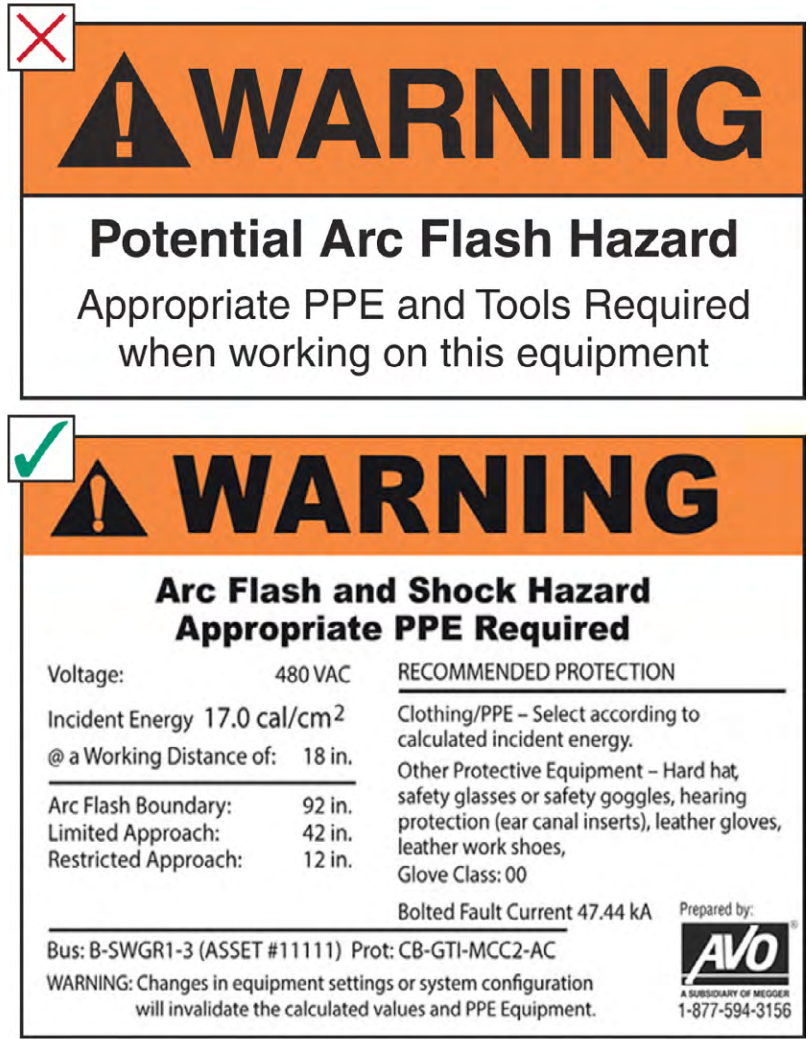

Fig. 2. Two examples of arc flash warning labels. The top label is inadequate, as it's missing a lot of crucial information.

It's important to use proper signage on electrical equipment, and that workers know the proper PPE to wear before beginning work on energized electrical equipment. The label shown in **Fig. 2** with an "X" beside it is a generic arc flash label that does not inform the worker of the incident energy present at the equipment, the arc flash boundary, or even what type of

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PPE is required. The label with a check mark beside it is a typical arc flash label that is based on the requirements in NFPA 70E, Sec. 130.5. The detailed label shows the voltage, incident energy value, the working distance, and the arc flash boundary.

Also notice that the Limited Approach and Restricted Approach boundaries are shown. The limited approach boundary represents that a shock hazard exists within this boundary. The restricted approach boundary represents an increased shock hazard due to the electric arc over combined with inadvertent movement.

WHAT IS AN INCIDENT ENERGY ANALYSIS?

Now that we know an arc flash hazard or incident energy analysis is required, what exactly is it? In a nutshell, mathematical methods are used to determine and reduce, if possible, the risk of personal injury due to exposure to incident energy from an arc flash. The purpose of the incident energy analysis is to identify the incident energy exposure of the worker, the arc flash boundary, the appropriate working distance, and the required calorie rating of the PPE.

The magnitude of the arc flash hazard is determined by the NFPA 70E equations or the IEEE 1584 standard, which was derived from actual test data that took place. Arc flash hazard is expressed in incident energy with the units cal/cm^2. Additionally, arc flash protective clothing is rated in arc thermal performance value (ATPV), which is also expressed in cal/cm^2. Essentially, you must be certain the cal/cm^2 rating of the PPE you are wearing is greater than the calculated incident energy (or cal/cm^2) of the equipment you're working on. With a proper arc flash study, this information should be presented on the arc flash label.

How can you be sure you are getting an accurate study? One of the most frequent questions asked is if an engineer is required to perform an arc flash study. The correct answer to this should always be "yes."

It's essential to have a qualified and properly trained individual perform the study, and engineering boards typically require a licensed professional electrical engineer (P.E.) to do it. In most cases, the Engineering Board of the state or governing body in which the study was performed requires a P.E. to certify the work.

It's vital to understand that people's lives depend on the information presented in these studies; thus, it's crucial they are accurate. If there is an incident, you can guarantee OSHA will consider whether the study was accurate and whether the individual who performed the study was qualified. It's also recommended to confirm the study was performed with proven engineering software.

INCIDENT ENERGY ANALYSIS PROCESS

Figure 3 shows the incident energy analysis process. Each of the tasks listed is a crucial component of a complete analysis, and it's very important that each is performed thoroughly and properly to create an accurate study.

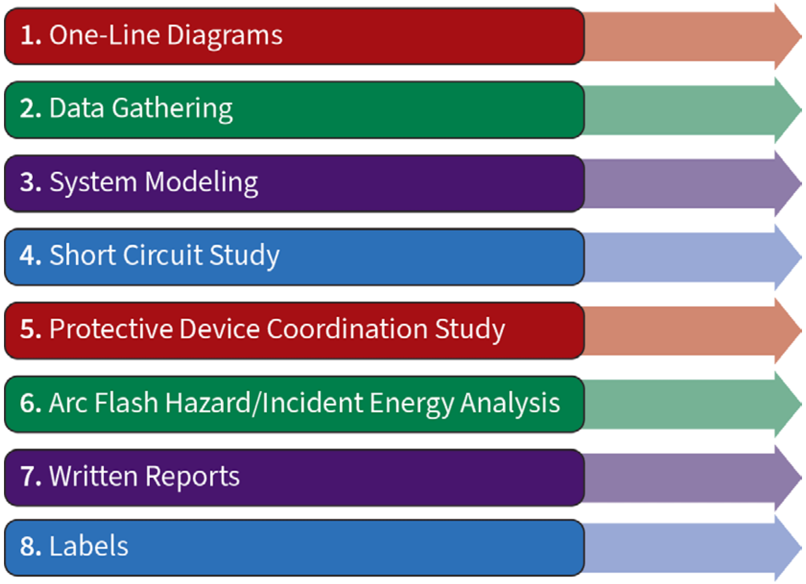

Fig. 3. These are the steps to include in an incident energy analysis process.

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Electrical one-line diagrams

The process begins with the evaluation of the electrical one-line diagrams, which should be kept up to date per NFPA 70E. For the study to be accurate, it is helpful if existing electrical one-line diagrams show the full power distribution layout. The one-lines should identify the sources of power, voltage levels, and electrical equipment such as transformers, generators, switchgear, motor control centers, panelboards, and the protective devices (**Fig. 4**).

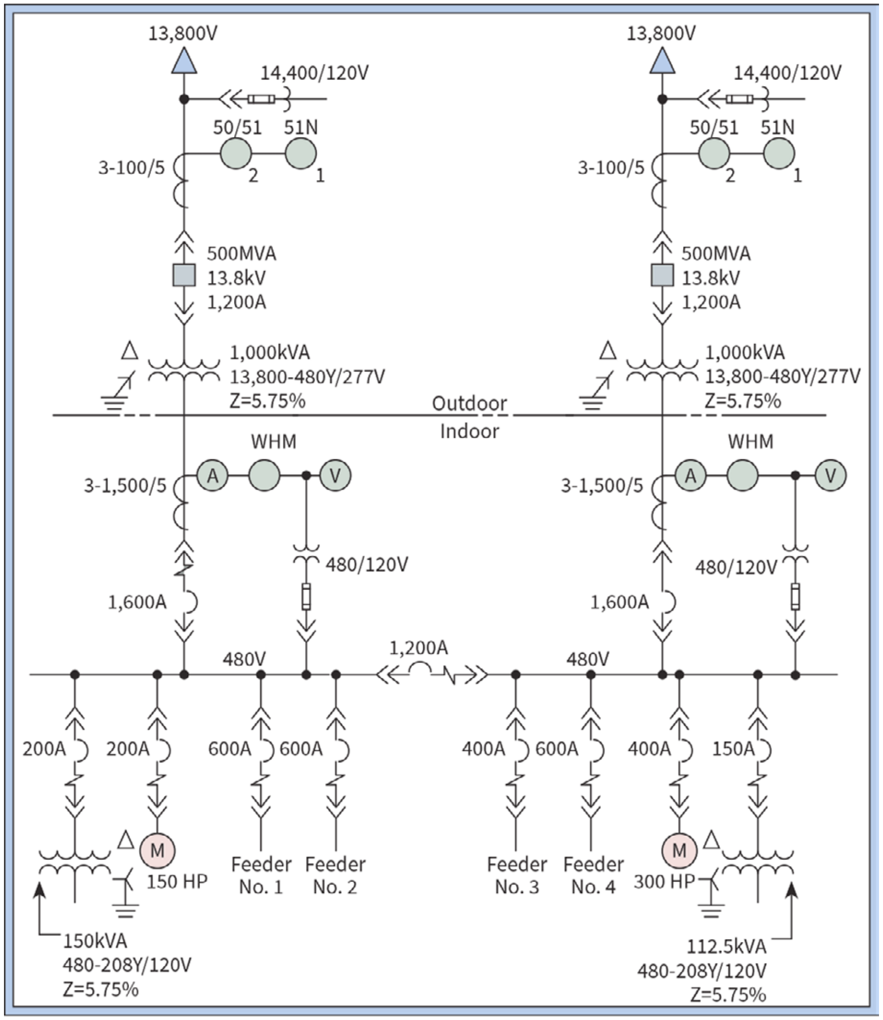

Fig. 4. Example of a typical one-line diagram.

Data gathering and system modeling

Where electrical one-line diagrams are not available, the data gathering process must identify all this information. Once the data is gathered, a one-line diagram must be created based on it. To properly perform the analysis, the process should be very thorough, where all the information of the equipment is gathered, such as ratings of the equipment, arrangement of components on electrical one-line diagram, nameplate of every electrical device, ratings and trip settings of every protective device, and sizes and lengths of all conductors.

IEEE 1584-2018 now requires the electrode configuration and enclosure sizes to be considered in the calculations. It is critical to obtain the information on actual equipment so that the study is accurate. Shortcuts are often taken here, which can cause the study to be inaccurate or invalid. The electric utility contribution, or available fault current, is also an essential piece of the puzzle for proper analysis. It can be challenging to get this information from an electric utility. Many times, an infinite bus calculation is used when the actual fault current cannot be obtained. However, when an infinite bus is used, the clearing time would be much faster than it would be with the actual level of fault current (**Fig. 5**), which results in a false calculation.

- I_{sca} = 28kA clears in 0.1 sec. (infinite bus fault current)
- I_{sca} = 9kA clears in 1 sec. (actual fault current)

The gathered information is then typically put into engineering software in the form of a one-line diagram model with the correct information selected for each component. This provides the basis for comprehensive power system modeling in performing all types of analysis.

Short-circuit study

As part of the study, a short-circuit analysis is performed

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to determine if the protective devices are properly rated to withstand a bolted-type short circuit fault. To determine this, the maximum available fault current is calculated at each significant point in the system, and as an additional analysis, the bolted fault currents are converted into arcing currents. The results are determined based on the existing rating of the equipment.

Protective device coordination

Another important aspect is the protective device coordination study. This allows the engineer to properly coordinate the protective devices so that you don't have an upstream breaker tripping before a downstream breaker in the event of a fault. If this happens, it could shut down critical equipment or possibly even an entire facility, depending on the configuration. In most cases, a protective device coordination study also allows the incident energy levels (or the arc flash hazard) to be reduced at various locations with recommended changes to existing settings on the breakers or relays.

Incident energy/arc-flash hazard analysis

The arc flash hazard (or incident energy) calculations are also performed as part of the study. As mentioned previously, the calculations are typically based on IEEE 1584; however, the calculations can be based on the equations depicted in NFPA 70E or NESC, depending on the type of facility and/or electrical equipment involved.

Written reports and labels

Of course, as part of the final deliverables, a written report is provided to inform the owner of the results and recommendations. Labels are also applied to the electrical equipment, which shows the incident energy, PPE requirement, arc flash boundary, and working distance for that piece of equipment.

Electrical one-line diagrams are typically provided with the deliverables as well, where the drawings can be customized to show specific incident energy levels, short-circuit current, etc., on the drawings.

Also, as mentioned before, since this is an engineering report and/or study, the documents are typically required to be certified by a licensed P.E.

UPDATE REQUIREMENTS

What do you do after the analysis is complete? Now you need a plan to keep it properly maintained and updated.

Per NFPA 70E Sec. 130.5, an incident energy analysis should be updated when major system modifications take place. This accounts for changes in the electrical system that could affect the analysis. In addition, the studies must be reviewed at a minimum of every five years. Changes to the available fault current or electric utility equipment could greatly affect the analysis.

Make sure you keep the studies up to date. If the information is not kept current, it is unreliable.

SUMMING IT UP

Hopefully, you now understand the steps involved in an incident energy analysis and what regulations or standards govern the process. Proactively managing these activities helps protect your employees and equipment, and reduces your risks of potential fines and litigation.

At the time this article was published, Downey was a Principal Engineer for AVO Training Institute (www.avotraining.com). He is an active member of the IEEE 1584 Working Group – Guide for Performing Arc-Flash Hazard Calculations, IEEE 1814 Working Group – Recommended Practice for Electrical System Design Techniques to Improve Electrical Safety, and serves as an alternate on the NFPA 70E Technical Committee. He can be reached at rdowney@westernelectricalservices.com.

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