Arc Flash Energy Reduction Techniques
Zone Selective Interlocking & Energy-Reducing Maintenance Switching

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***Abstract* - The safety of personnel that work on electrical power distribution systems has received increasing attention from a number of Standards and regulatory organizations in recent years. Organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the Occupational Safety & Health Administration (OSHA), the National Fire Protection Association (NFPA) and several other groups are actively engaged in ongoing discussions on improving electrical worker safety, specifically in the area of protection from Arc Flash hazards. While standards developed by these organizations discuss improvement opportunities, there are a number of techniques and technologies that are currently available for mitigating Arc Flash exposure. This paper will provide a general overview of the key arc flash reduction techniques, and will specifically focus on two of these technologies - Zone Selective Interlocking & Arc Energy Reduction Maintenance Switch Systems. The benefits, expected performance, and the appropriate application of each of these arc flash reduction solutions will be presented.**

***Index Terms* – Arc flash, NFPA 70E-2009, Incident energy, Flash Protection Boundary, Flash Hazard Analysis, IEEE Std. 1584, Personal Protective Equipment (PPE), instantaneous current circuit breaker, Zone Selective Interlocking, Selective Coordination**

I. INTRODUCTION

Ideally, work on an electrical system can only be 100% safe if that system is totally de-energized while work is being performed. In many instances, such as in "process" industries where facilities are required to operate continuously for "24/7/365", a totally de-energized system may not always be possible. The electrical system may need to be energized to conduct maintenance or to perform trouble-shooting tasks. The steps involved in confirming that an electrical circuit is indeed de-energized, may also put the worker at risk.

The National Fire Prevention Association (NFPA) published the NFPA 70E "Standard for Electrical Safety in the Workplace"[1] documents safety requirements [1] for working on electrical equipment. This Standard defines specific rules for determining the level of electrical hazards and the corresponding personal protective equipment (PPE) that is required for personnel to work in certain electrical hazard zones. Over the years, these regulations have forced both employers and employees to review and improve their electrical systems and safe-work practices to reduce electrical shock and electrical arc-flash hazards.

These electrical hazards are an on-going serious risk to the safety of those who work on electrical systems.

> "*Between five and 10 times a day, an arc flash explosion occurs in electric equipment somewhere in the United States that sends a burn victim to a special burn center*" , according to statistics compiled by CapSchell, Inc., a Chicago-based research and consulting firm that specializes in preventing workplace injuries and deaths.
>
> "*That number does not include cases sent to regular hospitals and clinics, or unreported cases and "near misses," estimated to be many times that number. There are one or two deaths a day from these multi-trauma events*", noted Dr. Mary Capelli-Schellpfeffer, principal investigator [4].

Therefore, for those circumstances where electrical work HAS to be done on an energized electrical system, much preparation, planning and protection must be carried out. A comparison of this energized electrical work was made to police bomb squads. These specialized workers do not go into an "energized" situation without careful planning, proper protection, and training. Employees facing work on electrical equipment should be similarly prepared.

To ensure employees are suitably prepared for hazardous electrical work, employers must plan for it. Employers must develop and implement formal Safety Plans and programs that ensure employees are prepared to face the hazards associated with energized electrical work. An employer should charter electrical safety teams who should have responsibilities and authority to drive a positive safety culture in the organization. These safety teams should be able to do things such as report directly to senior management, be encouraged to make technically sound choices, and to establish short and long-term goals towards safety improvements [8].

Over the years, a number of methods have been developed to help reduce the arc flash and shock hazards and risks associated with working on energized electrical equipment. Experience has shown that there is no one single solution for reducing these hazards and risks – in many cases, a combination of as many applicable solutions as practical is often the best approach. Some of these solutions have evolved, been refined, and have become such generally accepted "common-practice" over the years, that some have been adopted as “requirements” in various Codes and Standards.

This paper will briefly discuss some of the more commonly practiced arc flash reduction solutions, along with the existing Codes and Standards requirements. However, the paper will focus primarily on two solutions that are specifically mentioned as part of new options in the 2011 Edition of the NEC.

II. THE CODES & STANDARDS

A. OSHA

The Occupational Safety and Health Administration (OSHA) describes general industry electrical safety standards for the qualification of workers exposed to electrical shock hazards and the provision for protective equipment appropriate for the work to be performed [5]. OSHA enforces safety practices that are related to the NFPA requirements. OSHA’s electrical standards are based on the National Fire Protection Association Standards NFPA 70 (*National Electric Code*), and the NFPA 70E (*Electrical Safety Requirements for Employee Workplaces*).

B. NFPA 70E

The NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces [1], can be considered the “how to” standard that OSHA uses for enforcement. This standard outlines the detailed actions that employer companies must take to be in Federal compliance. These requirements include:

- A Safety Program with defined responsibilities
- Calculations for the level of arc flash hazard
- Warning labels on electrical equipment
- Personal protective equipment (PPE) for workers
- Tools for safe work
- Training for workers

C. NEC

The National Electrical Code (NEC) [2], in Section 110.16 Arc-Flash Hazard Warning, requires that a field marked label be placed on equipment to warn qualified persons of potential electric arc flash hazards. This field marking, as shown in Fig. 1, shall be located so as to be clearly visible to qualified persons before work is done on the equipment.

Fig. 1. Example of an Arc-Flash Hazard Warning label per NEC [2], Section 110.16

In order for the warning labels to carry enough information to show the danger zone for arc flash conditions, companies must determine that area within which only qualified workers with appropriate PPE should enter—the flash protection boundary.
Fig. 2 shows a typical warning label per NFPA 70E [1], which includes information such as the Flash Hazard Boundary, the arc flash energy (expressed in cal/ cm^2), and the recommended PPE level.

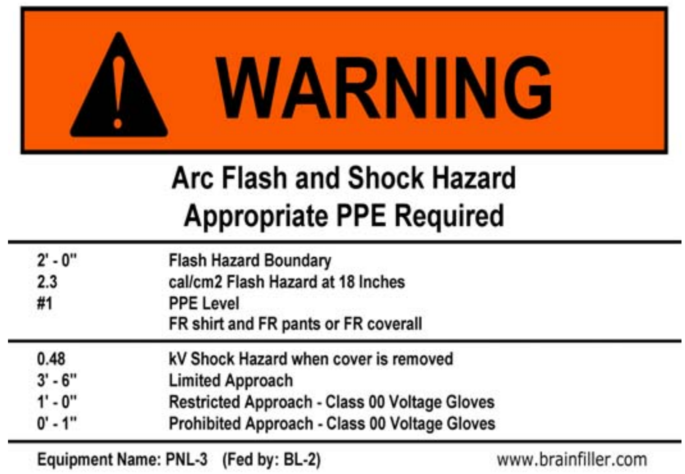

Fig. 2. Example of an Arc Flash Warning Label, per the NFPA 70E [1]

IEEE 1584 [3] provides a method to calculate the incident energy in order to specify the level of Personal Protective Equipment (PPE) required for workers.\

D. IEEE 1584

In 2002, the IEEE published IEEE Standard 1584, “*Guide to Performing Arc Flash Hazard Calculations*” [3] as a method for the calculation of

1) Incident Energy and
2) Arc Flash Protection Boundaries

associated with personnel working in a potential arc flash situation. The Standard presents formulas for numerically quantifying these two values.

For systems voltage below 1000 V, the <u>Arcing Current</u> can be found using the equations below [6]:

$$Lg\,Ia = K + 0.662 * Lg\,I_{bf} + 0.0966 * V + 0.000526 * G + 0.5588 * V * (Lg\,I_{bf}) - 0.00304 * G * (Lg\,I_{bf}) \quad \ldots(1)$$

where:

- Lg - is logarithm base 10
- Ia – is arcing current in kA.
- K - is -0.153 for open configurations. and -0.097 for box configurations.
- I_{bf} - bolted fault current for three phase faults in kA (symmetrical rms.)
- V – is system voltage (kV)
- G – is the gap between condactors (mm).

The Incident Energy is then determined from the arcing current as [6]:

$$\lg En = K1 + K2 + 1.081 \lg Ia + 0.0011\, G \quad \ldots (2)$$

where:

- En is incident energy (J/ cm^2) normalized for time and distance
- K1 is –0.792 for open configurations (no enclosure) and is –0.555 for box configurations (enclosed equipment)
- K2 is 0 for ungrounded and high-resistance grounded systems and is –0.113 for grounded systems
- G is the gap between conductors (mm)

Finally converted:

$$E = 4.184 * Cf * En * (t / 0.2) * (610^x/D^x) \quad \ldots (3)$$

where:

- E – is incident energy exposure in J/ cm^2.
- Cf – is a calculation factor equal to 1.0 for voltages above 1 kV, and 1.5 for voltages below 1 kV.
- En – is normalized incident energy in J/cm^2.
- t – is arcing time (seconds)
- D – is distance from possible arcing point to the person (mm).
- x – is distance exponent.

The Flash Protection Boundary is found using the equation below [6]:

$$D_B = [4.184 * Cf * En * (t / 0.2) * (610x/E_B)]1/x \quad \text{(eqn. 4)}$$

where:

- D_B – is distance of the boundary from the arc point in millimeters.
- Cf – is a calculation factor equal to 1.0 for voltages above 1 kV, and 1.5 for voltages below 1 kV.
- En – is normalized incident energy in J/cm^2
- E_B – is incident energy in J/cm^2 at the boundary distance. EB is usually set at 5 J/ cm^2 (1.2 cal/ cm^2) for bare skin, or at the rating of proposed personal protection equipment
- t – is arcing time (seconds)
- x – is distance exponent.

The apparent complexity of these equations makes solving them by hand cumbersome. An electronic version of the IEEE 1584 guide supplies an Excel spreadsheet that will automatically solve these equations, after the users' inputs basic information. While the IEEE 1584 guide provides a step forward in the understanding of arc-flash hazards, there are several points that are frequently misunderstood [7]. The use of this Excel spreadsheet from IEEE and other software 'calculator' tools made available by software companies, all help to simplify many of these error-prone set of calculations.

Since the introduction of the original NFPA 70E standard and the IEEE 1584 guide, there have been appreciable improvements in modeling electrical systems for analysis. Power systems analysis software programs are available today that integrate system coordination, short circuit analysis and arc flash calculations. Programs such as these have been developed to provide more 'real world' modeling and accurate analysis than using the estimation tables per NFPA 70E or the calculations per IEEE1584.

Whether done manually or via a software "tool", the end results from these calculations are the cautionary information to be placed on the label required by the NFPA 70E Standard, and most importantly, the PPE and Protection Boundaries that need to be followed by employees that work on energized equipment.

III. SOLUTIONS FOR ARC FLASH HAZARD REDUCTION

Some of the most commonly used methods for reducing arc-flash hazards are

A. Avoid the Hazard Area
   1) Minimize the risk with good safety practices
   2) Label equipment and train employees
   3) Move people further away

B. Redirect the Blast Energy
   1) Install arc-resistant switchgear

C. Reduce the Available Fault Current

D. Improve the Protection Scheme

E. Reduce Total Clearing Time
   1) Reduce Trip Settings

A. Avoid the Hazard Area

The safest way to prevent arc flash incidents is to add distance between an individual and the hazard areas. Avoid contact with the areas where the arc flash hazards exist. The approach of moving people further away uses the idea that the effects of an arc flash blast decrease with distance from the blast. Increased distance from the blast always helps.

Manufacturers provide remotely controlled or operated mechanisms for racking circuit breakers into safe operating positions. Various electronic communications links may be used to access operational and maintenance data, and to control the opening and closing of circuit breakers and switches.

Fig. 3. Remote Power Racking unit

Fig. 3. Example of a Remote Power Racking Systems that allows an operator to be outside the Arc Flash boundary (25 ft. or more during racking)

The use of robots, long-handled tools to put the worker further from the electrical circuit, infrared windows to allow inspection with cabinets and doors closed, remote 'racking' of electrical equipment, and current-limiting circuit breakers, are some of the other options

.In general, employers must establish a Safety Program as a key tool for employee safety. The Occupational Safety & Health Administration (OSHA), in enforcing worker safety procedures, cites the NFPA 70E guide as the "How To" source for compliance. One basic requirement is that an electrical safety program must be established for each facility with specific elements included. The safety program must stipulate procedures to address the hazards of working on energized equipment, with the goal being to remove the worker from the danger zone or to remove or reduce the intensity of the arc flash.

Employers must train and certify that employees are knowledgeable about arc flash hazards and how to avoid them. Various training modules must be developed to provide training for both un-qualified personnel, and for technicians and equipment operators that might be exposed to arc flash hazards.

Safety signs, safety symbols or accident prevention tabs shall be used where necessary to warn employees about electrical hazards that might endanger them. Sign and tags shall meet the requirements per NFPA 70E ARTICLE 130.7, *Alerting Techniques.*

The specifics of the electrical safety plan need to follow the completion of an arc flash hazard analysis. This analysis determines the flash protection boundary distance and the type of personal protective equipment (PPE) required for working in various situations.

IEEE 1584 [6] standard establishes nine key steps in the arc flash versus incident energy analysis process:

1. Collect system and installation data
2. Determine system modes of operation
3. Determine bolted fault current
4. Find protective device characteristics and arc duration
5. Document system voltages and equipment class
6. Determine arc fault current
7. Select the working distances
8. Calculate the incident energy
9. Calculate flash protection boundary

Proper protective equipment must be worn when any of this work is conducted within the established flash protection boundary for that equipment.

B Redirect the Blast Energy

Several switchgear manufacturers provide equipment that is arc resistant, built and testing in accordance with ANSI/IEEE Standard C37.20.7. Doors and internal structures have been reinforced, as well as providing improved discharge paths for the blast pressure and material associated with an arc flash. Type 1 arc resistant switchgear as defined by the Standard provides personnel protection only when in front of that switchgear.
Type 2 arc resistant switchgear as defined by the Standard provides personnel protection all the way around the external perimeter of the switchgear.

Arc resistant switchgear is one solution to reduce the hazard, but it does not solve all the arc flash issues alone, as the system may be considered to be no longer arc resistant once the doors are opened, depending on the design configuration of the switchgear.

C Reduce the Available Fault Current

Current limiting devices such as high impedance transformers and in-line reactors have been used for many years to reduce the available fault current. These techniques must however, consider the trade-offs of creating continuous losses in the system.
For low-voltage systems, current limiting fuses and fast-interrupting circuit breakers provide fast clearing times for reduction of incident energy. However, as the available fault currents are reduced, the arcing current may be as low as 38% of the calculated bolted fault currents [14]. As a result, when current limiting fuses are used for protection, the

available fault current is likely to be below the current limiting threshold of these fuses, causing them to take longer to trip and subsequently increasing the incident energy. These devices should be carefully selected to avoid this issue.

D. Improve the Protection Scheme

A number of different protection schemes have been implemented by electrical system design engineers over the years. Specifically, high-impedance and low-impedance bus differential relaying schemes have been used to provide high speed tripping.

These schemes use current transformers to monitor currents, and in conjunction with a relay device, accurately and very quickly trip when a fault occurs. This scheme monitors the magnitude of the current entering and leaving a zone, and if they are not the same, initiate a trip.

The trade-off to consider with these schemes involves the costs and complexity associated with the current transformers, system wiring and testing to validate the schemes.

Despite these cost challenges, the new ARTICLE 240.87 of the 2011 NEC has identified that these schemes, or approved equivalents, may be used as an option to provide fast tripping for arc flash reduction.

E. Reduce Total Clearing Time

On of the most efficient methods for reducing incident energy in an arc flash situation is to clear the fault quicker - by causing the over-current protective device to trip faster. The appropriate trip settings for an over-current protective device in an electrical power distribution system should be determined by qualified personnel conducting analyses on the available short circuit currents, selective coordination requirements, and arc flash hazards. Qualified personnel should be able to make the necessary trade-offs decisions based on the findings from the system analyses.

Where it is possible to reduce arc flash hazards by reducing the total clearing times of over-current protective devices, the electrical system designer should appropriately implement those options.

As with differential relaying schemes, the new ARTICLE 240.87 of the 2011 NEC has identified the use of Zone Selective Interlocking and Energy-Reducing Maintenance Switching as additional options for faster tripping and reduced total clearing time for arc flash reduction.

IV. NEW NEC REQUIREMENTS - ARC FLASH REDUCTION

In the investigation of the various ways to reduce the arc flash and shock hazards and risks associated with working on energized electrical equipment, there are many factors to consider. What are the hazards – the sources of potential damage, harm or adverse health effects on the facility or the employees? What are the risks – the probability that a person will be harmed or experience an adverse health effect if exposed to a hazard? Has an Arc Flash study been performed on the latest electrical system? Is there a Safety Program in place that includes training of employees on arc flash hazards? Has Personnel Protective Equipment (PPE) been made available for all personnel that perform hazardous electrical work?

Employees that work in the electrical inspection industry find that they may be exposed to shock and arc flash hazards while conducting the necessary inspections of electrical systems. The International Brotherhood of Electrical Inspectors (IBEW) is credited with submitting the original proposal that now requires arc reducing technologies to be used in certain applications involving circuit breakers. The goal of their proposal, now an NEC requirement, was to use currently available technologies, to continue to enhance safer working conditions.

Therefore, to help address this, the 2011 Edition of the NEC has a new set of solutions for addressing arc flash energy reduction in circuit breaker applications, as follows per ARTICLE 240.87

240.87 Non-instantaneous Trip. Where a circuit breaker is used without an instantaneous trip, documentation shall be available to those authorized to design, install, operate or inspect the installation as to the location of the circuit breaker(s).

Where a circuit breaker is utilized without an instantaneous trip, one of the following or approved equivalent means shall be provided:

(1) Zone-selective interlocking

(2) Differential relaying

(3) Energy-reducing maintenance switching with local status indicator

Informational Note: An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to ‘no intentional delay’ to reduce the clearing time while the worker is working within an arc-flash boundary as defined in NFPA 70E, 2009, Standard for Electrical Safety in the Workplace, and then to set the trip unit back to a normal setting after the potentially hazardous work is complete.

In order to maintain selective coordination in some applications, an upstream main circuit breaker may be chosen that does not have an instantaneous trip function. In these cases, if this main circuit breaker were to experience a short circuit condition, it would remain closed for its preset short delay time setting. And the longer it takes to trip, the higher the arc flash risk.

Therefore, the idea behind the IBEW proposal and the subsequent new NEC requirement is that in cases where the circuit breaker is used without an instantaneous trip, an alternate means shall be provided to reduce the fault clearing time while a worker may be within an arc flash boundary of that circuit breaker. Many circuit breaker manufacturers have designs where the instantaneous function may be turned "OFF". In cases where the instantaneous trip is turned "OFF", the circuit breaker will not trip via its instantaneous function, and per the new NEC requirement, an alternate means for reducing the clearing time shall be provided.

The three devices and technologies listed in this new NEC requirement have been available in the electrical industry for several years now. The IBEW saw the opportunity to further evolve safety improvements, and proposed the use of these devices as a solution for arc flash energy reduction in certain circuit breaker applications.

It seems a logical next-step in a future NEC edition to expand these enhanced safety requirements to include other types of over-current protective devices, besides just circuit breakers.

The focus of the following sections will be to primarily explore how the operation of the Zone Selective Interlocking (ZSI) and the Energy-reducing maintenance switching, provide a solution to reducing arc flash hazards.

V. ZONE SELECTIVE INTERLOCKING (ZSI)

A. Purpose of Zone Selective Interlocking

Zone Selective Interlocking (ZSI) is a scheme that has been used since the mid-1980s to improve the level of protection in an electrical power distribution system. ZSI was developed when electronic trip devices were first introduced in circuit breakers and protective relays. The focus of the ZSI scheme has traditionally been for system protection – specifically to speed up the tripping time for some faults without sacrificing selective coordination and interjecting nuisance tripping into the system. By being able to more quickly open circuit breakers during either short circuit or ground fault conditions, the stresses (thermal and mechanical) on the electrical system may be reduced.

Thermal stresses are the result of energy dissipated in the system during the fault, and is expressed as a 'Let-Through' energy, typically shown as an I^2t value (current, (I) squared times the fault clearing time).
Mechanical stresses are the result of the high magnetic forces associated with the peak current during the fault, and these forces have been seen to bend bus bars and damage insulators.

A key way to minimize the stresses on the electrical components of the system is to reduce the time that the fault condition exists on the system. This is done by carefully selecting over-current protective devices that can quickly operate to clear the fault condition. A coordination study of the electrical system must be performed to ensure that proper ratings of over-current protective devices are chosen. The settings of these devices are selected so that pick-up and time delay levels cascade down from the main power sources to the smallest loads, ensuring that the over-current protective closest to the fault trips. This allows for improved reliability and uptime of the remainder of the system.

It is important to note that the implementation of a ZSI scheme is independent of having a selective coordinated system. A ZSI scheme will NOT make an electrical system, which has not been set to proper pick-up and time delays on the over-current devices, selectively coordinate.

In a typical electrical power distribution system, the over-current protective devices are arranged in cascading "zones", from the power source(s) down to the smallest load circuits, as shown in Fig. 4.

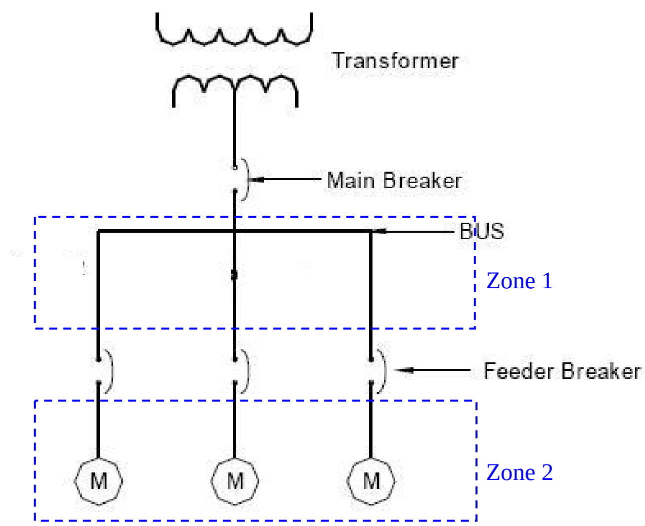

Fig. 4. Example of Zones in an Electrical System

B. How Zone Selective Interlocking Works

The concept of ZSI is best understood in a visual format – see Fig. 5. ZSI allows the electronics of circuit breaker trip units or protective relays to communicate across the distribution zones. The electronic interlocking of the devices causes the device closest to the fault to automatically over-ride its intentional pre-set short time delays and trip with no intentional delay. The result is that the other devices in that zone and also in the upstream zones remain closed and unaffected by the fault, and the fault is cleared much more quickly than a similar system without ZSI.

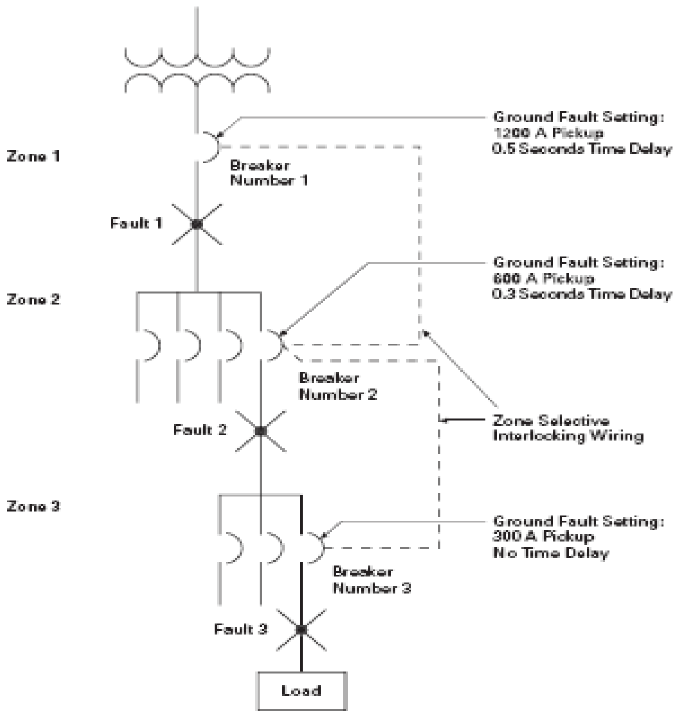

Fig. 5. Example of a Zone Selective Interlocking system.

If a fault exceeds the short time pickup of a down stream device (Zone 2), the trip unit will send a signal upstream to acknowledge that it recognizes the problem.

An example of this is demonstrated with a feeder fault, as shown in Fig. 6. For a short circuit fault that occurs on the load side of the feeder circuit beaker, both the main circuit breaker and the feeder circuit breaker's trip units sense the fault.

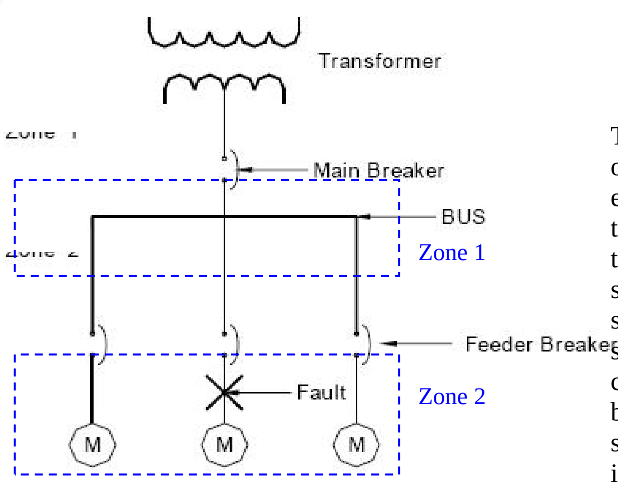

Fig. 6. A Fault at a Feeder Circuit Breaker

The feeder circuit breaker sends a blocking signal through the communication wires to the main circuit breaker, letting the main circuit breaker know that the fault is in the feeder circuit breaker's zone of protection, and that it will trip with no intentional delay. The blocking signal also tells the main circuit breaker to trip per its pre-set time delay if the fault is not cleared by the feeder circuit breaker.

This keeps the main circuit breaker from interrupting, therefore maintaining power to the rest of the system. Therefore, if a feeder fault occurs, the device closest to the fault in that zone will clear the condition without disrupting service to other areas of the facility, maintaining selective coordination. Most importantly, it will trip with no intentional delay, regardless of its preset delay, thereby minimizing stress on the system.

Notice that for faults that occur downstream of two series connected circuit breakers (e.g. a main and feeder), the system operates and responds exactly the same with or without ZSI.

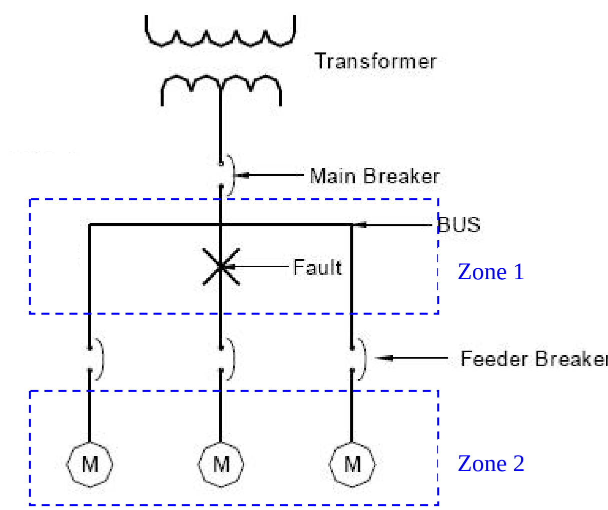

Fig. 7. A Bus Fault

The real benefit of ZSI becomes apparent when the fault occurs on the switchgear bus, as shown in Fig. 7, If for example a fault occurred on a primary stab during racking of the feeder breaker, this would create an arc-flash incident to the worker doing the racking. With the fault being on the line side bus, the downstream feeder circuit breaker does not sense the upstream fault, and consequently no blocking signal is sent to the main circuit breaker. Since the main circuit breaker senses the fault but does not receive a ZSI blocking signal, its electronic trip unit's logic over-rides the short time delay setting characteristics and trips with no intentional delay.

Most circuit breaker manufacturers provide electronic trip units with short delay time settings as low as 100 -150 mS. On the other hand, their published time-current curves show that their tripping time for ZSI is typically 80 – 100 mS, depending on the circuit breaker class, etc. This reduction of tripping time reduces the amount of energy that is let through the system.

Without ZSI connections, a selectively coordinated system will cause the circuit breaker closest to the fault to clear that fault, but to clear it typically with a preset intentional time delay.

With ZSI, the circuit breaker closest to the fault will over-ride its preset short-time and/or ground-fault delay settings and clear the fault with no intentional delay.
The ZSI feature over-rides the intentional delay, resulting in faster tripping times. The faster the tripping time, the lower will be the subsequent amount of let-through energy the system is subjected to during a fault condition.

C. ZSI as an Arc Reduction Solution

Equation 2 shows that the incident arc flash energy is directly proportional to the arcing time – the longer the arcing time, the higher the arc flash energy.

In the years since ZSI was first introduced, this technique has been used successfully to reduce the arc flash energy that would be released in an electrical system. By reducing this energy, the potentially for damage to equipment and facilities, and injury to personnel, is also reduced.

Table 1 shows the impact of the use of ZSI in reducing the incident arc energy from a case study [9] in an off-shore oil and gas production application.

TABLE 1 [9]
EFFECT OF ZSI ON INCIDENT ARC ENERGY

			Incident Energy (cal/cm^2)		
Trip Unit	Bolted Fault Current (kA)	Arcing Fault Current (kA)	Without ZSI Trip time (500mS)	With ZSI Trip time (150mS)	With ZSI Trip time (100mS)
# 1	19.9	10.3	36	17	14
# 2	17.3	8.3	20	8.1	6.4
#3	20.2	9.7	27	11	9

For example, referring to trip unit # 2 in Table 1, with a Bolted Fault current of 17.3kA, and Arcing Fault current of 8.3kA, the Incident Energy was determined to be 20 cal/ cm^2. With a ZSI scheme implemented on this system, and using the conservative clearing times of 150mS per the circuit breaker manufacturer's time-current curves, the Incident Energy was determined to be reduced by approximately 60% to 8.1 cal/ cm^2. During the subsequent commissioning and startup testing of the updated electrical system [9], trip times were measured at between 90 – 100mS. Table 1 shows that at 100ms trip delay time, the Incident Energy would be further reduced, by approximately 21%, to 6.4 cal/ cm^2. This represents a total 68% reduction in energy from the original 20 cal/ cm^2.

The table shows that the implementation of a ZSI scheme is an effective way of reducing the incident energy that may be hazardous to the equipment in a power distribution system, and especially beneficial to reducing the arc flash exposure to electricians that may be working on this system.

The 2011 Edition of the NEC, per ARTICLE 240.87, requires that an arc flash energy reducing technology, such as a ZSI scheme or others, be implemented in circuit breaker applications where there is no instantaneous trip function. Zone Selective Interlocking has proven itself over the years to be a simple and effective arc energy reduction technique for protection of electrical systems. It is now formally recognized through the National Electric Code requirements as also being especially valuable as a means for reducing arc flash hazard exposure to electrical workers.

VI. ENERGY-REDUCING MAINTENANCE SWITCHING

A. Purpose of Energy-Reducing Maintenance Switching

During an arc flash incident, the electrical energy is transformed into other forms of energy such as heat, radiation, light, and blast pressure. The incident heat energy component of the arc flash is currently used as a measure of the arc flash hazard. The heat energy is measured and expressed in calories per centimeter squared (cal/ cm^2). The various arc flash reducing approaches use this metric to gauge the amount of arc flash energy they allow.

In the day-to-day operation and maintenance of electrical equipment, circumstances occur where work must be done within Limited Approach Boundary of the energized system. In some situations, it may be impractical to de-energize the electrical equipment due to process limitations in the operation of the facilities. In these situations, in addition to employing all the other appropriate "traditional" solutions for arc flash reduction, it may be desirable to use an "Energy-Reducing Maintenance Switch" to further reduce the arc flash hazard.

An "Energy Reducing Maintenance Switch" is a device that has been designed specifically to be used by personnel only while they are required to perform work on energized electrical equipment, as permitted by the NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces [1]. This device is not intended to be continuously active.

The heat energy (cal/ cm^2) from an arc flash incident is directly proportional the duration of the time that the arc flash exists. It is therefore desirable to reduce the tripping time of an upstream over-current protective device, in order to reduce the arc flash hazard to personnel working on downstream energized equipment. An Energy-Reducing Maintenance Switch will provide this reduced tripping time in the event of a fault. The inclusion of an optional Energy-Reducing Maintenance Switch as part of a system's overall arc flash reduction strategy provides this enhanced personnel protection.

Once activated, the Energy-Reducing Maintenance Switch option provides a lockable switch feature that should be included in Lock Out/Tag Out (LOTO) safety procedures. Once the work has been completed, the Energy-Reducing Maintenance Switch is de-activated and the system returned to its optimal protection state.

B. How Energy-Reducing Maintenance Switching Works

The basic Energy-Reducing Maintenance Switching design is one that incorporates an additional electronic control circuit that may be separate from the normal instantaneous or short time protection circuits in the trip unit. The purpose of the separate control circuit is to allow the electrical worker, on demand, to 'switch-in' a system that will trip the over-current protective device in a time that will provide the minimum possible arcing time should an arc flash incident occur while energized work is being performed on that device.

Once the Energy-Reducing Maintenance Switching scheme is turned to an active state:

1) A local indicator is turned ON (as required by 2011 NEC ARTICLE 240.87),
2) The local protection settings are over-ridden by the Energy-Reducing Maintenance Switching settings.

Manufacturers of Energy-Reducing Maintenance Switching schemes provide appropriate written instructions for the safe installation and testing of the schemes. Once qualified personnel completes the energized electrical work, the Energy-Reducing Maintenance Switching scheme is switched OFF and the system returned to its normal operating state. In addition, all Lock Out/Tag Out (LOTO) safety procedures must be followed before bringing the system back to its normal state.

The selection of the settings for the Energy-Reducing Maintenance Switching may be integral to the trip unit on the circuit breaker [10], or done by optional remote settings via a remote switch contact operation, and also via various communicating devices [10] [13]. Some circuit breaker manufacturers provide plug-in modules for Energy-Reducing Maintenance Switching that may be mounted remotely from the circuit breaker [11].

In addition to having the Energy-Reducing Maintenance Switching scheme respond to phase currents, a design is available from a manufacturer that also senses and responds to ground-faults – as many phase to phase faults often start as phase to ground faults [11].

For some circuit breaker manufacturers, the tripping times that can be achieved by their Energy-Reducing Maintenance Switching schemes are even faster than the "Instantaneous" trip times of the trip units, depending on their fault sensing circuitry and the tripping schemes used.

C. Energy-Reducing Maintenance Switching as an Arc Reduction Solution

The Energy-Reducing Maintenance Switching scheme is designed to be used only during the period that a worker is exposed to the flash hazard. There are currently a few different basic types of Energy-Reducing Maintenance Switching schemes available today.

One such design scheme provides flexibility in the selection of the pick-up *level* for tripping. The pick-up may simply be set one time only at the lowest most sensitive level, or it may be set in relation to the calculated arcing fault current, the normal load current, and any possible transient currents from application specific transformer inrush or a motor starting [3]. An Energy-Reducing Maintenance Switching pick-up setting is then selected that is above the total load plus transient currents, but below the calculated minimum arcing current. This setting allows the device to trip at the expected arcing current, but avoids nuisance tripping from transient load currents.

Table 2 shows that the arc flash incident energy is reduced from 10.7 cal/ cm^2, by approximately 80%, to 2.2 cal/ cm^2 by use of this Energy-Reducing Maintenance Switching scheme [10].

TABLE 2
EFFECT OF AN ENERGY-REDUCING MAINTENANCE SWITCHING ON INCIDENT ARC ENERGY [10]

Energy Reducing Maintenance Switch	Bolted Fault Current (kA)	Arcing Fault Current (kA)	Clearing Time (ms)	Incident Energy (cal/cm^2)
Inactive	40	19.98	240	10.7
Active	40	19.98	50	2.23

System data: 480V System voltage; Switchgear, 24" approach boundary, Solidly Grounded.

The total clearing time for this separate Energy-Reducing Maintenance Switching scheme may be faster than the Instantaneous trip time of the electronic trip unit, as shown in Fig. 8.

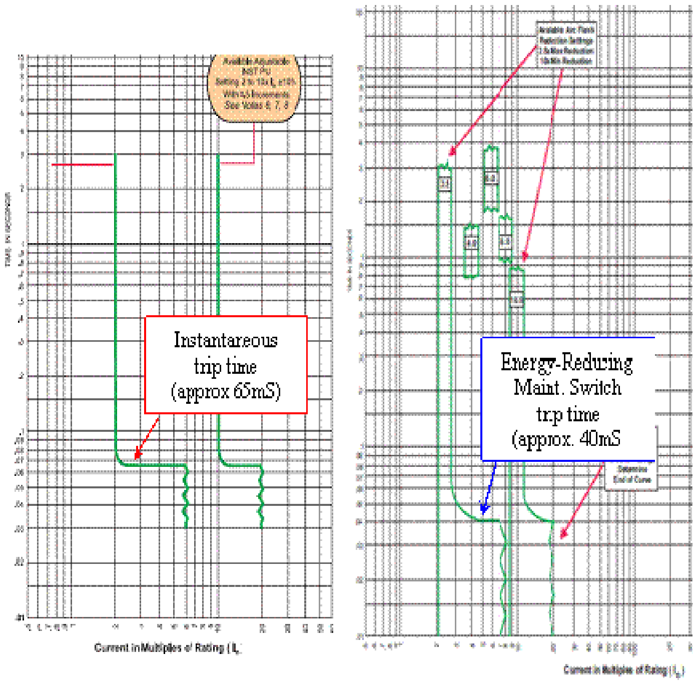

Fig. 8. Time-Current Curves showing faster Trip Time with Energy-Reducing Maintenance Switching [10].

As a result of its very fast tripping time, this Energy-Reducing Maintenance Switching design will yield lower arc flash energy than even if the circuit breaker tripped via the normal "Instantaneous" trip response. It's the benefit of this very fast tripping response that the 2011 NEC requires this type of technology to further enhance worker safety in hazardous arc flash circumstances.

An alternate Energy-Reducing Maintenance Switching design scheme is also available in a simpler configuration. With one particular design [12], the Energy-Reducing Maintenance Switching scheme is switched ON or OFF as needed, with the local indicator present as required by the 2011 NEC. This design does not provide a means separate from the protection settings for selecting a pick-up level for the Energy-Reducing Maintenance Switching. Instead, this desgn uses the existing Short-time delay pick-up setting on the trip unit. For Energy-Reducing Maintenance Switching, the Short-time current pick-up setting must be set below 85% of the calculated minimum arcing current at the system location where it is expected to provide "fast" interruption. At the completion of the energized electrical work, in addition to switching OFF the Energy-Reducing Maintenance Switching scheme, this short time pick-up setting must also be returned to its previous protection setting. When activated, this type of Energy-Reducing Maintenance Switching design also provides a faster tripping time (approximately 80mS) than normal short delay tripping, but its clearing time will not be faster than the normal instantaneous trip time of the circuit breaker [12].

Regardless of the manufacturer's design, an Energy-Reducing Maintenance Switching scheme will provide a faster tripping time in the event of a fault. The Energy-Reducing Maintenance Switching is a relatively new technology, with different features and configurations being evolved and offered by different manufacturers.

D. Are all Energy-Reducing Maintenance Switching devices Equal?

Since the primary purpose of an Energy-Reducing Maintenance Switching device is to provide very fast tripping times during an arc flash incident, a key parameter for selecting these devices, is the device's total clearing time in the event of an arcing fault.

While several manufacturers offer Energy-Reducing Maintenance Switching designs that meet the 2011 NEC requirements, the performance of the available designs are not all equivalent – the total clearing times of the various design solutions are different. For some manufacturers, the total clearing time provided by their Energy-Reducing Maintenance Switching device is even faster than the normal "no intentional delay" instantaneous trip time. For some other manufacturers, while their device meets the requirements per the NEC, the total clearing time provided by their Energy-Reducing Maintenance Switching design may be slower than their instantaneous trip times.

To ensure that the device with the fastest total clearing time is chosen for an arc flash reduction application, the electrical system designer should consult the manufacturer's published data to identify and verify the total clearing time performance of each Energy-Reducing Maintenance Switching device option. Typical time-current characteristic data is shown in Figs. 9 and 10.

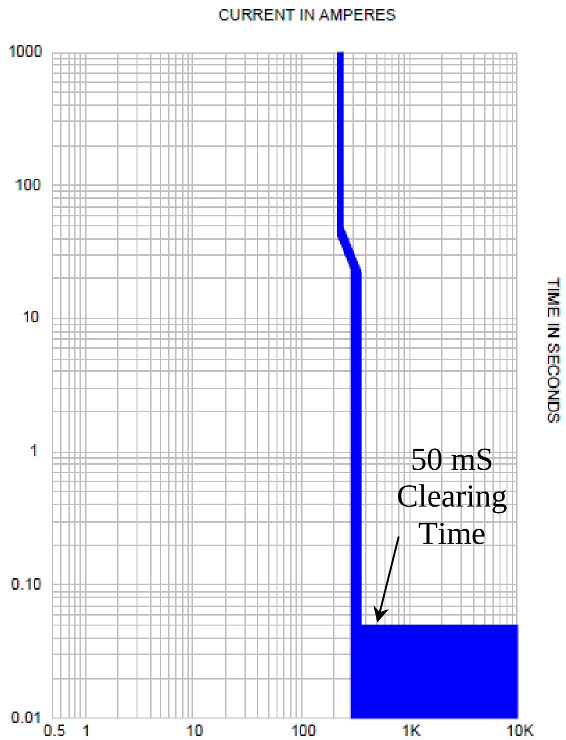

Fig. 9. Energy-Reducing Maintenance Switching at 50ms Total Clearing Time [10]

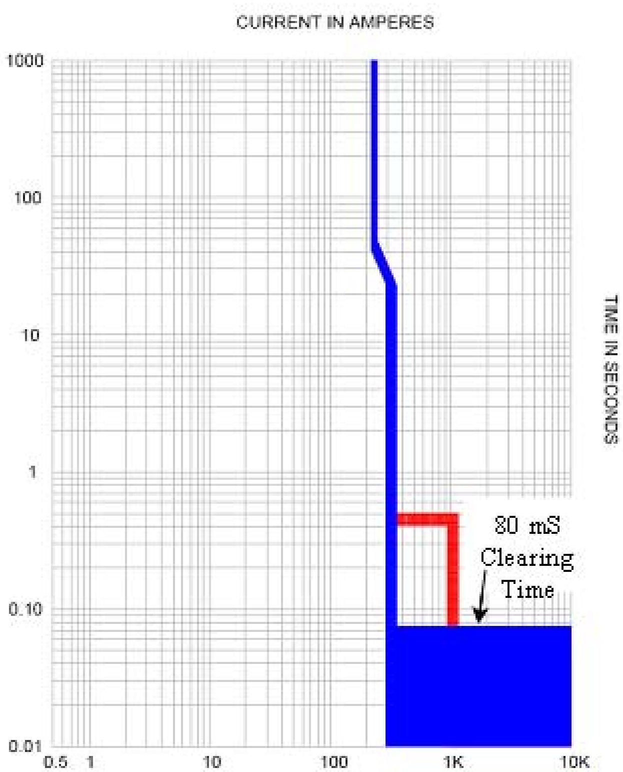

Fig. 10. Energy Reducing Maintenance Switching at 80ms Total Clearing Time [12]

The 2011 Edition of the NEC, per ARTICLE 240.87, *Noninstantaneous Trip*, requires that an arc flash energy technology, such as an Energy-Reducing Maintenance Switching scheme or others, be implemented in circuit breaker applications where there is no instantaneous trip function. While Energy-Reducing Maintenance Switching is a relatively new technique, it has proven itself to be a simple and effective arc energy reduction technique for protection of electrical systems. It is now formally recognized through the National Electric Code requirements as also being especially valuable as a means for reducing arc flash hazard exposure to electrical workers.

VII. ZONE SELECTIVE INTERLOCKING AND/OR ENERGY-REDUCING MAINTENANCE SWITCHING

The 2011 Edition of the NEC, per ARTICLE 240.87, requires that an arc flash energy reducing technology be implemented in circuit breaker applications where there is no instantaneous trip function. This paper's discussion shows that both Zone Selective Interlocking (ZSI) and Energy-Reducing Maintenance Switching schemes will meet this NEC requirement.

Designers of electrical power systems must carry out short circuit analysis, selective coordination studies of over-current protective devices, and also conduct arc flash studies to determine the levels of arc flash hazards in the electrical system. Good engineering practice encourages that these analyses be done early in the design phases, and updated whenever changes in the demand load or power sources occur. Protection from arc flash hazards will incorporate several of the solutions discussed earlier in this paper – from avoiding the hazard area, wearing the appropriate personnel protective equipment (PPE), to reducing the total fault clearing time. And even when used in combination, all these various solutions will never totally eliminate an electrical safety hazard. Just as experience has shown that there is no one single solution to reducing these hazards and risks, both Zone Selective Interlocking and Energy-Reducing Maintenance Switching schemes should be appropriately included for consideration as arc flash reduction solutions. While ZSI schemes has been in practice for many years now, Energy-Reducing Maintenance Switching devices are relatively new and have been the topic of controversy in recent years.

Zone Selective Interlocking can provide enhanced protection to a power distribution system that has already been selectively coordinated, without compromising coordination. The ZSI scheme, once properly installed, is always active, and will act to provide faster trip times and hence lower arc flash energies – resulting in reduced stresses on the electrical system, and reducing arc flash hazards to personnel that may be working nearby. While a ZSI scheme will provide a faster trip time than the pre-set short delay (or ground-fault) trip time, its response is typically slower than both the "no intentional delay" of the Instantaneous trip times, and the trip times of Energy-Reducing Maintenance Switching devices. Depending on the circuit breaker manufacturer, ZSI trip times are in the range of 80-130ms, Instantaneous trip times are typically 50-80ms, and Energy-Reducing Maintenance Switching devices are as fast as 40ms.

Fig. 11 shows a relative comparison of the tripping times for the various electronic circuit breaker trip functions – Short time delay, ZSI, Instantaneous, and Energy Maintenance Switching. The overlapping of the time bands indicate the typical variation to be expected between different types of circuit breaker designs (Molded Case versus Power circuit breakers), and between different circuit breaker manufacturers.

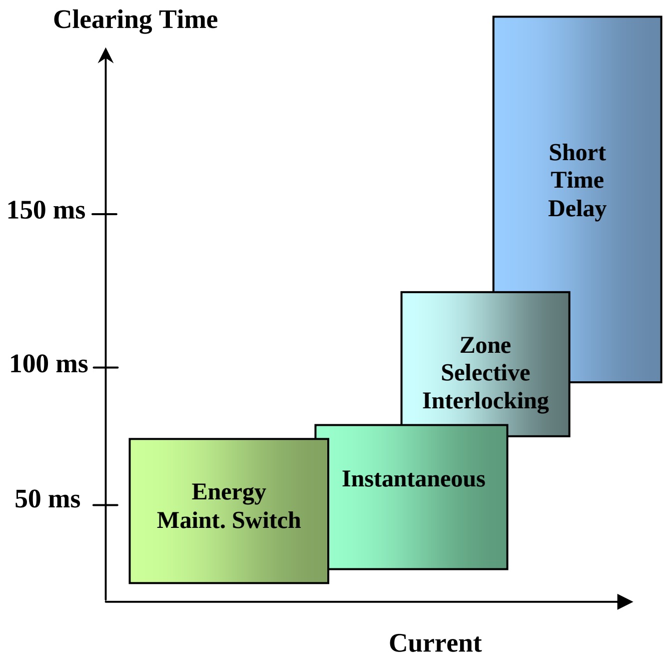

Fig. 11. Relative Clearing Times for Circuit Breaker trip functions

Most Energy-Reducing Maintenance Switching devices are specifically designed to be very fast – with total clearing times as fast as 50ms [10], which may result in significant arc flash energy reduction. However, for a circuit breaker where the Energy-Reducing Maintenance Switching device has been activated, a fault that is downstream of this circuit breaker, which exceeds the pick-up level of the Energy-Reducing Maintenance Switching device, will cause a trip. This unwanted trip would compromise the coordination of the system.

Whenever electrical power systems designers carry out their short circuit, selective coordination and arc flash analyses, to obtain an optimal final solution, possible trade-off decisions may need to be considered. This potentially difficult decision should be discussed with the appropriate personnel to determine the priorities for either maintaining selective coordination at all times based on the operational process requirements, versus forgoing the benefits of having a reduced arc flash hazard environment for personnel during planned energized work. There are times when the negatives associated with an unwanted interruption of power to a critical process, outweighs the risks associated with performing energized electrical work. In other cases, enhanced worker safety is deemed more critical than loss of selective coordination while energized electrical is being done. The 'right' answer should obviously be determined on a case by case basis, and will likely be determined by factors such as the impact of an unwanted power outage on the process, and the scope and/or duration of the energized electrical work to be done.

VIII. CONCLUSION

There simply is no argument that de-energizing electrical equipment results in the safest conditions for electrical workers. However, in some process industry applications for example, de-energizing the electrical system may not be practical, and in some cases may result in an even greater safety hazard.

The easiest way to reduce incident energy in an existing energized electrical system is to review and modify the over-current protection settings. Both the pickup and the time delay should be evaluated. If incident energy levels can be reduced to lower energies, there are overall benefits of improved safety.

The 2011 Edition of the NEC, per ARTICLE 240.87, requires that an arc flash energy reducing technology be implemented in circuit breaker applications where there is no instantaneous trip function. The NEC identifies Zone Selective Interlocking (ZSI) and Energy-Reducing Maintenance Switching, and other devices, as ways to meet this requirement. While ZSI has been around for many years, Energy-Reducing Maintenance Switching schemes are relatively new. Several circuit breaker manufacturers currently provide Energy-Reducing Maintenance Switching devices that are designed to have very fast tripping times. To ensure that the device with the fastest tripping times are chosen, the electrical system designer should consult the manufacturer's published data to identify the total clearing time performance of each Energy-Reducing Maintenance Switching design option.

Reducing arc flash hazards to electrical personnel is an evolutionary process. No individual solution will eliminate all of the hazards of working on energized equipment. However, ongoing electrical product development activities that focus on worker safety and the routine adoption of safety related requirements by the various Codes and Standards organizations will keep the reduction of this hazard as an important objective.

IX. ACKNOWLEDGEMENTS

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