ELECTRICAL EQUIPMENT TASK BASED RISK ASSESSMENT – USING THE HRN METHOD

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Abstract – This paper describes how a commonly used machine risk assessment methodology was 'slightly' modified for use to evaluate common tasks associated with electrical equipment. The method can be used to provide a hazard rating number (HRN) for a specific electrical task performed on a specific piece of electrical equipment. The author has applied this methodology to an entire site's electrical distribution system from the incoming utility, on site power distribution, 24kV to 480V or 2400V substations, switchgear, and motor control centers. The method considers the effectiveness of the site's maintenance program, health and age of the equipment, active / passive controls, engineering controls, use of procedures, and arc flash energies. This paper will present specific examples for the 'as-found' condition and then explore how mitigation methods affect the HRN score. The results can be used for decision making on how to spend capital to improve safety and prevent electrical injuries.

Index Terms — hazard rating number (HRN), arc flash, electrical tasks, risk, risk assessment, residual risk, mitigation, arc flash

I. INTRODUCTION

Securing internal corporate funding for infrastructure related capital projects has always been challenging for any number of reasons. The author was requested to review the electrical distribution system of a legacy operating facility which had a series of recent equipment failures and a serious arc flash employee injury. Much of the electrical equipment infrastructure dates to the 1960s. The author developed a scope of work for a project in which existing equipment would be updated with current technology and replace equipment that was well past its service life. At a project funding request meeting, the author was challenged as to how the current scope was determined. Leadership conveyed that due to capital constraints there was only interest in spending capital on the assets with highest 'risk' to personnel injury and items that 'improved electrical safety.' Reliability was not part of the consideration and will be managed on future improvement projects. This paper describes the method that was developed to quantify 'risk' that could be used to re-define the project scope or work to meet leadership objectives.

II. DEFINING "RISK" QUANTITATIVELY

A. Industrial Revolution and Development of Standards

The Industrial Revolution in the 1800's and early 1900's exposed the worker to many hazards in the workplace due to the advent of machinery used in manufacturing. Labor groups experiencing dangerous and unhealthy working conditions along with serious accidents injuring workers created pressure on local governments for protections and improved working conditions. The first legislation to protect workers came in the form of the Massachusetts Factory Act of 1877 [1]. Shortly thereafter, other New England states followed with similar laws. Each state had their own bureau of industrial statistics at factories where inspection and workers interviewed. One of the common injuries was to the hand from getting caught in machinery although early forms of machine guard was actually common during the period. Figure 1 is from the Library of Congress's National Child Labor Committee Collection which shows a child worker near a machine.

Fig. 1 – Lincoln Cotton Mills, Evansville, IN 1908 [2]

In 1913, the Department of Labor was formed with the goal of improving working conditions for workers. But it was not until the 1970 Occupational Safety and Health Act (OSHA), "…which gave the Federal Government the authority to set and enforce safety and health standards for most of the country's workers" [3]. Today, OSHA 1910 Subpart O – Machinery and Machine Guarding provides the minimum requirements of machine guarding [4]. ANSI/B11 Standards, Inc. origins date to the early

1900's and today the ANSI/B11 series of standards are considered voluntary consensus standards which are recognized by OSHA. In addition, ANSI/B11.0 – Safety of Machinery has been harmonized with ISO 12100:2010 but ANSI/B11.0 exceeds the requirements of ISO 12100:2010 [5] [6]. The basis of ANSI/B11 is to assist machine manufacturers and owners in the protection of workers from injury. The process to determine machine protection requirements is based on a risk assessment process.

B. Calculating Risk

We live with 'risk' throughout our entire lives. We all have a 'risk' of falling just walking. We all do 'risky' activities each day, like drive in our automobiles or stepping in and out of the shower or bathtub. Risk is simply the combination of the probability of an event and its resulting consequence (Risk = Likelihood x Consequence). Seems simple but boundaries need to be established for the likelihood of something happening that results in an injury and the severity of the injury.

ANSI/B11.0 contains the details on how a risk assessment process is performed for the tasks required of a worker to operate the machine. The basic steps are as follows:

- Set boundary/limits of the assessment
- Define the tasks performed and the hazards
- Develop or select a risk scoring system
- Decide what is unacceptable levels of risk
- Determine mitigation plans on how to reduce risk
- Determine what is acceptable residual risk
- Implement and validate solutions
- Document results

Annex F – Risk Assessment Matrices of ANSI/B11.0 provides some risk rating systems that can be used but there is not a universally accepted method / system. The author's employer's machinery risk assessment guardians have selected on a method called the Hazard Rating Number (HRN) methodology.

C. HRN Method

Since neither ANSI/B11 or ISO1200 discuss the HRN methodology, the author searched for its origins. This method was created by Chris Steel in 1990 where it was first published in the June 1990 edition of "The Safety & Health Practitioner" [7]. In his article, Steel does mention that there are many ways to calculate risk and that they all involve some sort of subjectivity on the part of the evaluators. Steel's method simply consists of HRN = Probability of Exposure (PE) x Frequency of Exposure (FE) x Maximum Probable Loss (MPL) x Number of Persons at Risk (NP). Steel assigned a number range to each of these factors with a suggested definition to each value. The results are then provided with a risk range score that equates to a level of risk and action timetable. See Tables I through V below.

TABLE I
PROBABLITY OF EXPOSURE (PE)
(Per method proposed by Steel [7])

Value	Probability	Explanation
0	Impossible	Cannot happen under any circumstances
1	Unlikely	Though conceivable
2	Possible	But unusual
5	Even Chance	Could happen
8	Probable	Not surprised
10	Likely	Only to be expected
15	Certain	No doubt

TABLE II
FREQUENCY OF EXPOSURE (FE)
(Per method proposed by Steel [7])

Value	Frequency
0.1	Infrequently
0.2	Annually
1	Monthly
1.5	Weekly
2.5	Daily
4	Hourly
5	Constantly

TABLE III
MAXIMUM PROBABLE LOSS (MPL)
(Per method proposed by Steel [7])

Value	Loss
15	Fatality
8	Loss of 2 limbs/eyes or serious illness (permanent)
4	Loss of 1 limb/eye or serious illness (temporary)
2	Break – major bone or minor illness (permanent)
1	Break – minor bone or minor illness (temporary)
0.5	Laceration / mild ill health effect
0.1	Scratch / bruise

TABLE IV
NUMBERS OF PERSONS AT RISK (NP)
(Per method proposed by Steel [7])

Value	Quantity
1	1-2 persons
2	3-7 persons
4	8-15 persons
8	16-50 persons
12	More than 50 persons

TABLE V
HAZARD RATING NUMBER (HRN)
(Per method proposed by Steel [7])

HRN	Risk	Action Timetable
0-1	Acceptable risk	Accept risk / consider action
1-5	Very low risk	Action within 1 year
5-10	Low risk	Action within 3 months
10-50	Significant risk	Action within 1 month
50-100	High risk	Action within 1 week
100-500	Very high risk	Action within 1 day
500-1000	Extreme risk	Immediate action
Over 1000	Unacceptable risk	Stop the activity

For clarity the following example is provided: Four (4) people carpool to work five (5) days a week. The route they travel uses a mix of state road and interstate highways. Traffic is fairly heavy most of the time. The car they travel in has all the latest safety features (air bags, automatic pre-collision breaking, lane watch monitoring, etc.). PE – it is unlikely or even possible they could be in an accident. FE - they commute daily. MPL – they commute in a car with the latest safety features so injuries from an accident are minor and probably limited to lacerations and bruises. NP – Four (4) people are commuting. HRN = 2 (PE) x 2.5 (FE) x 0.5 (MPL) x 4 (NP) = 5 equating to a 'low risk.' Note that there is some subjectivity in this example. We have inherently made some assumptions – the driver is a safe driver, speed limit is followed, non-aggressive driving, car is in good maintenance, etc.

Steel's HRN method was revisited by Derek Coulson in 2015 determining that the HRN method is still a valid method today to quantify risk [8]. Coulson did suggest that based on his work as a machine safety practitioner to modify a few terms as well as the probability of exposure table. Coulson changed Probability of Exposure (PE) to Likelihood of Occurrence (LO) and Maximum Probable Loss (MPL) to Degree of Possible Harm (DPH). Table I above was modified per the italics in Table VI below. The reasoning for the modification was the willingness of people to override safeguards. Basically, "0 - Impossible" was not achievable in reality.

TABLE VI
LIKELIHOOD OF OCCURRENCE (LO)
(As modified by Coulson [8])

Value	Probability	Explanation
0.1	***Almost Impossible***	***Possible in extreme circumstances***
0.5	***Highly Unlikely***	***Though conceivable***
1	Unlikely	***But could occur***
2	Possible	But unusual
5	Even Chance	Could happen
8	Probable	Not surprised
10	Likely	Only to be expected
15	Certain	No doubt

For the remainder of this paper we will use the following terms for the HRN calculations presented – equation (1).

HRN = Number of People (NP) x Frequency of Exposure (FE) x Likelihood of Occurrence (LO) x Degree of Possible Harm (DPH) (1)

III. APPLYING THE HRN METHOD TO ELECTRICAL EQUIPMENT

A. Risk Assessment for Machinery versus Electrical Equipment

The author's corporate machine safety guardians have spent several years developing internal standards and guidance documents on how to perform the Coulson modified HRN method on operating machines throughout the company. The method is well understood by leadership so the electrical version needs to be very similar to build on the understanding of the HRN method currently established.

The author initially worked with internal machine safety guardians to understand the process they follow for machine risk assessments, how they interpret the tables that are part of the HRN method, mitigation measures, and validation. One of the machine guardians ask, "Why are you creating this? Everybody knows that if you touch electricity you die." The other guidance provided was to make sure that whatever is developed uses the full range of the HRN values otherwise, the method becomes ineffective. It quickly became clear that the same internal guidance for machine safety could not be followed for the electrical technology (i.e. engineers, technologists, safety professionals). But whatever was developed had to follow a similar process to machine safety to be accepted by senior leadership.

It should be pointed out that any risk assessment is subjective. Risk assessments need to be performed with teams of people that are familiar with the technology being evaluated. Even then different people may have different objectives and perceptions. It is important to have an experienced risk assessment leader that can be objective and try and normalize the process as best as possible. For example, the risk assessment performed on two (2) similar machines by different evaluation teams needs to yield similar results.

B. Electrical Task Risk Assessment HRN Score Tool

Just like machine risk assessments, boundaries, tasks performed, and evaluation team needs to be defined to perform an electrical risk assessment. This section discusses how the electrical technology created additional definitions of how to determine LO and DPH specific to electrical equipment. Also, it is important to note that this electrical assessment is independent of the system voltage and shock hazard. The main reason for excluding the shock hazard is that likelihood of a fatal shock greater than or equal to 50 volts is high. The electrical assessment process does not address equipment reliability directly, it cannot predict arc faults, and if a task scored low it does not mean that an event will not cause significant personal injury or damage to equipment.

1) *Evaluation Team:* The evaluation team should consist of the site electrical safety professional, electricians, operators (if trained to operate electrical equipment), and a technical resource that can lead the evaluation process. Other interested parties may be the site safety manager, plant manager, or maintenance manager.

2) *Boundaries:* Next, the team needs to decide on the boundaries of the electrical assessment. It needs to be decided if the team is only going to look at one (1) piece of equipment like a single line up of low voltage switchgear or if all low voltage switchgear at the site will be evaluated as a group. This can affect FE. It is recommended that the team define the groups of equipment for assessment. For example, switch yard, switchgear (by voltage level / class), transformers, motor control centers (by voltage class), panelboards, and any site-specific equipment that has an arc flash incident energy greater than 1.2 cal/cm^2 at the appropriate working distance.

3) *Tasks:* Now that the team has defined the equipment to be evaluated, they need to develop all possible tasks that are performed on the equipment. This is a brainstorming session, and the team needs to realize that this session is important as the tasks will be common across equipment types. Below are some examples of tasks:

- Manual operation of disconnect switch handle

- Manual operation of circuit breaker
- Rack in and rack out of circuit breaker / equipment
- Withdrawing equipment from cubicle
- Infrared inspection (doors open on energized equipment) or use of infrared windows
- Application of ground sets
- Absence of voltage testing
- Phase rotation check
- Visual inspection
- Meter readings
- Trouble shooting of racking mechanism
- Trouble shooting of breaker operation (open or close)
- Walking past equipment (i.e. equipment located where there is high foot traffic)
- Others

4) *Task frequency:* The team needs to consider how often the task or exposure occurs. This is where the beginning of Frequency of Exposure (FE) is developed. This exposure should be based on the number of exposures on an annual basis. For example, if there is substation maintenance being performed there may be a significant number of operations during a short period of time. This would be in addition to the number of normal operations of the task that occur throughout a year. For example, if a shutdown requires the opening and closing of the circuit breakers in a 480V switchgear line up of nine (9) breakers then for that specific piece of equipment FE should be as follows – 9 breakers x 4 open / close energized operations per breaker = 36 operations to perform substation maintenance plus 6 operations of any of the 9 breakers throughout the year this would be a total of 42 exposures / 12 months = 3.5 times a month which equates to a "weekly" task frequency.

5) *Arc Flash Personal Protective Equipment (PPE):* This is where departure starts to occur from machine safety risk assessments. Typically, machine risk assessment are performed on machines that do not include guarding or interlocks. The assessment is used to determine if guarding and interlocks improve the HRN scores. For electrical, we are starting with the equipment in its current state, operation procedures, arc flash incident energy levels, and existing safe practices. For electrical, a failure of the equipment can happen at any time so as part of the task, it needs to be understood if the person exposed to the hazard is wearing arc flash PPE or not. This is where it was discovered a combination of the incident arc flash energy and PPE usage could be used as a way to determine the degree of possible harm (DPH).

6) *Exposure to Equipment:* Again, this is where electrical differentiated from machine safe risk assessments. The electrical technology wanted to understand if a worker was 'directly' interacting with power system components. It is well known that many arc flash events occur when a worker directly interacts with power system components. This concept is used to adjust the Likelihood of Occurrent (LO) as well as Frequency of Exposure (FE).

7) *Equipment Condition / Procedures:* This is where the team discusses the age, condition, maintenance practices, working access / clearance, training program, operation procedures, past operation issues and failures, etc. This allows the team to form a basis as to the performance of the equipment, operation personnel, identify additional hazards, and reflect on how the equipment is utilized. This information feeds into how the Likelihood of Occurrence (LO) is determined for a specific task.

8) *Arc Flash Hazard at the Person:* It was found while developing this method that arc flash incident energy is very important in determining the Degree of Possible Harm (DPH). Arc flash is really the main hazard (other than the shock hazard) when working on / near energized electrical equipment. For machinery safety, the DPH table is much easier to define the injury type. For the electrical technology, the DPH from an arc flash event can vary greatly depending on if the person exposed is wearing PPE or not wearing PPE, body position, distance from the arc flash event, etc. But for this method, arc flash incident energy was equated to mechanical energy for the purposes of assessment.

9) *HRN Method Elements:* Using the information gathered above and tasks created, the evaluation team can now score a task. Based on the author's use of the method at a specific site, below are some of the learnings:

    a) NP: The number of persons performing the task was usually in the one-to-two-person range. It would be rare to have a task where more than two persons are involved.

    b) FE: For the frequency of exposure, a new table was created to adjust FE as to whether the task being performed had direct or no direct exposure to power system components. See Table VII.

    c) LO: For the likelihood of occurrence, an electrical technology guidance table was specifically created to help evaluation teams select a value. See Table VIII.

    d) DPH: For the degree of possible harm, an electrical technology guidance table was specifically created to help evaluation teams select a value. See Table IX.

TABLE VII
FREQUENCY OF EXPOSURE (FE) - ELECTRICAL

No Direct Exposure		Direct Exposure	
Value	Frequency	Value	Frequency
0.1	Monthly	1	Infrequently
0.2	Weekly	1.5	Annually
1	Daily	2.5	Monthly
1.5	Constantly	4	Weekly
		5	Daily

C. *Likelihood of Occurrence Guidance - Electrical*

To guide evaluation teams in selecting a LO value, a guidance table (Table VII) was specifically created. This table has its basis from the hierarchy of controls as presented by The National Institute for Occupational Safety and Health (NIOSH) [9]. See Figure 2.

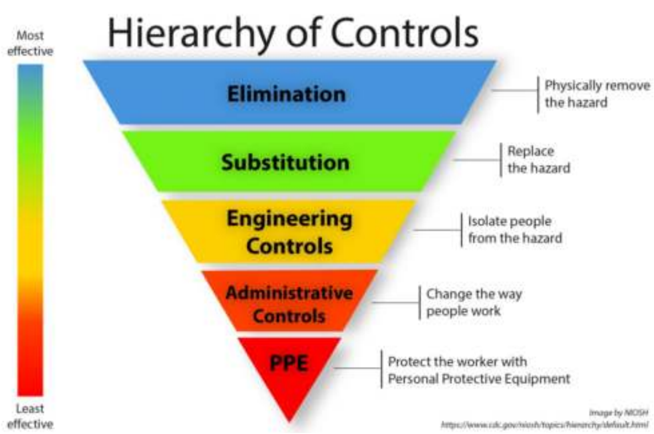

Fig. 2 Hierarchy of Controls [9]

TABLE VIII
LIKELIHOOD OF OCCURANCE (LO) – ELECTRICAL

LIKELIHOOD OF OCCURRENCE GUIDANCE - ELECTRICAL				
Risk Level	No controls	15	15	N/A
	PPE / Admin -	15	10	5
	PPE / Admin +	10	8	2
	Active Engineering Controls	5	5	1
	Passive Engineering Controls	2	2	0.5
	Inherently Safe	0.5	0.5	0.1
	No access	0.1	0.1	0.1
Common Task - More hazardous because it is "common" and person can get complacent.		Common	Unusual	ECR / General Access
Unusual Task - Less hazardous because the person concentrates more and does better job planning.		Direct exposure or interaction with power system parts		No direct exposure or interaction with power system parts

In Table VIII, the hierarchy of controls has been broken down into several categories to define Risk Level. The author has developed a guidance table for each of the Risk Levels that evaluation teams use to select Risk Level. This guidance table is outside of the scope of this paper. In general, no access equals elimination. PPE / Admin – or + is a function of the age of the equipment, how well PPE requirements are followed, procedures, training, etc. Engineering controls has been broken down into two (2) levels – 'active' means that someone must do something, and 'passive' means that the control is always in place. The selection of LO is highly subjective, and this is why the viewpoints of various evaluation team members is critical for a consensus.

D. *Degree of Possible Harm Guidance - Electrical*

As previously mentioned, the electrical technology uses arc flash incident energy levels instead of mechanical energy or machine speed. To gain an understanding of the types of injuries caused by arc flash events at various incident energies, the author referenced a few papers on the subject [10] [11] [12] [13] [14]. Table IX shows an estimation of the possible harm at different arc flash incident energy with and without wearing arc flash PPE. This table is to give evaluation teams something to consider on how to select a value for the DPH. It assumes PPE is maintained and worn correctly.

TABLE IX
DEGREE OF POSSIBLE HARM (DPH) – ELECTRICAL

DPH - ENERGY GUIDANCE					
Arc Flash Incident Energy		Incorrect or No PPE		Correct PPE	
		DPH	Injury Type	DPH	Injury Type
Energy Level	>60 cal/cm2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	8	1st and/or 2nd Degree Burns / Multiple Broken Bones / Puncture Wounds / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC
	> 40 cal/cm^2 to 60 cal/cm^2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	4	1st and/or 2nd Degree Burns / Multiple Broken Bones / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC
	>25 cal/cm^2 to <= 40 cal/cm^2	8	3rd Degree Burn / Broken Bones / Minor Puncture Wounds / Loss of Eye(s) / Permanent loss of hearing / MTC plus RWC or DAWC	2	1st and/or 2nd Degree Burns / Possible Broken Bones / Concussion / Hand or Foot Injury / Bruises / MTC plus RWC or DAWC
	>8 cal/cm^2 to <= 25cal/cm^2	2	3rd Degree Burn / Concussion / Bruises / Non-permanent loss of hearing / Recoverable eye injury / MTC or RWC	1	1st and/or 2nd Degree Burns / Concussion / Bruises / MTC or RWC
	>=1.2 cal/cm^2 to <=8 cal/cm^2	1	3rd Degree Burn / MTC or RWC	0.5	1st and/or 2nd Degree Burns / FAC
	<1.2 cal/cm^2	0.1	1st Degree Burn / FAC	0.1	N/A

Note: Not for shock assessment and voltage level / current level is not addressed.
FAC: First Aid Case **MTC:** Medical Treatment Case
RWC: Restricted Day Case **DAWC:** Days Away from Work Case

E. *Worked Examples for Sample Tasks*

The following examples are from an actual plant evaluation.

1) Example 1: The site has a looped 24kV underground distribution system. To create tap points to feed site unit substations there are sixteen (16) above ground junction boxes – Figure 3. The junction box has bolted side covers and inside is bus bar on standoff insulators with cable terminations. The site has had one recent cable termination failure creating an arc flash in the box but the box contained the arc flash. The evaluation team came up with six (6) tasks that are performed on or in these boxes while it is considered energized.

a) Task: Opening enclosure and testing for absence of voltage (AOV). This task per site procedure requires two (2) people so NP is 1.

b) Task Frequency: *Task Frequency:* Assumed one (1) emergency and five (5) non-emergency load transfers per year where AOV testing is performed at four (4) different locations two (2) times to isolate and apply ground set to a junction box. So the frequency is 48 times / year. For selecting a value for FE, the task is performed close to weekly and there is direct exposure to power system components, so FE is 4.

c) Equipment Condition / Procedures: The boxes are custom built out of metal. Experience has shown that they are rugged and have contained an arc flash recently. Enclosures are in good condition and all covers are secured. There are site well defined procedures on performing the task and electricians are well trained.

d) Arc Flash Incident Energy: The equipment is labeled with an incident energy greater than 60 cal/cm^2 at a working distance of 36 in (91 cm). The electricians wear 100 cal/cm^2 rated arc flash suits for this task. In addition, they use a 10 ft (3 m) hot stick with non-contactor voltage tester.

e) LO: Using Table VIII the risk level is determined to be PPE/Admin + but a common tasks – LO is 10. We arrived at PPE/Admin + because equipment is in good condition, procedures are in place and followed, and electricians have good training on the task, but the lock out for energy isolation is very complex.

f) DPH: Using Table IX based on the arc flash energy and the electricians are wearing PPE – DPH is 8.

g) HRN Score: Doing the multiplication for the above – HRN score is 1 (NP) x 4 (FE) x 10 (LO) x 8 (DHP) = 320 (Very High Risk).

h) Action: Now the evaluation team needs to determine what is an acceptable level of risk. Internal guidance the author's company for machine risk assessments is if the HRN score is 10 or less then no mitigations need to be applied. If greater than 10, plans are required to eliminate or reduce the risk (i.e. implement mitigations / safeguards) to a tolerable level. For this example, the evaluation team needs to develop electrical based mitigation measures to see if the HRN score can be lowered to a more tolerable level. See section below on mitigations for this example.

Fig. 3 24kV Aboveground Junction Box
(Used with permission from the Author)

2) Example 2: The site has several 480V switchgear line ups that date from 1960s to 2021 and are of various manufacturers – Figure 4. For 480V switchgear the team developed thirty-six (36) tasks but not all tasks were associated with all switchgear. For this example we will look at the tasks of visual inspection of the switchgear and arc flash PPE is not required to perform this task.

a) Task and Frequency: Site procedures require monthly visual inspections of equipment. Only one person is required so NP is 1 and FE is 0.1 because performed monthly and there is no direct exposure to power system components.

b) Equipment Condition / Procedures / LO: The equipment is from the 1960's and has been maintained in good working order. Equipment is simple because no trip units and breakers are fused and just operate as switches. No main breaker on switchgear. Since the inspector is not interacting with the power system components and LO has been determined to be PPE/Admin + then LO is 2.

c) Arc Flash Incident Energy / DPH: This equipment does not have a main breaker and is only protected by an upstream 24kV fuse on the primary of the transformer. The arc flash incident energy at the 480V switchgear is greater than 60 cal/cm^2 at a working distance of 24 in (61 cm). Using Table IX based on this arc flash energy and the inspector is not wearing PPE the DPH is 15.

d) HRN Score: Doing the multiplication for the above – HRN score is 1 (NP) x 0.1 (FE) x 2 (LO) x 15 (DHP) = 3 (Very Low Risk).

e) Action: For this example, the HRN score is 3 or very low risk and no action is required. But if the equipment were properly maintained and for some reason be in a high traffic area with daily traffic, the LO could easily go to PPE/Admin – which would be an LO of 5 and FE of 1 and changing the HRN score from 3 to 75.

Fig. 4 480V Fused Metal Enclosed Switchgear
(Used with permission from Author)

F. Mitigation and Mitigations for Sample Task / Residual Risk

The following mitigations discussed below are just for Example 1 above. As the electrical HRN method was developed a list of possible mitigations was created. A sample of those possible mitigations are provided in Table X.

1) Example 1 Mitigations: The task has an HRN score of 320. The team brainstormed to come up with possible mitigation measures.

   a) Mitigation 1: The initial arc flash study used the Ralph Lee equations to calculate arc flash incident energy because the current version of IEEE 1584-2018 is not applicable above 15kV [15] [16]. The team decided to utilize the National Electrical Safety Code (NESC®) – 2023 Table 410-4 to determine the arc flash energy at a 48 inch (122 cm) working distance [17]. For the clearing time of the protective device for the 24kV system it was determined that the arc flash incident energy is more likely to be 40 cal/cm^2 at a 48 inch working distance. This changes DHP from 8 to 2. We also decided that since the site has good training and a well written procedure we would change LO from a common task to an unusual task which changed LO from 10 to 8. Mitigation 1 HRN Score: Doing the multiplication for the above – HRN score is 1 (NP) x 4 (FE) x *8* (LO) x *2* (DHP) = *64* (*High Risk*)

   b) Mitigation 2: In this mitigation, the evaluation team took into the consideration that the electricians were using a hot stick to perform the task and in reality, the working distance really should be 5 or 6 ft. At that time, the team did not have a tool to calculate the arc flash energy at that working distance. An assumption was made that the arc flash energy would drop to somewhere between 8 cal/cm^2 and 25 cal/cm2 which yielded an HRN score of 32 (Significant Risk). This was still not the required HRN score of <=10.

   c) Mitigation 3: Next the team, investigated what hardware or equipment changes could be made to the electrical system design. The team decided that the electrical distribution system would benefit from a device with faster clearing time for a fault on the 24kV system. The utility would not change their protective device settings. So, the team considered installing a new protective device downstream of the utility lines where the site has control and could modify and own the protective device settings. The team reviewed possible relay settings that dramatically shortens the clearing time of the protective device such that the arc flash energy per 2023 NESC® Table 410-4 would be between 1.2 cal/cm^2 and 8 cal/cm^2. Now since we have put a passive engineering control system in place that is always in service and does not require any human interaction the team changed the LO from 8 to 2. In addition, the DPH was changed from 4 to 0.5 because the arc flash incident energy has been permanently lowered. Mitigation 3 HRN Score: Doing the multiplication for the above – HRN score is 1 (NP) x 4 (FE) x 2 (LO) x 0.5 (DHP) = 4 (Very Low Risk). Although this will require a capital investment, an acceptable HRN score can be achieved.

   d) Mitigation Summary: The team presented the task and mitigations to plant management for acceptance of the different mitigations. In this example, the mitigations are all technical or involve capital. This may not always be the case as some mitigations could be procedural changes or the purchase of new tools which are quick changes to improve safety.

TABLE X
POSSIBLE MITIGATION / SAFEGUARDS - ELECTRICAL

Mitigation Description
Increased equipment maintenance
Change operation procedure (i.e. operate up stream device)
Add infrared view ports
Install ground ball studs on equipment
Barricade / change access near equipment
Update / validate / check arc flash study
Change working distance and re-calculate arc flash energy
Operation of breakers with extension tool or remote racking (manually installed or fix mounted)
Lower arc flash energy by changing upstream protective device settings (permanently or temporarily)
Replace equipment with technology with lower arc flash energy
Others

IV. CONCLUSIONS

The reader needs to realize that this method and how tasks are scored has a subjective element that cannot be ignored. Steel, the originator of the HRN method, even mentions this in his article. The author needed a method to quantify risk as it relates to electrical equipment so that the prioritization could be given to electrical safety improvements and not strictly reliability improvements. The method was run on the electrical distribution system of an existing facility for 118 tasks on equipment such as air insulated switchyard, 24kV switchgear, transformers, bus duct, 2400V motor control center, 480V switchgear, and 480V motor control centers. Of the 118 tasks 64 had a HRN score greater than 10 which resulted in 104 mitigations created, discussed, scored, and reviewed by plant management for implementation. It took well over 200 manhours and nine months to develop the method, complete the evaluation, gain leadership alignment on mitigation, and start implementing site mitigation plans as well as plan a large capital project. A few of the learnings from implementing the method are:

1) Arc flash energy is the main hazard and the driver to generate a high or low HRN number.

2) Not all mitigations are practical or cost effective.

3) Some mitigations can be very simple and be implemented immediately without significant capital (i.e. procedures, barricading, longer hot sticks, etc.).

4) It is okay to have residual risk – risk above an HRN score of 10. For instance, if a score started at 200 and the only mitigation that was feasible drive the score to 50 that is a significant reduction in risk. Management needs to be aware and accept that there is residual risk to be managed.

5) LO is very subjective, and users of this method may want to consider a different method to determine LO.

6) The author recommends evaluation teams group equipment types together that have common tasks. This will increase the exposure frequency versus evaluating tasks on a single piece of equipment. The author's view is that this is acceptable due to the electrical hazards involved in working with electrical equipment. Treat each group of electrical equipment as a "machine."

V. REFERENCES

[1] J. MacLaury, , "Government Regulation of Workers' Safety and Health, 1877-1917", U.S. Department of Labor, Accessed September 30, 2023 online at https://www.dol.gov/general/aboutdol/history/mono-regsafeintrotoc.

[2] L. W. Hine, photographer. *Boy Sweeper, Lincoln Cotton Mills, Evansville, Ind. Carding Machines: Floor Slippery. See report for conditions. Location: Evansville, Indiana.* United States Indiana Evansville, 1908. October. Photograph. Accessed September 30, 2023 online at https://www.loc.gov/item/2018673844/.

[3] J. MacLaury, Judson, , "The Job Safety Law of 1970: Its Passage Was Perilous", U.S. Department of Labor, Accessed September 30, 2023 online at https://www.dol.gov/general/aboutdol/history/osha.

[4] Occupational Safety and Health Administration. (1970). "1910 Subpart O – Machinery and Machine Guarding", Accessed September 30, 2023 online at https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartO

[5] ANSI / B11.0 – 2023, *Safety of Machinery*, Houston, TX

[6] EN ISO 12100:2010, *Safety of machinery – General principles for design – Risk assessment and risk reduction,* European Committee for Standardization Management Centre: Avenue Marnix 17, B-1000 Brussels

[7] C. Steel, 1990, "Risk Estimation", *The Safety & Health Practitioner*, June, pp. 20-21.

[8] D. Coulson, June 26, 2014, "Risk Estimation: 25 years on", *Safety & Health Practitioner*, Accessed September 30, 2023 online at https://www.shponline.co.uk/blog/risk-estimation-25-years/.

[9] Centers for Disease Control and Prevention / The National Institute for Occupational Safety and Health (NIOSH), "Hierarchy of Controls", Center for Disease Control and Prevention (CDC) / The National Institute for Occupational Safety and Health (NIOSH), Accessed September 30, 2023 online at https://www.cdc.gov/niosh/topics/hierarchy/default.html.

[10] R. Lee, "Pressures Developed by Arcs," IEEE Transactions on Industry Applications, vol. IA-23, n. 4, pp. 760-764, July/August 1987.

[11] T . E. Neal and R. F. Parry, "Shrapnel, Pressure, and Noise", IEEE Industry Applications Magazine, May / June 2005, pp 49 – 53.

[12] D. R. Doan and T. Neal, "Field Analysis of Arc Flash Incidents and the Related PPE Protective Performance," 2009 IEEE IAS Electrical Safety Workshop, St. Louis, MO, USA, 2009, pp. 1-5

[13] T . E. Neal and R. F. Parry, "Shrapnel, Pressure, and Noise", IEEE Industry Applications Magazine, May / June 2005, pp 49 – 53.

[14] C. M. Wellman, "OSHA Arc-flash Injury Data Analysis," 2012 IEEE IAS Electrical Safety Workshop, Daytona Beach, FL, USA, 2012, pp. 1-5

[15] Lee, R. H.; "The other Electrical Hazard: Electrical Arc Blast Burns", IEEE Transactions on Industry Applications, vol IA-18, no. 3, pp. 246-251, May 1982.

[16] IEEE 1584-2018, *IEEE Guide for Performing Arc-Flash Hazard Calculations, New York*, NY:IEEE

[17] IEEE C2-2023 – 2023 National Electrical Safety Code® (NESC®), New Yor, NY: IEEE

VI. VITA

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