Practical approaches to mitigating Arc Flash exposure in Europe

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Abstract - Increasing number of electrical system operators in Europe realize that the existing standards for operating an electrical installation, such as the Dutch NEN 3140, (based on EN 50110) are starting to provide guidance to reduce arc flash hazards. Not all equipment in the field meets the latest standards, moreover Internal Arc Classification (IAC) does not consider risks associated with normal maintenance practices such as trouble shooting, testing and verification of de-energized state of the electrical equipment.

Arc Flash Hazard calculations can conveniently quantify the potential risk and show that excessive high arc flash incident energy necessitates de-energizing of the equipment before maintenance can be performed. Yet, this is not always acceptable to plant operations. This paper will address various approaches to significantly lowering the probability of an arc flash incident and ways to limit the consequences by system design, equipment modifications and alternate protection settings and work methods. It will also discuss strategies to deal with personal protection equipment (PPE).

Index Terms — Arc Flash Hazard Analysis, Incident energy, Flash Protection, Boundary, IEEE 1584, Personal Protective Equipment (PPE)

I. INTRODUCTION

An arc flash is a rapid release of energy due to an arcing fault between a phase conductor and another phase conductor, a neutral conductor or ground. An arc flash (arc) happens when electric current flows through air between two conductive parts. Arc faults are generally limited to systems where the voltage is in excess of 120 Volts AC or 50 Volts DC. Most of arc flashes are related to work on the electrical system.

An important point is how arc flash hazards can be dealt with by a company's safety standards. Each country has its own code for working on electrical installations, in CENELEC countries these are based on European Standard EN 50110: Operation of electrical installations. One of the key concepts of this standard is that work is divided into three categories: live working, dead working and working in the vicinity of live parts. Because most work is carried out under the dead working condition it is often assumed that arc flash hazard is not a concern. Some work activities however take place in close proximity of energized conductors. Even making the equipment safe to work can expose the worker to a hazard.

The American NFPA 70E standard can—with regard to this subject- be seen as an analogous to EN 50110 (and their national extensions). It covers shock hazard in a similar way. In addition it requires risk assessment for arc flash hazard, meaning that before work can be carried out near energized conductors the following must be done:
• the hazard must be known (through an arc flash hazard analysis),
• measures are to be taken to reduce risk,
• wearing the appropriate PPE when risk cannot be reduced through other means.

Leveraging knowledge and practical experiences both from Europe and U.S., this paper describes solutions to avoid arc flash hazard, as well as solutions to limit its effect. Either the probability or the effect can be acceptable, however the combination is most important. If there is any arc flash risk, the first question is how to prevent the risk. When no sufficient options for risk prevention apply, the next question will be how to minimize the effect. After all, the workers need clear information about the risk. The approach is used both for network design or extension, as well as for maintenance activities. Although DC systems can have significant potential arc energy as well, this paper will focus on AC systems. A formal calculation method for potential arc energy in DC systems is under development.

This paper will discuss solutions that can be applied to prevent or reduce arc flash hazards and damage to equipment. The options to prevent Arc Flash incidents are based on:
• safe systems,
• way of working,
• proper maintenance.

To reduce the arc flash energy level, there are several design options, retrofit methods, and work procedures one can implement. These options are based on:
• reduce potential arc fault energy,
• safety practices.

If in the end there is still an unacceptable risk, proper selected PPE’s should be used as a last line of defense.
II. PROBABILITY OF AN ARC FLASH

A number of factors can contribute to arc faults within switchgear, however the human factor plays a paramount role in arc flash safety. Experts estimate that over 70% of Arc-Flash incidents in Europe occur during or immediately after electrical work.

Most of the arc flash incidents that the authors learned about, were the result of human error, such as touching a test probe to the wrong surface, tools or accessories such as breaker shaft extensions slipped on live parts of the installation, forgotten tools, dangling unshielded secondary wiring, or a worker entering the wrong panel. Some work activities such as voltage testing, impedance measurements, fault finding, and commissioning take place with energized conductors in close proximity, either because they are allowed exceptions or because the activity requires it. Even making the equipment safe to work can expose the worker to a hazard. Although internal arc faults are often caused by human mistakes or ignorance, switchgear designs do affect the probability of making mistakes or touching live parts.

A common misconception is the delusion that high voltage systems are more dangerous than low voltage systems, which is not true with regard to Arc Flash hazard. Low voltage installations can have very high potential arc energy levels, and the highest probability on arc flash is in low voltage. Work on high voltage is often executed by workers who are more educated, and better prepared with regard to the installation that they are working on, than low voltage workers. In contrast, low voltage systems are operated and modified more frequently.

Insulation failures can increase the probability of arc faults as well, obviously due to improper installation, poor maintenance, moisture, whiskers, animals, or even normal wear and tear. Loss of insulating properties resulting from elevated temperatures can be caused by applying the equipment above its continuous rating or from improperly torqued or aligned contact joints. Another cause can be voids in insulation, which eventually lead to failure of the insulation when stressed at high voltages, or the presence of dust, contamination, or moisture on insulating surfaces. These conditions can lead to tracking across insulating surfaces, providing a path for conduction between two different potentials.

Arc flash caused by technical deficiencies might create significant damage, however the probability that these kind of failures lead to injuries is low, compared to failures related to working activities.

European statistic data on accidents at work is not as detailed as in US, however many persons who spent their career in the electrical domain, know about one or more real life arc flash examples that have happened. In Germany alone, about 600 electrical accidents are reported each year [6]. Almost 25% of those are arc-fault incidents, often with severe burns on the hands and the face, sometimes fatal [7]. More than 50% of all electrical incidents, and more than 90% of all arc flash incidents happen in Low Voltage switchgear [7]. The number of arc-faults that have not resulted in personal injury can only be guessed at, but is presumably much higher.

III. POTENTIAL ARC FLASH EFFECT

In the event of an arc flash the initial flash usually establishes a highly conductive plasma that sustains the current. The plasma will conduct as much energy as is available and is only limited by the impedance of the arc and the overall electrical system impedance. This massive energy discharge burns the bus bars or wiring, vaporizing the copper or aluminum and thus causing an explosive volumetric increase. The result is a fiery explosion, possibly leading to serious and fatal injuries.

Potential arc flash effects are difficult to estimate, because an arc fault current behaves quite differently than the bolted fault current that the system was designed for. In low voltage systems, the arc fault current that is produced during an arc flash is usually much lower than the available bolted fault current that occurs during a direct short circuit. This current level can often be below the instantaneous rating or short circuit setting of the protecting circuit breaker or fuse resulting into longer tripping times and increasing energy.

The most common injuries from arc flash are burns. Experiments have shown that at 1 second, 1.2 Cal/cm² of heat energy can cause a second degree burn [2]. Incident energy is primarily depending on arc fault current, working distance and clearing time.

- The arc fault current depends primarily on available fault current. Distance between conductors, voltage, grounding method, and design are smaller factors affecting the arc fault current as well.
- Distance from the arc has an inverse exponential effect on the amount of arc energy that the worker will be exposed to. Incident energy at the hands and eventually the face of the worker is usually well above the energy exposure at the chest.
- Incident energy is directly proportional to arcing time. The ignition of untreated clothing during an arc incident can extend the energy exposure to the body, possibly resulting into serious secondary burn injuries.

In addition to burns, an arc flash can cause inhalation injuries. When inhalation injuries are combined with external burns the chance of death can increase significantly. Other dangers, beside burns, from the arc flash do include the toxic gases, rapid pressure increases, shrapnel, and hearing damage due to noise.
IV. ARC FLASH HAZARD ANALYSIS

Arc flash hazard analyses are used to identify and quantify potential dangerous situations and enable the end user to make fact-based decisions rather than assumptions in a matter of personal safety. Arc flash hazard analyses calculate the energy released by an arc fault. The method for performing arc flash calculations is described in the IEEE Standard 1584-2002. This standard takes numerous design factors into account and is based on many years of research and empirical testing of the Arc Flash phenomenon [3]. Currently a joint IEEE / NFPA working group is actively revising the standard and planning to release an even more accurate model in 2014. It is not sure if the new standard will include a DC model or not. It is expected that IEC will accept and adapt the new IEEE 1584 standard at the moment that it is released.

Arc flash hazard analysis consists of the following steps:

1. Short circuit calculation – comprehensive network components evaluation
2. Coordination study - Balance coordination and arc flash hazard
3. Arc flash hazard analysis according IEEE 1584 - Incident energy and arc flash boundaries for all locations:
   - Arc fault current depending on short circuit current, distance between conductors, voltage, grounding method, and design.
   - Incident energy depending on Arc fault current, working distance, clearing time.

As an alternative to arc-flash hazard analyzes by means of power system modeling software, simple free online arc calculators exist. Although no in depth evaluations have been done by the authors, it is the authors opinion that these kind of tools are less suitable for complex power system architectures. Performing calculations individually and on an occasional basis increases the probability of mistakes, especially for complex systems, having multiple grid configuration options. Moreover, it is unlikely that accurate data is available in every situation. The occasional nature of the use of online arc flash calculators can also tempt users to input assumptions instead of facts, resulting into misleading information for both most obvious and worst-case scenarios.

A practical rule which is being used by the authors, instead of calculating energy levels for some LV sub distribution panels, is NEN3140, a local Dutch standard, which states that there is arc flash danger if the installation is fed by a fuse size >25Amp or MCB >16Amp

V. PREVENTING ARC FLASH INCIDENT

Most obvious means to prevent incidents is built-in equipment safety. Approaches to eliminate or minimize the probability of an arc flash incident occurring, may include perfectly logical choices for new installations as well as radical operational procedures or significant investments in existing networks, particularly when the potential incident energy is impermissibly high.

A. Safety by design

The selection of safe switchgear designs is an effective start to reduce the probability of an arc flash incident. IEC 62271-200 is an optional type test for High Voltage switchgear to assign rating of the Internal Arc Classification (IAC). TR 61641 is an addition to the IEC 61439 series for low voltage assemblies to run tests under conditions of internal arcing and assess the safety for personnel and protection for the assembly itself. Due to the common roots, the arc fault tests for Low Voltage Switchgear assemblies according to IEC/TR 61641 are more or less similar to those in the IEC 62271-200, however less strict on duration of the arc. IEC/TR 61641 allows four ways for an assembly to pass an internal arc test:

- either the arc exists for the full duration of the applied power, or
- the energy to the arc is interrupted premature for the duration of the applied power, or
- the arc dies through self-extinction, or
- it is not possible to initiate an arc at all.

The first option requires a disproportionately heavy duty enclosure design or directing the exhaust of hot gasses in a way that is not harmful to persons in the vicinity of the assembly. In the second case extinction of the arc can be established through interruption by a protection device. The third option is to design a circuit to self-extinguish an internal arc. Self-extinction can be caused by a situation where the short circuit cannot gain enough energy available to maintain the arc, or the arc length is too long to sustain the plasma temperature due to heat dissipation. For voltages over 600 V this is hard to realize.

The fourth option is create an arc fault free zone to prevent an arc from occurring at all. Assemblies or parts of an assembly that have no accessible active parts, either by application of insulation or through barriers that fully enclose the live parts, are referred to as arc fault free zones (see figure 2).

![Fig.2] Top view of a motor starter unit with arc fault free zone, combined with an arc proof bus bar compartment

To some extent intrinsic safe switchgear designs such as Internal Arc Class (IAC) rated switchgear for high voltage (IEC 62271-200) and low voltage (IEC/TR 61641) do reduce the probability of arc flash injuries, as long as the panels are operated within their specification. However, their level of protection typically only applies in sealed condition and may allow category zero PPE requirements for racking, breaker operation, etc., as long as the assembly is closed and sealed. Whenever work is carried out and panel doors are opened, the switchgear can most probably no longer be considered arc proof and a hazard to workers may be present and should be evaluated.

Arc Fault Free assemblies can be operated without addition of arc flash precaution measures, as long as the activities are limited to the arc fault free zones.
Some IAC rated systems are designed to avoid any activity that may compromise the internal arc classification of the switchgear, for example by means of a cable test facility (CTF) consisting of test probes and integral cable test ports accessible from the front, fully independent of the cable termination enclosure. The operation of the CTF should be integrated in the interlocking system of the operation panel, ensuring the test probes can only be inserted in and removed from the access points under safe condition with closed circuit breaker and the changeover switch in earthed position.

The main driver for safe design is to provide personal protection, but assembly protection (continuous energy supply) could be an additional advantage.

B. Way of working

Most arc flash incidents happen during isolation, work or testing. The first question should be if particular activities such as racking in and racking out are really necessary, and if there is no simpler way to achieve the same result. Some operations have become a habit rather than a strictly necessary activity. Proper and clear safety rules are important to minimize the risk of arc flash incidents. In these safety rules general rules should be for methods of isolation, use of measuring instruments and use of PPE’s. These general rules should cover most situations. However sometimes it is necessary to have location specific or equipment type specific rules. Reasons for this can be: known safety issues with certain equipment due to non-ideal design characteristics or condition.

In general minimizing arc flash incidents starts with awareness. Many electrical personnel have been working for years according certain rules and might not understand the need for change. The awareness comes also with understanding the safety rules and most important, the reason why those rules are there is a basic condition for the acceptance of these rules. A series of information sessions and training is common to achieve that people will work accordingly.

Article 6 of European Council Directive 89/391/EC on risk assessment sets out employer's duties under the "general principles of prevention" of incidents. As always there will be risks associated with activities and they have to be addressed in the safety rules. Most difficult question is to determine what risk is acceptable. There are no straight answers for this, and as EN 50110 is not prescriptive with regard to arc flash hazard, answers will be different for every European organization.

A risk assessment should be done to determine the probability, effect, and acceptance level of arc flash hazard resulting into decisions if and how to perform certain activities, what is acceptable and when and where to use PPE’s to mitigate residual risk. A company should work according their standard for risk assessments, and involve experienced professionals. Items to take into account during the risk assessment are:

- type of equipment
- age and condition of equipment
- competence of workers
- frequency of the activity
- duration of the work
- calculated arc flash energy / hazard risk category (HRC)

C. Maintenance

A proper inspection program can indicate the need for maintenance and prevent dangerous situations during e.g. switching, leading to arc flash incidents. Mechanical issues such as improperly torqued or aligned contacts or loose metal parts in the installation and inaccurate insulation, for example excessive amount of moisture, can contribute to a potential arc flash risk, especially during switching operations and racking in/out. The condition of the equipment should be periodically inspected as part of an effective maintenance program, especially in harsher environments.

VI. REDUCE POTENTIAL INCIDENT ENERGY

The potential arc flash energy can be reduced through reducing available fault current, or fast clearing of the fault before it develops into a serious arc flash condition. Another option to reduce the potential energy exposure, is to move people further away. There are few ways to reduce the available fault currents in power systems:

- Operate double-ended substations with a Normally - Open tie
- Change out transformer – Smaller kVA and/or higher impedance
- Add Reactors

One of the best and most efficient ways to lower the incident energy, which inherently lowers the HRC at electrical equipment, is to clear the fault quicker, hence the protective device trips faster. The ways and methods to clear a fault faster using various protective devices described in this paper are based on:

- Protective devices and coordination
- Zone selective interlocking
- Arc reduction maintenance settings

Customer-specific equipment, or adjustments of protection units can affect the performance of the switchgear construction. Therefore serious attention should be paid to required protection settings for the users application and settings that are valid for the integrity of the whole assembly, as tested.

For both reducing fault current and tripping times the eventual implications on operations should be taken in consideration.
A. Protective devices and coordination

Reducing fault current sounds good in theory, however lowering the fault current doesn’t automatically reduce the incident energy during an arcing fault, especially when fuses are used for circuit protection. As shown in the Time-Current Curve of Fig.4, the arcing fault current can be very low, especially at equipment located electrically far down in the power system. Also, the arcing fault current can be as low as 33% of the calculated bolted fault current at any particular location per the NFPA 70E-2012. Because of this, many times, when fuses are used for circuit protection, the available fault current is not high enough for the fuse to go into current-limit, hence taking much longer to trip and causing the incident energy and HRC levels to increase. At high available fault currents, the fuse will go into current limit, hence tripping faster and keeping the incident energy and HRC lower. In the example of Fig. 4, the electronic trip circuit breaker protecting the same circuit can be adjusted for complete coordination and still trip fast on the low arcing fault current. In this case, the circuit breaker works the best for low available fault current. Optimization of relay settings may in some cases require replacement of old protection devices.

This example shows that there is no “one single answer” to solve arc flash issues in a power system. The best and most comprehensive way to solve arc flash issues in a power system is to conduct an arc flash study. Then from the study, determine each location where the HRC is considered to be unacceptable. These locations must then be individually evaluated to determine the most effective means of reducing the incident energy while maintaining the highest degree of reliability.

Arc quenching devices can respond on fault currents within a few milliseconds. The arc is instantly sensed through catching the light of the arc flash. An electronic circuit checks for an overcurrent in the main circuit. Then, the quenching device makes the short circuit at ultra-high speed, and the arc is quenched. The bolted short circuit current flows through the quenching device until the circuit breaker opens. Combination of arc quenching device with current limiting fuses is a potential solution to overcome the limitations of current limiting fuses, and this combination also mitigates the stress to the equipment by reducing the fault clearing time. Like an air bag in a car, proper installation and operation of the device cannot be primary tested after installation, which could eventually be considered as a disadvantage.

B. Zone Selective or Reverse Interlocking.

Bus Differential Protection and Zone Selective Interlocking (ZSI) are other related ways to provide fast tripping of circuit breakers. The concept of bus differential protection (87B) measures 100% of the current into and out of a bus. Simply put:
- If 100% I IN = 100% I OUT, then no trip
- If 100% I IN ≠ 100% I OUT, then trip all bus breakers instantaneously.

ZSI was based on a similar idea of comparing the currents within zones, for low-voltage switchgear. It substituted a control logic system communicating between feeder breakers and main breakers. In many modern electronic and digital trip units of the low-voltage breakers the option for ZSI is already build into the device. It is commercially available with up to 3 levels as shown in Fig.6, although 2 levels (main breaker and feeder breakers) application are the most common.

ZSI is best described visually. Refer to Fig.6 and assume a high level short circuit occurs on the load side of a feeder breaker. Both the main breaker’s and the feeder breaker's digital trip units sense the fault. The feeder breaker sends a blocking signal to the main breaker letting it know that the fault is in its zone of protection. The blocking signal tells the main breaker to only trip per its time delayed standard settings (backup to
the feeder breakers) while the feeder breaker is the first to clear the fault. However, if the fault occurs in the switchgear, such as on a primary stab fault occurring during racking of the feeder breaker (creating an arc-flash incident to the worker doing the racking), then no blocking signal is sent to the main breaker. Since the main breaker senses the fault but does not receive a blocking signal, its control logic bypasses the short time and ground fault time delay setting characteristics and trips almost instantly. It lowers its time delay settings to approximately 2 cycles, just enough time delay to assure nuisance tripping does not occur.

Next, he uses its lockout features and applies a lock for normal lockout – tag-out procedures. Upon completion of the maintenance, the lock is removed, the maintenance switch is manually opened, and all previous trip unit settings are again re-activated, without need for recalibration.

Appropriate warning signs should be provided to maintenance personnel to alert them that switching to alternate settings needs to be done prior to any work, and that it will override normal selective coordination and increase the possibility of nuisance trips. An example is shown in figure 7. In case of multiple sections in one panel, it should be clear to which section the maintenance switch is connected, or the switch should operate multiple protection devices in parallel. Selection of the maintenance setting should activate an alert in a decentralized control system and procedures must ensure that the breaker is returned to its normal position at the conclusion of maintenance activities. In older heavy industrials plants it is common to find substations without transformer secondary main breakers. In that case applying a maintenance switch can be more complex.

In recent years, some High-voltage protection relays also became available with Reverse Interlocking. The idea behind Reverse Interlocking is exactly the same like the ZSI in Low Voltage systems. Reverse Interlocking is intended primarily for bus differential protection for smaller power systems where bus differential relaying would generally not be applied.

**C. Maintenance settings**

Maintenance settings can significantly lower the potential incident energy by providing shorter clearing times and/or lower current setting. Many modern solid-state trip units and protective relays for low voltage and high voltage switchgear are now employing group settings which can be utilized for maintenance settings (lower pickups and/or faster trip times). An external switch is used to instruct the relay or trip unit to use the maintenance settings. Before work is performed, the electrician simply switches to the maintenance position.

**D. Move people further away**

The approach of moving people further away, is based on the knowledge that an arc blast expands volumetrically and during this process, cools dramatically with distance. Distance from the fault always helps. There are certain tasks associated with distance that lend themselves very well to reducing arc flash exposure. The most notable is racking HV and LV breakers. Many documented accidents have occurred during this operation. Traditional IEC switchgear designs place the worker directly in front of the switchgear cell while racking the breaker. There are ways to lower incident energy exposure during racking:

- Put an extension on the racking tool
- Use a robot or remote racking device

Lack of distance between the switchgear and wall sometimes limits the use of a racking tool extension. The robot approach locates the worker up to 15 meters away. The robot must know the number of turns in or out and torque limits of the breaker, so as to not over torque the shaft, jam it with misalignment or cause a failure. The robot should stall and back out if torque limits are exceeded.

Another example of moving people further away is remote switching. For example by a chicken switch. It slips over a pistol grip operator, and holds onto the...
switchgear front with magnets. The operator is connected with a cord so that you should be out of the arc flash boundary when you operate the breaker.

Something which is sometimes forgotten is that people who are not directly involved in switching/work (and not wearing PPE's) should be outside the hazard boundary.

Fig.8) Conventional Racking (left) compared to Robot (right)

E. Safety practices

Using good safety practices is another important contributor to prevent injuries and mitigate arc flash hazards. The Starting point should always be to de-energize equipment versus “working it live” unless de-energizing increases hazards or if it is infeasible due to design. If possible, any switching should be done remotely.

Fig.9) Bad Practice – Exposed Back of Neck

Fig.10) Good Practice – Entire Body Protected

In case of local switching, the worker should make sure that door latches or door bolts are closed and tightened before operating a switch, and one should stand to the side and away as much as possible during switching operations as shown in Figs. 9 and 10. If PPE is used, the selection of a level of PPE should be a balance between the calculated incident energy exposure and the work activity being performed in order to provide enough protection to limit injury to a second degree burn in all cases and to minimize new risk introduction caused from heat stress, poor visibility or limited body movement.

For existing LV and HV systems that are not arc proof, arc resistant, arc free or internal arc classified, any local operation of a live system, including switching, is considered as a potential arc flash risk that requires evaluation before work is carried out. Measures to protect workers are based on arc flash calculations. The only exception is passing by in absence of maintenance or operation activities. The very short time that someone is in the hazard area makes the risk negligible.

VII. LABEL EQUIPMENT & TRAIN PERSONNEL

When hazards are known and steps have been taken to prevent and reduce them, the next step is to embed arc flash safety into the daily routines. Hazard Rating Categories have to be visible for anybody who has access to the substations, and it is important to train personnel and contractors to get them familiar with arc flash hazards and how your electrical safety program has changed. Implementing the results of an arc flash hazard analysis takes time and there may be locations where work methods or PPE requirements need to be changed temporarily until implementation is finalized. High hazard locations may be marked for extra care during procedure to get a work permit.

The arc flash hazard calculation study will result in a worst-case incident energy at working distance for each location, including an arc flash boundary and required PPE to mitigate hazard. In case of multiple network configuration options, the label is usually based on worst-case. A label at each location will help in reminding workers of arc flash risk and the hazard at that location. Following the EC Safety Signs Directive (92/58/EEC) for provision and use of safety signs at work, arc flash labels should be yellow (or amber), they must be triangular and the yellow must take up at least 50% of the sign, so that wherever the signs are, they are recognized as a warning sign.

In Europe there is a general tradition of eliminating risk through built in safety in the switchgear design, and in the absence of a prescriptive standard for arc flash safety, there is a lack of knowledge and awareness for arc flash hazard among electrical workers. Many workers encounter arc flash safety as almost a cultural change. It takes quite some effort and time to get arc flash awareness embedded in daily routines. As we have to deal not only with electrical workers who are employed by the end user, but also with contractors, the simplicity of safety measures has significant importance. Part of the authors practical experiences are based on a simplified arc flash safety approaches. One of the end users decided to merge HRC 0 and 1, and makes no distinction between HRC 2 up to HRC 4. Only the dangerous areas
(>40Cal/cm²) are labeled. Breakers with HRC 0 and 1 may be operated by trained operators in adequate protective wear. Work with HRC 2 - 4 will, if really necessary, only be performed by maintenance people, with adequate protective means.

The simplistic approach of merging HRC categories is a practical compromise, provided that only simple work with a short duration is being carried out, such as the operation of a breaker, or making a system safe to work. It certainly has the downside of over-dressing, on the other hand the risk of under-dressing is eliminated and the simplified approach does increase arc flash awareness, moreover it stimulates workers to minimize the number and duration of activities in the vicinity of live parts.

Fig.10) Example Warning sign NAM

A typical initial training on a simplified approach of arc flash safety will last between half a day to a full day to cover the following items:
- Introduction to arc flash hazard and terminology.
- Explanation of arc flash safety and how it impacts the work methods.
- How link Hazard Rating Category to work activities.
- Selection of the right level of PPE from an arc flash label.
- Company specific rules

VIII. USE OF PERSONAL PROTECTIVE EQUIPMENT

When all other avenues have been exhausted and workers are still at risk of being exposed to arc flash hazard, as a last line of defense, Personal Protective Equipment (PPE) can be selected using the results of an arc flash hazard analysis. The calculated Arc Thermal Protective Value (ATPV) can be used for obtaining European CE marked garments according to the draft IEC 61482-2 garment standard. Although IEC 61482-2 has not been adopted yet by CENELEC as an EN standard, some Notified Bodies did already certify garments submitted by manufacturers to be CE certified and labelled to this standard. CE marking is required for all PPE used in Europe.

For a practical solution to mitigate any remaining arc flash hazard, a proper selected system of PPE can be devised that protects people against burns and eyesight injuries in most practical cases. For example a set of PPE for all electrical workers that could be exposed to arc flash hazard, adequately protecting them in 80% of the cases, but comfortable enough for day to day work. The 20% cases of high hazard will need additional PPE which may only be required occasionally, and not by all personnel. Wearing HRC3 or 4 garments, gloves and head- and neckware, is only acceptable for activities with short duration because it is cumbersome, hot, and increases fatigue. Moreover it hinders the employee’s natural sensors and reduces mobility. PPE definitely is not an option for long-term operations, or complex work, such as a repair or modification. Although PPE up to 80 Cal/cm² is commercially available, the authors do not consider any work at locations with HRC higher than 4, as an option.

![Fig.10) Example Warning sign NAM](image)

<table>
<thead>
<tr>
<th>Hazard Risk Category</th>
<th>Clothing Description (Typical Number of clothing layers given in parenthesis)</th>
<th>Required Minimum Arc Rating of PPE calming²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Non-flammable, flameable materials (e.g., untreated cotton, wool, rayon, or silk, or blends of these materials with a fabric weight at least 4.5 oz/A (1)).</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>FR shirt and FR pants or FR coverall (1)</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Cotton underwear conventional short sleeve and long pants, plus FR shirt and FR pants (1 or 2).</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Cotton underwear plus FR Shirt and FR cover all, or cotton underwear plus two FR coveralls (2 or 3).</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>Cotton Underwear plus FR Shirt and FR Pants plus multi-layer flash suit (3 or more).</td>
<td>40</td>
</tr>
</tbody>
</table>

Based upon maximum energy for a 2⁰⁴ degree burn (1.2 cal/cm²)

Fig.11) Protective clothing needed is determined by Hazard Risk Category (1-4)

Apart from the applicable hazard risk category, personal protection against arc flash hazard starts with fire resistant underwear. Inappropriate underwear could ignite or melt, thus having an adverse effect on protection aggravating the outcome of an electric arc incident. Nevertheless FR underwear is often considered as uncomfortable and warm. The authors are not aware of any company enforcing fire resistant underwear to employees and contractors.

Another controversial issue is ear protection, which would be needed in case of an arc flash. Many electrical workers refuse to wear them, because it hinders their sensors, eventually introducing new risk.

IX. CONCLUSIONS

Following safety standards based on EN 50110 does not automatically mean that arc flash is not a concern. It is the authors’ collective opinion that the best and most comprehensive way to identify and solve arc flash issues in a power system is to conduct an arc flash study. Most excessively high incident energy exposures can be mitigated through a variety of techniques. Our experience in performing arc flash hazard analysis tells us that there is no one single answer to reduce arc flash hazards; you need a total system approach. What works in one organization may not work effectively in another organization.

Modifications to existing equipment, protective devices, new specifications utilizing “safety by design” concepts, use of robots, alternate maintenance procedures, etc., can all be effectively used to dramatically improve electrical safety. Many of the techniques and suggested solutions are very cost effective; but even the higher cost solutions are small investments compared to the costs of dealing with the consequences of a major electrical
accident. Customer-specific equipment or adjustments of protection devices can affect the performance of the switchgear construction. Therefore serious attention should be paid to required protection settings for the users application and settings that are valid for the test results, such as IEC/TR 61912-2, and more important safeguard the integrity of the whole assembly.

In the absence of prescriptive standards in Europe, the final assessment of whether a risk is acceptable or solutions are needed to reduce the probability or the effect, remains a decision for the electrical experts within the organization of the end user. Proper information is essential, a crucial question for the experts is: Would the decision still be justifiable when something went wrong? A simplified approach makes it do-able to implement arc flash safety for dealing with situations that are rare, and should be prevented as much as possible. The authors have the opinion that Arc Flash calculations are very important, although the focus should remain on intrinsic safety, PPE is considered as a last line of defense and excessive time in high level PPE should be avoided.

What specific benefits did we see from the arc flash hazard analyses?

First, it appears that the awareness of arc flash hazard has improved at plants that participated in arc flash hazard assessments, for example when it comes to protecting the person next to the one who is working in the electrical installation. Measures based on facts are easier to explain than measures based on guesses and feelings. It is also a fact that the selection and use of PPE has improved. Arc Flash calculations showed several times how misleading guesses and feelings can be. In practice we encounter many HV systems which have HRC lower than 25cal/cm2. Much more often we see potential danger in LV. Especially, if protective devices are only on the high voltage side of the transformer. LV systems are less transparent, hazards are often underestimated, and operation staff for LV systems is usually less skilled than for HV systems. Last but not least, situations with potential back flow of electrical energy are more obvious. The performed Arc Flash hazard analyses do have implications for new projects as well. Arc Flash calculations should now be part of the design calculations for expansion and new constructions to make sure that new installations despite of arc safe designs, have acceptable potential fault energy levels.

As is the case with many maintenance and safety topics, quantification of the financial returns of an arc flash hazard analysis is rather complex. Fact is that safety in the oil and gas industry is important. The probability of an Arc Flash is low but the consequences can be enormous. Thanks to the hazard analysis, we can now determine the effect. In itself, performing an hazard analysis does not offer any guarantee that fewer accidents will occur, but it does provide the right pointers for making well-considered decisions.

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XI. REFERENCES


XII. VITA

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