Direct and Indirect Benefits of Arc Flash & Electric Shock Studies

Baseline Definition

Electrical Safety was always high up on the priority list of the US American occupational health and safety environment. This priority showed result. The number of accidents and incidents with lost time injuries related to electric shock fell continuously in the last 20+ years. This favourable decline had one side effect that went unnoticed for some time. The more the frequency of electric shock incidents was reduced, the more the so-called arc flash incidents moved into the spot light, taking over the infamous number 1 place at the beginning of this century. It was time to respond to this 'new' high hazard.

Not surprising, the respective standardization bodies in the USA defined new requirement on Arc Flash and for US American companies it became mandatory to meet this changed standard already several years ago. Many companies headquartered in the USA have started programs to comply with the change.

In the Asia Pacific region, local standards in the various countries regarding electrical safety and especially arc flash have not yet been aligned or synchronized with the US American level of protection as defined in the NFPA 70 E, IEE 1584, OSHA publications, etc.. However, once the large standardization bodies in the USA and Europe have defined such changes, the requirement of these new standards become globally state-of-the-art, hence expected to be followed by all international companies. Changes recognized as state-of-the-art become the rule internationally, even if the local standard has not yet been adjusted or changed. The legal perspective is quite clear, state-of-the-art has to be applied and followed, or severe liability issues might arise especially at the corporate level and in liability-focussed legal systems as can be found in North America, UK, and Australia .

One question that is usually asked prior or during An Arc Flash Study is "What are the benefits?" There are a number of obvious ones, directly related to the compliance part. However, by expanding the scope of the study, a number of additional indirect benefits can be added with no or only minor additional cost as the required time is mostly negligible.

The aim of this paper is to highlight both areas, the direct and indirect benefits. This document describes benefits or the negative impacts arc flash or electric shock incidents will result in. The aim of Arc Flash & Electric Shock Studies is to eliminate or greatly reduce these negative outcomes, to prevent recurrence, and to provide a higher degree of awareness on all levels throughout a company.

1. Direct Benefits

1.1. Compliance

The main reason to carry out an Arc Flash & Electric Shock Study is usually triggered by the need to prove compliance with international and/or internal standards. Local requirement, be it national standards or industry best practices must be considered as well and will flow into the study.

An internationally operating company needs to be in compliance with the most demanding safety regulation (recognized as state-of-the-art), at least with such regulation as are mandatory in the country of origin, headquarter, or listing. If a company deviates from this mandatory requirement the following results might occur and need to be considered. The following summary is based on many actual occurrences. It is by no means prioritised or quantified as the impact differs significantly from corporation to corporation, depending on type of and business exposure, location, etc.:

- Negative media attention (especially if it happens during a time with lack of breaking news or when certain interest groups like NGOs see their chance to become very active)
- Loss of trust of financial markets
- Severe financial impact as the market capitalization (share price) might drop significantly
- Due to lower share price, higher interest rates to finance running operations and capital expenditures
- Group-wide increase of insurance premiums (e.g. worker's comp., property insurance)
- Question by regulators regarding overall management principles plus additional audits by governmental bodies
- Loss of trust of suppliers and customers might cause loss of business
- Other companies, operating internationally, have to defend their supply chain, orders might be cancelled or delayed
- Legal actions by authorities, interest groups, unions, etc.
- Sudden and high time demand as management on various levels of the organization has to deal with inquiries made by authorities, work councils, unions, NGOs and other parties – not to forget the various corporate functions.
- Top management is forced to change their priorities, as crisis management requires time and cannot be postponed. This might delay planned redirection of strategies, opening of new customer groups, introduction of new products, etc. In general the long-term results can be very negative and expensive.
- Disruption of the existing equilibrium between the social partners in the organization. Severe incidents might cause strike and other industrial actions
- All the above has a negative impact on the financial results and will furthermore damage the reputation of the company or corporation

- Good-will is eventually required to speed up recovery or to gain trust and market share back. Good-will actions are usually expensive and have a direct impact on the profit / bottom line of a company or corporation

1.2. Occupational Health & Safety Improvement

The nature of Arc Flash and Electric Shock Studies is to eliminate as far as possible any arc flash and electric shock incident. However, this demanding goal might not always be achievable, but the frequency (probability) of arc flash or electric shock events will be reduced **and** - equally important - the severity of any remaining incident will be lowered to a level where severe injuries and especially fatalities are not expected anymore.

Further details are:

- The electric power distribution system of a plant will be analysed completely
- The arc flash intensity (incident energy release) will be calculated for every circuit and at every location where people might face an exposure – even where it is not expected
- The safe distance (arc flash boundary) from where on persons will not be harmed anymore by an arc flash will be calculated (considering certain PPE requirement)
- PPE levels will be defined for every exposure location, describing in details what PPE needs to be worn in order to avoid injuries
- Corporations usually define the requirement regarding maximum PPE level accepted in an operation (e.g. level 2 PPE, which means level 2 and below are acceptable, level 3 and above are not acceptable and have to be avoided). Arc flash exposure with an incident energy level requiring higher than maximum accepted PPE level will be identified and technical solutions prepared to reduce the PPE level to the accepted level (or even below). Such corrective actions might require change of equipment, adjustment of setting parameters of safety equipment (MCBs, relays, etc.), further analysis like Load Analysis / Load Profiling, or other activities
- The same applies to incident energy exposures that are beyond any adequate PPE level (> 40 cal/cm^2). This is especially important to avoid fatalities!
- Besides the definition of the arc flash boundary, detailed information about electrical shock safety will be given as well. The study will result in the definition of the approach boundaries that are relevant to avoid electrical shock or allow safe work on energized equipment. These boundaries are Limited Approach Boundary, Restricted Approach Boundary, and Prohibited Approach Boundary
- With the results of the study, an organization will be able to reduce exposures, reduce the need to wear heavy (cumbersome) PPE, and last not least be a much safer place for all staff members, visitors and contractors working on the site
- Warning labels will be provided on all relevant electrical equipment throughout a plant for all discrimination levels. These labels will inform every person about inherent arc flash hazard intensity, what PPE needs to be utilised and what the various approach boundaries are regarding arc flash and electrical shock. In short,

every person will have the information at hand before opening any panel, or getting closer to electrical equipment

- Al relevant persons (mainly Safety Managers, Facility Managers and Technical personnel) on the studied site will be informed or trained that they understand the information on the labels, what it means for safe working, why it has to be followed, the reasons behind it, etc..

1.3. Higher Level of Asset / Business Interruption Protection

Besides the planned and expected improvement regarding occupational health, one important positive side-effect of the Arc Flash Study is the impact it has on asset protection and related business interruption. By reducing the probability and severity of arc flash and electric shock incidents, the impact on the property or physical assets of a site is equally significant. Arc flash is one severe ignition source to start fires in industrial or commercial environments. Statistics show arc flash being a significant cause of fires and of explosions (arc blast) with their devastating effect on physical property.

Loss of property due to fire and explosions always goes hand-in-hand with

- Financial loss due to replacement costs
- Business interruption loss, due to production time loss, unavailability of production facilities, raw materials and other material required for manufacturing
- Consequential financial loss due to loss of customers, loss of market share or even loss of markets, loss of preferred supplier, contractor or customer, interruption of up- and down-stream supply chains
- Knock-on effects like loss of key personnel (won't wait until operation can proceed), delayed investments, delayed introduction of new products, and others having a financial negative impact.
- Another knock-on effect difficult to quantify is the loss of reputation
- Increased insurance premiums (Property Damage / Business Interruption / Workers Comp, etc.)

1.4. Higher Reliability of the Electrical Distribution System

The Arc Flash Study is an exercise that will cover the complete electric power distribution system of a plant. As such it is one of the very few opportunities to look at the whole of the distribution system in one go. Deviations from good design, installation, and operation will be identified. Equipment or circuits with a high incident and loss potential will be identified as well and furthermore, the severity quantified. In particular, the protection equipment (Relays and Circuit Breakers) are also tested for reliability and precision of the calculated settings as the Relay and Circuit Breaker calibration tests are a requirement and a prerequisite of the Arc Flash Study.

All parts of the study will increase reliability of the installation. They are in overview:

- **Updated Single Line Diagrams**

  Changes in electric power distribution systems are reality and do happen on an on-going basis. Unfortunately, these changes are not always documented. As-built line diagrams are what every Maintenance Manager wants to work with, but reality is that only few plants keep their documents on an as-built level.

  The prerequisite of an Arc Flash Study are as-built single line diagrams of the complete power distribution system. Without it, the study cannot be performed. Updated, as-built documentation is a major corrective action and improvement to prevent accidents and incidents, especially in regards to electric power distribution systems.

  As-built single line diagrams will reduce maintenance costs due to

  - Reduced down-time
  - Reduced time to identify/pin-point cause of a problem (incident / short circuit, etc.)
  - Reduced repair time (no individual risk analysis required prior to start of work)
  - Reduced time for preparing and approving work orders, repair team briefings, etc.

- **Protection Device Coordination Study**

  Optimized coordination of all protection devices in an electric power distribution system will significantly reduce down-time of the system or parts of it. A system that is not coordinated in an optimal way will cause the unnecessary shut-down of extended areas of the power distribution system that should not be affected by the tripping of a single protection device.

  Besides preventing the unnecessary shut-down of parts of the distribution system, the time required for maintenance to bring all circuits back into operation will be more time consuming as the failure search need to include all parts of the electric power distribution system that have tripped (in the worst case the complete system). In a coordinated system only the circuit where the failure occurred will trip, hence maintenance is guided directly to the circuit that has caused the trip and repair work will start immediately. In the case of a complete system trip, long delays will result due to the need to check one circuit after another until the defective one is found.

Time Current Curves of each Discrimination Level are prepared to illustrate the coordination/incoordication between affected feeders. The protection settings are also segregated appropriately in the report for the technical and maintenance personnel to identify and familiarise themselves with the feeders. This documentation are almost never submitted originally by design consultants and only submitted upon request and most often for an additional fee.

- **Fault Current Analysis (Short Circuit Study)**

  This analysis calculates the fault current at each panel, feeder, busbar and/or switchboard and is required to carry out all other studies or analysis. The results will be compared with the individual electrical component to identify adequacy regarding possible fault currents. The Main Short Circuit Fault Diagram is prepared as part of the study to ease operations and maintenance. This drawing is also usually not submitted by design consultants and only submitted upon request and usually for an additional fee.

- **Electric Shock Hazard Study**

  The calculation of the fault currents of every circuit leads to the definition of certain boundaries that are defined to be of importance to prevent electric shock. These boundaries are printed on the warning label and need to be considered if work on energized equipment is necessary. Knowing these boundaries and having them visible on every piece of respective equipment will prevent the frequency of accidents, hence make the overall system more reliable following the simple principle "No incident = No downtime = Higher reliability."
  The boundaries as defined by NFPA 70 E are:

  - **Limited Approach Boundary**
    A shock protection boundary to be crossed by only qualified persons (at a distance from a live part), which is not to be crossed by unqualified persons unless escorted by a qualified person. The limited approach boundary is the minimum distance from the energized equipment where unqualified personnel may safely stand. No untrained personnel may approach any closer to the energized item than this boundary.

  - **Restricted Approach Boundary**
    A shock protection boundary to be crossed by only qualified persons (at a distance from a live part), which, due to its proximity to a shock hazard, requires the use of shock protection techniques and equipment when crossed. To cross the Restricted Approach Boundary into the Restricted Space, the qualified person, who has completed

required training, must wear appropriate personal protective equipment (PPE). Also, he/she must have a written approved plan for the work that will be performed and must plan the work to keep all parts of the body out of the Prohibited Space.

- **Prohibited Approach Boundary**
  A shock protection boundary to be crossed by only qualified persons (at a distance from a live part) which, when crossed by a body part or object, requires the same protection as if direct contact is made with a live part. Only qualified personnel wearing appropriate personal protective equipment (PPE), having specified training to work on energized conductors or components, and a documented plan justifying the need to perform this work may cross the boundary and enter the Prohibited Space. Therefore, personnel must obtain a risk assessment before the prohibited boundary is crossed.

- **Arc Flash Study**
  This study will result in detailed information on incident energy levels, arc flash boundaries, arcing current and duration and – most importantly - the required PPE for each and every location if work on energized equipment is required. The Arc Flash Boundary is the safe approach distance from energized equipment or parts. Entering into the space as given by the arc flash approach boundary, the defined PPE has to be used.

  The main effects on higher reliability can be seen in the reduction of probability and severity of arc flash occurrences. Even complete elimination is possible (see Best Case / Worst Case Simulation).

- **Best Case / Worst Case Simulation**
  All locations that result in higher incident energy other than the defined maximum (e.g. Level 2 PPE) will run through worst case / best case simulations to develop technical solutions that will reduce the PPE level from unacceptable to acceptable. All corrective actions will significantly improve the reliability of the electric power distribution system as well and thus reduce or even eliminate incidents that are costly as described above.

2. Indirect Benefits

2.1. Identification of Maintenance Issues

The Arc Flash Study requires checking each and every part or component of the electrical distribution system – without exception. Such detailed work is usually not performed during normal operation and maintenance. The study will identify various deviations from best practices, which then can be reported following a defined and agreed reporting schedule. Identifying unfavourable conditions will allow response and rectification by management, thus eliminating severe loss potentials or reliability reducing situations and conditions.

2.1.1. Cable Management

Installations not following best practice will be identified. Examples are

- Inadequate cable runs/phase,
- Cables not in conduit,
- Cables not in respective trays or channels,
- Damaged conduit and/or cable trays,
- Damaged cables,
- Too short cables,
- Too long cables,
- Cable spaghetti,
- Overload potentials,
- Insufficient cleaning intervals,
- Wrong colour coding,
- Insufficient and/or inadequate cable connections,
- Cable damage potentials e.g. sharp corners, insufficient bending radius,
- Wrong location (high hazard exposure like heat, chemicals, water, vibrations),
- Cables not in use anymore, but not removed,
- Others

2.1.2. Neglected Equipment

- Equipment not in use anymore, but not removed,
- Equipment not maintained, not included in preventive maintenance schedules,
- Damaged equipment (e.g. damaged or missing panel doors, corrosion, etc.)

2.1.3. Inadequate Connection

- Certain lose connections that are obvious to the naked eye can be identified (not replacing thermographic inspections),
- Wrong connection (e.g. taped instead of required connector, unsuitable connectors),
- Missing connectors

2.1.4. Contamination

- Rodent, bird Infestation
- Dust, lint accumulation,
- Garbage/waste disposal (e.g. packaging material),
- Oil, grease contamination,
- Chemical contamination,

2.1.5.Unnecessary Exposure to Hazards

- Misusing MCC and similar locations for storage,
- Misusing cabinets for storage, accumulation of unnecessary items,
- Misusing MCCs or similar locations for other purposes like workshops, meeting area, offices, rest area, etc.,
- Inadequate minimal (required) distance between machinery and equipment,
- Blocked access resulting in no or insufficient maintenance,
- Exposure to physical impact due to missing guards, hitting barriers, installation in traffic areas, etc.

2.1.6. Housekeeping

- All obvious deviations from proper housekeeping like waste accumulation, inadequate cleaning intervals, etc.

2.2. Inadequate Installation

2.2.1. Special atmosphere proofed equipment

- No explosion proofed electrical equipment (IP6x) based on requirement of hazardous location,
- Inconsistent installation of explosion proofed equipment,
- No dust proofed electrical equipment based on requirement of hazardous location,
- Inconsistent installation of dust proofed electrical equipment,

2.2.2. Outdoor vs Indoor Installation

Electrical equipment designed for indoor installation is used outdoor (water / humidity exposure)

2.3. Occupational Health & Safety Issues

Extending the scope of the study some elements regarding occupational health & safety can be covered as they will be discussed during the study. These elements are usually subject to mandatory and specific occupational health & safety audits. Examples of these elements are described in the following (but not limited to):

- Adequacy of provided PPE, especially in relation to the resulting arc flash intensities of the study.
- Conditions of PPE like wear & tear, shelf life time (e.g. gloves), storage conditions, location and availability etc.

- Visual and Electrical tests on PPE based on OSHA 1910 and ASTM.
- Adequacy of earthing mats (size, location, thickness, wear & tear, etc.)

2.4. Management Issues

By studying the complete electric power distribution system, deviations from best practices regarding certain management subjects will become apparent as well (besides the already described maintenance issues). It is understood that probably all management issues are addressed in various audits that are part of the company culture and set of procedures. However, the Arc Flash & Electric Shock Study follows a different path, more detailed than usually achieved during audits and therefore it is possible to identify deviations and/or the severity of deviations in a different way.

Management issues that might be addressed are as follows:

2.4.1. SOPs (Standard Operational Procedures)

Electrical safety is based on various SOPs that are an integral part of any work on electrical equipment. Deviations from SOPs might be identified during the analysis due to discussions, document review, or other observations.

2.4.2. Preventive Maintenance

As already mentioned in the maintenance issues, deviations from best practice preventive maintenance might be uncovered during the study

2.4.3. Documentation

Part of the study is to review required documents. Missing documentation or errors in the documentation will become apparent.

2.4.4. Qualification

Certification of staff members (and/or contractors), that are working on electrical equipment need to be checked.

2.4.5. Training

Training levels of staff and contractors, etc.

2.5. Extended Data Analysis

The Arc Flash Study leads to large amounts of data that is utilised for the various calculations. This data is reported and part of the study. Currently the scope of the study focusses only on the data that is directly required for the study and which is relevant to understand the results is reported in details. One could also say, the study creates “Big Data” and it should be investigated how this Big Data can be utilised for further analysis. This add-on analysis might result in more conclusions; indicate other technical solutions and improvements that might not necessarily be part of the original study.

Considering all data available, the following additional analysis steps might be possible:

2.5.1. Arc Flash Study Data

Different presentations, probably with additional results or conclusions. Defining additional filters to allow presentation of results in different ways, making more sense to different people or parts of the organization (e.g. EHS / Maintenance / Production / Management, etc.)

2.5.2. Arc Flash Study – Data Extension

Additional data, consisting of other electrical characteristics, further component and equipment information can be retrieved as well if the scope of the study would be extended. Examples of such extension might be

- Load Flow Analysis
- Motor Starting Study
- Load Profiling
- Bottlenecks
- Others

2.5.3. Benchmarking

As the same study is done for various locations (following identical principles and reporting), certain results could be used for benchmarking giving management the opportunity to

- Compare results on a site to site basis
- Identify areas of concern
- Set priorities regarding capital expenditure (investments)
- Optimize audit schedules and priorities
- Draw conclusions regarding safety performance
- Draw conclusions out of the study results that might otherwise be missed without comparison

Reporting

A detailed report covering all relevant data regarding Arc Flash and Electric Shock will be provided as required by the scope of the study and defined in the respective technical documents.

Elements covering the indirect benefits as highlighted earlier in this paper are not part of the Arc Flash and Electric Shock Study. Therefore observations made in this respect will not be included in the final report of the study. However, as a safety specialist, Global Risk Experts (GREx) feels strongly obliged to the continuous improvement process and will communicate all observed deviations from best practices, inadequate or faulty equipment and installations, maintenance and housekeeping issues, violations of state-of-the-art procedures and processes, deviations from best practices, and other relevant loss potentials.

All observations will be reported by the respective GREx engineer during the daily close-out meeting at the end of each day the engineer is on site. This procedure allows discussions and immediate verification or clarification. Upon request, brief Minutes of each close-out meeting will be provided or any other form of written report that is chosen by the customer.

We have to stress, that pointing out issues that are not directly included in the scope of the Arc Flash and Electric Shock Study (see above) demand both, direct corrective action, and further analysis and evaluation whether this issue is more wide-spread or broader. Both actions are not included in the scope of the Arc Flash and Electric Shock Study and are the sole responsibility of the respective site management. Extending the scope of the Arc Flash and Electric Shock Study can be discussed between the parties and agreed upon.

Conclusions

The Arc Flash & Electric Shock Study has a clearly defined scope of tasks, activities, and deliverables. It is in the nature of such a study to analyse deviations from best practices that are directly connected to the scope, but it doesn't stop there. It also identifies deviations that are only loosely connected with the scope. It would be a missed opportunity if information exceeding the scope would not be shared and therefore would not be considered for or lead to corrective actions.

Compliance with the respective international and internal standards is a given goal. **Compliance +,** however, should be aimed at.

By choosing a suitable external service provider to carry out Arc Flash & Electric Shock Studies for a company and to choose the same provider for all sites of a company has many advantages. First of all, results become comparable and can be utilized in a broader context, other than just compliance. Loss potentials, deviations from best practices, areas of concern, and other observations can be reported and utilized to improve the overall performance of a company. This work will significantly support already existing audit procedures and activities, supplementing not replacing them. Management will be able to create a higher degree of awareness regarding Electrical Safety throughout the organization, and – last not least – it can be become an important cornerstone in the management principle of continuous improvement.

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