ELECTROWAVE
Power Solutions Ltd.
Specialised Electrical Engineering Services

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

ENGINEERING TECHNICAL NOTE No3 FOR ELECTROWAVE CLIENTS

HEALTH AND SAFETY AT WORK

UNDERSTANDING THE DANGERS OF AN ELECTRICAL ARC FLASH

Tech Note Date 15/11/06
Study researched and compiled by Cliff Forbes

ELECTROWAVE
Power Solutions Ltd.
Specialised Electrical Engineering Services

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

Table of Contents

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

UNDERSTANDING ELECTRICAL ARC FLASH REQUIREMENTS

1 PREAMBLE

This "Engineering Technical Note" is compiled for information only.

We are presently working on 2 projects conducting "Arc Flash Calculations" and presenting solutions within two large manufacturing UK multi national companies. At these companies to make everyone aware of the "ARC FLASH" conditions we had to start with "Power Point Presentation" awareness training seminars for all the personnel from the general office personnel thro' to the engineering personnel.

From an engineering point of view we thought it might be of interest to you as more and more of our MCC's designed nowadays have very large energy sources. The problem experienced on many sites is that it can be somewhat difficult to isolate certain parts of the plant, and in many cases commissioning has to be conducted during a LIVE scenario. Also, older protection switch gear may not react fast enough to prevent higher fault currents?

We have very interesting engineering video's, movies and Power Point Presentations on this subject that will highlight and present solutions to the danger facing operatives (and Sub-Contractors) working on electrical plant.

If you require any further information please contact us on any of the numbers listed above;

As you will see it can be a very interesting, frightening and complex subject (hope we don't bore you too much), if you go to the document summary we have bullet pointed all the major elements.

2 UK Regulation Document

Electricity at Work - Safe Working practices (HSG85) - HSE, Revised 1993.

3 Here is one helpful Link

http://www.st-andrews.ac.uk/services/safety/webpages/electrical/electrical-regs.html

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

4 And Here's the Background

Arc Flash is the ball of fire that explodes from an electrical short circuit. The unfortunate aspect of Arc Flash is that many times, there is a person standing in its path. This explosion includes a ball of fire and molten metal as well as a pressure force or blast.

This overview discusses the ball of fire only. Although the pressure blast can be enormous, enough to knock a person across the room, it is another topic and is not discussed here. Arc Flash temperatures can easily reach 7500 to 8500 degrees C.

These temperatures can be reached by a fault in several seconds if not several cycles. The heat generated by the high current flow may melt or vaporize the material and create an arc. This Arc Flash creates a brilliant flash, intense heat, and a fast moving pressure wave that propels the arcing products. In fact, in one of our engineering videos you will see exactly what damage a 10kA fault can do to a test manikin.

Some of the effects of an arcing fault include:

Extreme Heat, Pressure Waves, and Sound Waves.
Molten Metal, Shrapnel and Vapour.
Intense Light.

Arc flash is related to the available fault current and total clearing time of the over-current protective device during a fault. It is not necessarily linear, as lower fault currents can sometimes result in a breaker or fuse taking longer to clear, thus extending the arc duration and thereby raising the arc flash energy. To perform an accurate arc-flash hazard analysis a realistic value for the three-phase bolted fault and the total clearing time for the affected over-current protective device must be known.

Arc flash is measured in thermal energy units of calories per centimetre squared (cal/cm2) and for arc flash analysis is referred to as the *INCIDENT ENERGY* of the circuit. 1.2 cal/cm2 of thermal energy on a person's skin for a short period of time generally produces a second degree burn. A second degree burn, although painful, is considered curable. This amount of energy can be compared to holding your hand several inches above a disposable lighter. The intent of an arc flash hazard analysis is first to determine the amount of personal protective equipment (PPE) required by the worker to limit any burn to a second degree burn and second, to determine the safe distance away from energized equipment for unprotected persons.

Second degree burns occur if the temperature of human skin is raised to 75

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

degrees C for 0.1 seconds. Even if the fault is cleared in a shorter period of time, if a workers clothing catches fire or melts to his skin, the time limit of the exposure could be several minutes if not longer. Depending on the material, clothing may ignite when temperatures reach between 370 and 760 degrees C. If clothing and equipment are worn to limit the exposure of the worker to limits below those identified above, the worker should walk away from an accident, with minimal injury.

5 Types of Faults

In order to understand the hazards associated with an arc flash incident, it's important to understand the difference between an "arcing" short circuit and a "bolted" short circuit. A bolted short circuit occurs when the normal circuit current by-passes the load through a very low impedance path resulting in current flow that can be hundreds or thousands of times the normal load current. In this case, assuming all equipment remains intact, the fault energy is contained within the conductors and equipment and the power of the fault is dissipated throughout the circuit from the source to the short. All equipment needs to have adequate interrupting ratings to safely contain and clear the high fault currents associated with bolted faults.

In contrast, an arcing fault is the flow of current through a higher impedance medium, typically the air, between phase conductors or between phase conductors and neutral or ground. Arcing fault currents can be extremely high in current magnitude approaching the bolted short-circuit current but are typically between 38% and 89% of the bolted fault. The inverse characteristics of typical over-current protective devices generally results in substantially longer clearing times for an arcing fault due to the lower fault values.

The amount of energy released during an arcing fault depends upon the voltage, the current, and the duration of the arc. The arc duration is dependent on the arcing fault current magnitude and the protective device settings. Due to its nature, the magnitude of an arcing fault is subject to many variables and therefore is difficult to perfectly predict.

Using sound judgments and assumptions, it is reasonable to think of the arcing fault as a range of possible currents that result in a minimum and maximum arcing fault current.

6 Benefits of Performing an Arc-Flash Hazard Analysis

In addition to reducing or preventing injury to workers, the additional benefits associated with performing an arc flash hazard analysis can include most of

**Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk**

the following:

a) Provides workers with the best possible PPE (not dressed like a spaceman).
b) Insurance premiums can be reduced.
c) Brings electrical system documentation up to date by providing current and accurate one-line diagrams.
d) System reliability can be enhanced with a proper protective device coordination study to insure device closest to the fault opens in the least amount of time.
e) Over duty equipment can be identified from an accurate system wide short circuit analysis.
f) Since the system is typically modelled on software/spreadsheets, it will be easy to make future changes or upgrades with minimal expense or effort.
g) Most importantly, there will be fewer injured worker when an analysis is performed and recommended procedures are followed.

7 Costs of Not Performing an Arc-Flash Hazard Analysis

Costs due to not performing an Arc Flash hazard analysis can range from minor costs associated with fines, to millions of pounds for lifelong medical cost and can include any of the following:

a) Cost of non-compliance fines.
b) Cost associated with lost productivity.
c) Increased equipment repair costs.
d) Medical expenses for injured workers.
e) Legal costs.
f) Most importantly, loss of life, there is no price for this.

8 Prior To Beginning an Arc-Flash Hazard Analysis

Prior to beginning an Arc Flash hazard analysis, the following questions should be answered to help in the assessment:

a) Are the over-current protective devices set to trip in the fastest possible time?
b) Is the site having unexplained outages?
c) Has the site been expanded and/or added new electrical equipment?
d) Is the equipment rated to safely clear available fault current?

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

e) What can be done to mitigate excessively high fault currents or long tripping times?
f) Has equipment been properly tested and maintained to insure proper operation?

NOTE: Proper maintenance and coordination of protective devices is vital when doing an Arc Flash hazard analysis. All the studies in the world are useless if the equipment does not function as expected or designed.

9 Steps Required To Accurately Calculate Incident Energy

The general procedure required to perform an Arc Flash evaluation include:

a) Determine the system modes of operation and confidence tolerance of system model.
b) Calculate a minimum and maximum bolted fault current at each equipment bus. The bolted fault current should be as accurate as possible. While assuming an infinite source is conservative for sizing equipment, it is generally not conservative for arc flash calculations. When accurate data is not available, it is prudent to apply a minimum and maximum tolerance for the utility contribution, and component impedance values when calculating the bolted fault current.
c) Estimate the minimum and maximum arcing fault current at each equipment bus.
d) Determine the arcing fault current seen by each protective device.
e) Determine the trip time of each protective device based on the minimum and maximum arcing fault current it sees.
f) Calculate the largest incident energy at the specified working distance, including appropriate arcing fault tolerance.
g) Calculate the Arc Flash Boundary.
h) Determine the required PPE level.
i) Document the results and generate labels to be placed on the MCC's.
j) After an arc-flash hazard analysis has been completed, additional engineering may be required to lower high levels of incident energy to manageable levels. Only a complete electrical system analysis can identify the level of personal protective equipment required at each location in the system.

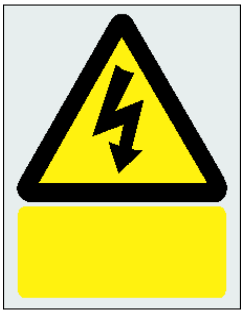
Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

10 Labelling Requirements

Labelling identifies the minimum Arc Flash warning label requirements that must be field installed at time of installation. We have attached a typical label below;

Flash Protection. *Switchboards, Rittal panels, industrial control panels, and Motor Control Centres (MCC'S) commissioning, servicing, or maintenance while energized, should be field marked to warn qualified persons of potential electrical Arc Flash hazards.*
The marking should be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

10.1 Figure 1: Example of Label with Minimum Requirements



Arc Flash and Electrical Shock Hazard		
Description	Parameter	Value
Available Fault Current;	kA	
Cal/cm^2 Flash Hazard at 450mm	Cal/cm^2	
Shock Hazard POTENTIAL	Volts	
Arc Flash Boundary;	mm	
Minimum PPE Requirement;		Number;
PPE in Text;		

To improve safety and worker compliance, additional information can be included on the label including the flash hazard boundary, working distance and required PPE. When additional labelling is included, it must be assured that the information is understood by everyone required to work on the equipment. Too much information that is unclear to the workers will be ignored and can be as bad, if not worse, than no information at all. It is extremely important the labelling is as clear and accurate as possible. While it

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

is obvious that insufficient PPE is dangerous, over-clothing workers can also increase the risk of an arcing fault due to limited mobility and visibility. Large equipment such as switchgear can often have different levels of incident energy due to feeder and protective device configuration. Multiple labels can also be placed on a single piece of equipment depending on the access point and proximity to the arc source for a given activity. However, it is good practice to provide a single label for the largest incident energy available.

Workers should not enter the flash protection boundary to work on live parts unless they are wearing the proper PPE for the level of hazard that could occur. The specific flash protection boundary, working distance, and incident energy values should be readily accessible to all workers, either identified by an equipment mounted label, or otherwise documented and available for reference or review.

11 Personal Protection Equipment

Personal protective equipment (PPE) is required to limit workers exposure to incident energy should an incident occur. Incident energy causes burns, which are the major hazard to individuals from an arc flash. As a benchmark, 1.2 cal/cm2 is the energy at which a 2nd degree burn will occur. At 3 cal/cm2 a light weight cotton shirt may ignite. One layer of flame-retardant material typically provides protection up to 4 cal/cm2. Three layers of flame-retardant material typically provide protection up to 25 cal/cm2. The PPE should be based on the highest expected incident energy from the calculations.

There are 5 Arc Rating levels of PPE;
Class 0 for incident energy up to 1.2 cal/cm2
Class 1 for incident energy up to 4 cal/cm2
Class 2 for incident energy up to 8 cal/cm2
Class 3 for incident energy up to 25 cal/cm2
Class 4 for incident energy up to 40 cal/cm2

Once the incident energy, flash boundary and required PPE are determined, labels can be generated and displayed on each piece of equipment or results can be documented for reference.

Some examples of where PPE may be required are: during load interruption, during the visual inspection that verifies that all disconnecting devices are open, and during the lockout/tagout. Adequate PPE is also required during the tests to verify the absence of voltage after the circuits are de-energized and properly locked out/tagged out.

When used, PPE represents the last line of defence against injury. The

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

protection is not intended to prevent all injuries but to mitigate the impact of an Arc Flash upon the individual, should an incident occur. In many cases, the use of PPE has saved lives or prevented injury. The calculations will provide a level of protection that is balanced between the calculated estimated incident energy exposure and the work activity being performed. It is important to realize that too much PPE can also be a hazard. Workers can be protected for more incident energy that is available but may not be able to perform their intended duties due to heat stress, poor visibility, and limited body movement. At all times, professional judgment must always be used in the selection of adequate PPE.

12 Current Limiting Devices

Current limiting protective devices can reduce incident energy by clearing the fault faster and by reducing the current seen at the arc source. These current limiting effects are typically only applicable at high fault currents. It is important to understand that if the available fault is not within the current limiting range of the fuse, the faster clearing time may not be achieved, and a false sense of security may exist. Since the arcing fault current is often substantially less than the bolted fault, the current-limiting effects must be evaluated carefully. It is typical practice to use the faster trip times associated with current-limiting devices without making adjustments for any reduced let through current. Arcing faults that clear in ½ cycle or less, as required in current-limiting devices, will typically, but not necessarily, result in lower incident energy.

13 Parallel Sources

Arcing faults can also be fed from parallel sources as is typical in a duel Main Transformer configuration or with on site generation capabilities to name a few. It is important to understand that the energy at the fault location will be based on the total fault current from all of the sources, while the time required to clear the fault will be based on the portion of the fault current that flows through each protective device. It is also important to understand that some fault sources, such as utility feeds, are constant, whereas other fault sources, such as induction motors, are transient and only contribute current for a few cycles. The total clearing time of the over-current protective device depends on all these variables.

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

14 System Reliability

Traditionally, protective device coordination was used to protect equipment and provide reliable system operation by incorporating time delay trips for upstream breakers. Arc flash protection now adds worker safety into the equation, resulting in the possibility of giving up some coordination for safety by requiring faster trip times, resulting in lower arcing fault currents. Since less energy is released the faster you can clear the arcing fault, alternative protection schemes such as differential, zone-interlocking, and arc sensing trip units are finding their way into protection schemes. The downside is that faster trip times can cause less power system reliability through reduced selectivity and an increased chance of nuisance tripping. No matter what, life safety concerns shall always take precedence.

15 Implementation

Long hand calculations can be performed to calculate incident energy and flash boundary values. But even for small systems, the process is somewhat involved. Our Spreadsheets can be used to automate the process and complete the Arc Flash calculations, yet you still need to determine a minimum and maximum fault current at the bus, determine the total arcing fault current flow through the primary protective device, determine the trip time from manufacturer's trip curves, and manually document the results in report and label formats. Determining the trip time is probably the most time consuming process. Time current curves are sometimes hard to obtain and is typically prone to error when processed manually. Making changes is also a tedious process by hand.

16 Summary

This overview of Arc Flash requirements suggests several approaches for conducting an Arc Flash hazard analysis for typical electrical systems. Following the suggestions contained herein does not guarantee complete safety, and users should take all reasonable, independent steps necessary to minimize risks from Arc Flashes.

You should be aware that the models described herein are based upon measured arc current incident energy under a specific set of test conditions and on theoretical work on the subject. Distances, which are the basis for equations, are based on the measured distance of the test instrument from the Arc Flash point source.

This information included in this report is intended to provide guidance only for the calculation of incident energy and Arc-Flash protection boundaries. Once

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

calculated, this information needs to be used as a basis to develop strategies that have the goal of minimizing burn injuries. Strategies include specifying the rating of personal protective equipment (PPE), working de-energized, applying arc-resistant switchgear, and following other engineering techniques and work practices. The information included addresses the hazard presented by incident energy only. Other potentially hazardous effects of molten metal splatter, projectiles, pressure impulses, and toxic arc by-products have not been considered in these methods. It is expected that future work will provide guidance for these other electrical hazards.

The information presented is not intended to imply that workers be allowed to perform work on exposed energized equipment or circuit parts. It must be emphasized that the industry recommended way to minimize electrical injuries and fatalities is to ensure that equipment is de-energized and in an electrically safe work condition. But even the act of creating an electrically safe work condition, subjects the worker to potential hazards, which if they occur, require PPE for protection against arc-flash burns.

Obviously, the best way to prevent an arc-flash hazard is to totally de-energize the equipment. It would be great if we could turn off the country everyday so electrical workers could go to work. However, even if you can totally de-energize the equipment you need to open devices upstream somewhere. It is best if this can be done remotely, but if it cannot be, workers must be trained and know the proper Arc Flash protection required for the given task.

Thanks for your time, hope this was helpful……….