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# Review on Electric Arc Flash and Electric Arc Blast Impacts

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***Abstract* - In working place, the one of the serious and common electrical hazard is electric arc flash. The immense heat energy released from an electric flash is up to 35,000oF is danger to people close to the flash and can even be incurable. An electric arc flash will occur when the current leaves the main path and travels through air which is acting as a medium to another conductor or to the ground/earth. There is no need of direct contact with energized part to create arc flash injuries. If the people are inside the arc flash boundary, which results in critical injury or death and it will destruct the complete equipment involved. To prevent and protect arc flash, the Institute of Electrical and Electronics Engineers (IEEE) and the National Fire Protection Association (NFPA) began a collaborative research to give a better understand and awareness about arc flash phenomena. This paper deals with various effects, prevention, risk assessment and protective measures for the workers who are subjected into electric arc flash**

***Key Words*— Arc Flash, Flash Boundary, IEEE, NFPA**

## I. INTRODUCTION

An electric arc flash is a blast because of low impedance connection to ground or any of the phase in the network systems and shown in fig. 1. Speedy and repeated heating of surrounding air with extreme pressure results in arc flash/blast [1]. An arc flash will vaporize the copper wires, which will expand the volume of the copper up to 67000 times of its original volume.

Fig. 1: Typical Arc Flash in Control Room

Among many technical persons, there is a misunderstanding that hazards due to arc flash hazards are more at higher voltages. But, the effect will be same for low voltages also, such as 400V, to have more significant level of arc flash hazard because the faulty current is as high as the fault current due to high voltage.

Table I
Different Temperature Levels

| S.NO | HOT SPOT | TEMPERATURE |
|---|---|---|
| 1 | Skin temperature for curable burn | 176°F |
| 2 | Skin temperature causing cell death | 205°F |
| 3 | Ignition of clothing | 752°-1472°F |
| 4 | Burning cloth | 1472°F |
| 5 | Metal droplets from arcing | 1832°F |
| 6 | Surface of sun | 9000°F |
| 7 | Arc terminals | 35,000°F |

Time taken by the protective device for clearing the fault current is too long and high fault currents, it is common to have an arc flash hazard on low voltage network [2]. The various impacts of arc flash which includes serious injuries and medical costs, serious skin burns or even death, damage to equipment's and repairing cost, replacement of switchgear, and finally loss in production loss. The intensity of the arc flash will be determined by the factors which includes the heavy fault current, the time taken for short circuit interruption, and the boundary between the arc and individual. Excellent design and configuration of the equipment can be made to affect the above said factors and it will reduce the hazard due to arc flash. The following chapters will explain the causes of electric arc

flash, risk assessment, arc prediction, impacts and protective measures.

## II. Causes of Electric Arc Flash

When the heavy fault currents are flows through live conductors, the potential differences and other factors, which will ionize the air around the conductors, the current will flows through a low resistance path between the neighboring conductors [8]. Initiation of arc due to the following actions:

i. Dust and impurities: On insulating surfaces, dust and impurities will provide a path for current, it allows to flashover and it creates arc discharge across the conductor surface.

ii. Corrosion: Impurities are developed due to the equipment parts corrosion on the insulating surfaces. This leads to arcing with nearby conductors of another phase or to the ground.

iii. Vapor condensation and water dripping can create a flashover to ground and potential acceleration to phase-to-phase arcing.

iv. Accidental touching: Contact with live parts accidently can initiate arc faults.

v. Dropping tools: Momentary short circuit is caused by dropping tools accidently, producing sparks and initiating arcs.

vi. Over-voltages across narrow gaps: Whenever the air gap between the conductors is very narrow in different phases, during over voltage, the arc will strike.

vii. Failure of the insulating materials.

Some of the arcing faults hazards are shown in fig. 2 and effect are listed below:

i. When the casualty is several feet far away from the arc, fatal burns will occur. Heavy burns will be common at a distance of 10 feet.
ii. The droplets of molten metal due to arcs spray at high pressure will penetrate through the body.
iii. The high Pressure droplets may be higher than 2000 lbs/ sq. ft. and the pressure will throw the workers near the incident across rooms and knocked them off.
iv. Clothes will be burned even several feet away and compared to exposed skin, clothed areas will be burned severely.
v. The magnitude of blast sound is as high as 140 dB at 2 feet distance from the arc which cause hearing loss.

**Fig. 2.a: Hand Burned by Arc Flash**

Fig. 2.b: Clothed Areas Burn

### *A. Safety Strategy*

The ways to avoid electrocution hazards is to ensure worker is not part of the live electrical circuit [5]-[6]. Some of the safety strategy are discussed in this paper are as follows and listed in table II.

Table II
Safety Strategy

| Electrocution Hazard | Safety Strategy |
|---|---|
| Usage of broken or damaged tools | Properly maintenance of tools and tools should be insulated. Usage of proper tools can help electrical workers safe. Moreover, test tools are the most important personal protective equipment (PPE) for electrical workers. |
| Wrong level PPE | The need for PPE focuses on arc flash. NFPA-70E, which addresses the electrocution hazards. For example, insulated gloves in addition to leather gloves need to be wore as PPE for |

| | |
|---|---|
| | electrocution hazards |
| Working on energized equipment | De-energize the electrical equipment prior to repair or inspection. Proper PPE, monitor the target circuit and incoming line to determine if they are de-energized. Verify the live voltage source using test instrument. |
| Insufficient safety training | Safety training program must be established. For safe working environment, workers should follow National Fire Protection Association standard known as NFPA 70E – The Standard for Electrical Safety in the workplace. |
| Limited preventive maintenance | Conduct preventive maintenance regularly. Use the resources to help create a successful proactive maintenance program. |
| Usage of outdated or defective test equipment to troubleshoot | Test equipment should be well maintained. By test instrument, built and tested to IEC design standards to protect against arc flash and transients. |
| Maintaining small distance in arc flash boundary | The boundary for the flash protection is the minimum safe distance from the energized system that cause an arc fault. Warning signs in live work can helps to keep safe. |

B. Probability of Survival

The injuries due to arc flash are known to be severe. According to statistics, the probability of survival decreases with the increase in age of the victim. The burn injury statistics is shown in fig. 3.

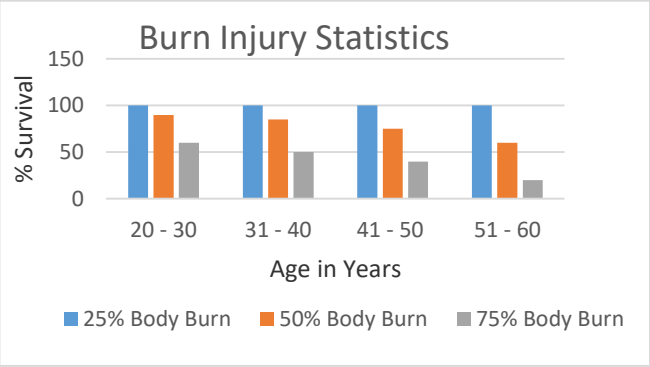


Fig. 3: Burn Injury Statistics – Probability of Survival

Treatment may takes years of skin embedding and rehabilitation. The possibility for the victim return to normal work or retain the same quality of life is very less. Some of the costs related electrocution hazards are:

- Treatment
- Litigation fees
- Production loss

## III. Electric Arc Flash Risk Assessment

The issue of arc-flash hazard is of increasing focus, firstly in the USA and recently in Europe. During 2000 to 2010, Health & Safety Authority (HSA) indicate that over 2,000 reported injuries and 26 deaths because of electrical accidents in the workplace in Ireland [3]. The important requirement under Safety, Health and Welfare Act 2005 is, "all the employer shall ensure that practicable, the safety, health and welfare at the work place". The assessment for the arc risk is shown in fig. 4.

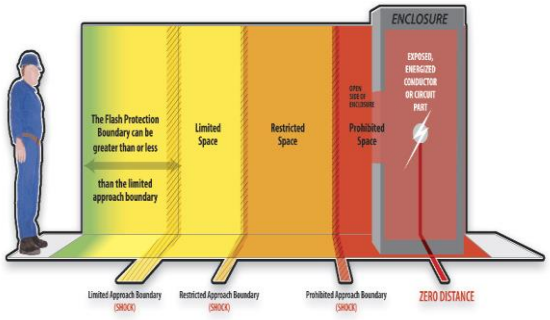


Fig. 4: Arc Risk Assessment

A. Arc-Flash Risk Treatment in USA

In US, the arc flash hazard is taken as a focused approach and it is driven by Occupational Safety and Health Administration (OSHA) and National Fire Protection Association (NFPA) through its National Electrical Code (NEC).

The authority NFPA-70E sets out a different process for safe working conditions and the standard insists the workers to document an electrical safety programme and implement the same and that directs the activity for the electrical hazards, voltage, energy level, and circuit conditions [4]. It recommends that, electrical conductors and circuit parts should be de-energized and have lockout/tag out devices applied.

The standard gives the procedure and also sets out the requirements where equipment cannot be de-energized and locked out. The standard NFPA 70E provides the live conductor boundary, boundary for arc flash and electric shock protection. The electric shock boundary will be affected based on the voltage level and the equipment type containing the electric conductors.

It is recommended that the workers are needed to follow NFPA safety procedures while working on electrical equipment [7]. When workers are needed to work on the live equipment, they should assess the associated hazards including wearing the appropriate personal protective equipment (PPE). Based on IEEE 1584, the NFPA has been developed a technique and they calculated arc incident energy levels and it is listed in table III.

Table III
Hazard Category and Clothing Layer

| Hazard Category | Incident Energy ($cal/cm^2$) | | PPE Description | No. of Clothing Layers |
|---|---|---|---|---|
| | L | U | | |
| 0 | 0 | 1.2* | Flammable and non-melting materials (i.e. Cotton, wool, rayon, or silk materials) with a fabric weight | 1 |
| 1 | >1.2* | 4 | FR shirt and pants or FR overall | 1 |
| 2 | >4 | 8 | Cotton underwear – short sleeve and brief/shorts, flammable shirt and pants | 1 or 2 |
| 3 | >8 | 25 | Cotton underwear plus flammable resistant shirt, pants with FR overall, or cotton underwear with two FR overall | 2 or 3 |
| 4 | >25 | 40 | underwear with FR shirt and FR pants with multilayer flash suit | 3 or more |
| 5 | >40 | No Maximum | No PPE Specified in NFPA 70E | |

B. Arc-Flash Risk Treatment in Europe

The EU Workplace Health and Safety Directive will insist all employers around the country to assess the safety and health of people who are engaged in work. EU directives highlighting the risk analysis, ensuring the safe working practices and methods.

The PPE is appropriate and it should then be worn on hand. The rating of PPE must be higher than the prospective incident energy. The PPE must be certified by CE and comply with the IEC or EN standards. For arc flash, clothing should be certified by IEC/EN 61482 and the standard defines two classes of garment, Class 1 and Class 2. The classes of garments should be certified by CE using EN340 and ISO 13688.

The wearing of hand protection is most important because hands can be significantly exposed more than the upper body. The EN standards are developed for hand protection are under development and it is recommended that, ASTM is the international standard draft of test method for determining the glove arc rating, working group WK14928; and EN 61482-1 modified for the gloves testing.

For head protection, EN standards are under development and it will provide an appropriate testing method for headwear or face shields, to protect from the thermal hazards. The test methods developed by DuPont for face shield testing is ASTM F 2178 – 08 - Open Arc Test and GS-ET-29 Box Test. DuPont has wide research and, manufacturing a fabric called NOMEX, which is used as PPE for an electric arc flash.

In Europe, CENELEC CLC TC 78 has been sets up a method for calculating the incident arc energy level but it is expected that committee will take several years for report and IEEE1584 will be the best standard available for this purpose.

## IV. Prevention Of Arc Flash

The possibility of preventing an arc flash from electrical systems is very less but can reduce the risk. The Risk Control Hierarchy by NIOSH [9] describes the ways to reduce risk to its low level. Highest priority is given to methods that controls the risk by proactive and lower priority is given to reactive method of controlling the equipment damage after the incident has occurred.

1. Elimination/Remove the hazard

a) Work on energized equipment, when it is absolutely necessary.
b) Removing the workers from the arc flash boundary eliminates the risk of human injury.

2. Substitution or replace higher risks with lower risks
3. Engineering control to limit and/or prevent the risk
4. Awareness of risks and its consequences thereof
   a) Train all workers on the hazards of arc flash.
   b) Conduct an arc flash study to properly identify the hazards, boundaries and required PPE.
5. Administrative controls, create regulations, and work processes
   a) Allow only qualified persons wearing the proper PPE and using the correct tools to work on.
   b) Prior to work, implement a preventive plan for electrical systems in work place based on NFPA 70B.

On routine basis, preventive maintenance should be conducted to ensure safe operation of electrical equipment's. This program not only ensures that the equipment is functioning properly, but also it identifies hazards before an accident. As part of a maintenance program, all the equipment should be cleaned and inspections should be conducted by qualified personnel [10]. As per the statement of NETA, the maintenance program should be based on reliability, unique to each plant or organization and to each equipment.

## V. Analysis of Injury

The arc flash injuries analysis indicated that their blast pressure will damage internal organs. The workers also injured when equipment explodes or blast pressure forcing them into hard objects. The powerful environment surrounded by the arc flashes prohibited the use of older pressure sensors. By using special instruments, the pressure were measured in the area of a person who are standing near the arc blast.

The arc flash light will cause flash blindness, when the eye's retinal cells are affected due to exposed thermal energy. The visible light wavelengths range from about 400 to 700 nm, but the blast produces light in the 200-600 nm range. The wavelengths are in the UV range, and the effects of UV rays on eyesight are known.

The blast pressure of arc flash produces plenty of noise and it will cause hearing loss even if a person is protected from the other effects. As per OSHA regulations, the noise should not exceed 140 decibels in work place, even with hearing protection. The several tests showed that sound level 3 feet away from the blast measured between 150 and 170 decibels. Sound is alleged by people to double in intensity of every 10 dB, so a 170 dB noise is eight times louder than the 140 dB OSHA limit [11].

## VI. Conclusion

In industrial electrical environment, arc flash and arc blast are very real danger and need to be mitigated. The best practices suggested by several society/association are need to be followed to reduce the risk of those events. The new comprehensive arc-flash calculations are generated by lots of research will help to strengthen the IEEE 1584 for performing arc-flash hazard Calculations. The research also insists the workers in such organization to use the personnel protective equipment (PPE) in mitigating the adverse effects of an arc flash. This importance is bounce back in OSHA safety regulation, requiring employers provide the PPE to protect the workers against the hazards associated with an arc flash. This review dealt with the basic concepts of arc flash and its effects on the equipment and the person who subjects to arc flash accidents.

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