Arc Flash Facts Sheet (Spring 2005)

1) General
   a) NFPA 70E defines flash hazard as "a dangerous condition associated with the release of energy caused by an electric arc."
   b) IEEE defines incident energy as the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event.
   c) An electrical arc will oscillate and escalate if not constrained.
   d) A 1-ph arc can engulf a second or third conductor in two cycles.
   e) Arc current propels the arc away from the power source.
   f) Barriers or insulation limit the arc.
   g) The pressure from an electric arc is developed from two sources:
      i) Expansion of the metal as it vaporizes
      ii) Heating of air by the arc energy
   h) When copper vaporizes, it expands by a factor of 67,000. This accounts for the expulsion of near-vaporized droplets of molten metal from the arc (droplets could be propelled up to 10 feet).
   i) At 1 second, 1.2 cal/cm2 of heat energy can cause a second-degree burn.
   j) Skin damage will occur based on the intensity of the heat generated by an electrical arc accident. The heat reaching the skin of the worker is dependent on the following three factors:
      i) Power of the arc at the arc location
      ii) Distance of the worker to the arc
      iii) Time duration of the arc exposure
   k) Enclosing a 3-phase arc in a box can increase the energy up to 3 times that in open air.
   l) The other effects of an arc flash which are not calculated are as follows:
      i) Damaging noise levels
      ii) Explosive expansion of surrounding air due to rapid heating by the arc causing pressure impulses and projectiles

iii) Melting/vaporization of arc electrodes and metal components in the vicinity of the arc causing molten metal splatter

iv) Toxic byproducts are released

2) Standards

a) OSHA

i) 1910.269(l)(6)(i) -- When work is performed within reaching distance of exposed energized parts of equipment, the employer shall ensure that each employee removes or renders nonconductive all exposed conductive articles, such as key or watch chains, rings, or wrist watches or bands, unless such articles do not increase the hazards associated with contact with the energized parts.

ii) 1910.269(l)(6)(ii) -- The employer shall train each employee who is exposed to the hazards of flames or electric arcs in the hazards involved.

iii) 1910.269(l)(6)(iii) -- The employer shall ensure that each employee who is exposed to the hazards of flames or electric arcs does not wear clothing that, when exposed to flames or electric arcs, could increase the extent of injury that would be sustained by the employee.

iv) 1910.269(l)(1), (1910.333(b)(2) -- Electric lines and equipment shall be considered and treated as energized unless they have been locked out and tagged out and grounded. (See exceptions to grounding under section on temporary grounding).

v) 1910.269(l)(9) -- Non-current-carrying metal parts of equipment or devices such as transformer cases and circuit breaker housings shall be treated as energized at the highest voltage to which they are exposed until it is determined that the parts are properly grounded.

b) NFPA

i) The NFPA publishes the *National Electric Code* (NEC) NFPA 70-2002.

ii) NEC is a minimum guideline for safe design and installation of electrical distribution systems.

iii) The NEC does not cover employee safe working practices.

iv) OSHA approached NFPA to develop an electrical standard for employee safety.

v) The document created for employee safety is called NFPA 70E-2004©NFPA, *Standard for Electrical Safety in the Workplace*.

vi) The intent of NFPA 70E regarding arc flash is to provide guidelines which will limit injury to the onset of second-degree burns.

vii) NFPA 70E-2004 130.3 (B)©NFPA Protective Clothing and Personal Protective Equipment for Application with a Flash Hazard Analysis allows 2 methods:

(1) Where it has been determined that work will be performed within the flash protection boundary by 130.3 (A), the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker (in calories per square centimeter).

(2) As an alternative, the PPE requirements of 130.7 (C)(9) shall be permitted to be used in lieu of the detailed flash hazard analysis approach described in 130.3 (A). This “table” method for determination of hazard risk category and the selection of personal protective equipment is described in section 5 of this classroom manual.

viii) NFPA 70E-2004 Annex D.6©NFPA presents the following equations for use in predicting the incident energy produced by a three-phase arc on systems rated 600 volts and below. The parameters required to make the calculation are:

(1) Maximum “bolted fault” three-phase short circuit current available at the equipment.

(2) Total protective device clearing time at the max short circuit current.

(3) Working Distance

ix) The equations used in NFPA 70E-2004 Annex D.6©NFPA were derived from the IEEE paper by Doughty, Neal, and Floyd

(1) Paper was titled "Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600 V Power Distribution Systems"

(2) Presented at the IEEE IAS 45th Annual Petroleum and Chemical Industry Conference, September 28-30, 1998.

x) The estimated incident energy for an arc in open air is:

$$E_{MA} = 5271 D_A^{-1.9593} t_A \left[0.0016 F^2 - 0.0076 F + 0.83938 \right] \quad (4\text{-}8)$$

xi) The estimated incident energy for an arc in a cubic box is:

$$E_{MB} = 1038.7 D_B^{-1.4738} t_A \left[0.0093 F^2 - 0.3453 F + 5.9675 \right] \quad (4\text{-}9)$$

where:

E_{MA} = maximum open arc incident energy, in cal/cm2

D_A = distance from arc electrodes, in inches (for distances 18 in. and greater)

t_A = arc duration, in seconds

F = bolted fault short circuit current, in kA (for the range of 16 to 50 kA)

c) IEEE

i) In 1960, an AIEE paper was written that identified the potential for injury from arcing faults caused by such things as tools contacting bare buses, rodents, dust, insulation failure, or loose connections. The focus was on the nature of arcing faults and the protective equipment and relaying schemes that could be used to extinguish the arc. This paper was entitled "Arcing Fault Protection for Low-Voltage Power Distribution Systems - Nature of the Problem" by R.H Kaufmann and J. C. Page.

ii) In 1982, an IEEE paper was written that highlighted the electric arc flash hazard. The paper described the electric arc blast as the other electrical hazard. The thermal hazard was described as second degree burns up to 10 ft from the arc and third degree burns up to 5 ft. It also presented a theoretical methods of evaluating the open air arc hazard and gave information on protective measures that should be taken to avoid serious injury.

iii) The Petro/Chem Industries Committee of the Industry Applications Society of IEEE formed a working group to raise awareness of electrical personnel to the hazards associated with arcing faults. In addition, tests were run at high-power test labs and analytical information was gathered to quantify the hazards associated with arcing faults. In September 2002, IEEE issued the Guide for Performing Arc-Flash Hazard Calculations, IEEE Std P1584™ -2002.
   (1) Working on a revision 1584a
   (2) Provides a method for calculating based on equations developed using actual testing and statistical analysis
iv) This standard includes a spreadsheet calculator that can be used to solve the equations.
v) A detailed arc flash hazard analysis using this method requires the following steps:
   (1) Step 1: Collect power system data
   (2) Step 2: Determine the power system's modes of operation
   (3) Step 3: Determine the bolted fault currents
   (4) Step 4: Determine the arc fault currents
   (5) Step 5: From the protective device characteristics, find the arcing duration
   (6) Step 6: Record system voltages and equipment classes
   (7) Step 7: Determine working distances
   (8) Step 8: Determine incident energy for each work location in the study
   (9) Step 9: Determine the flash-protection boundary for each work location in the study
vi) The empirically derived model is based on actual test data, it is valid for these ranges:
   (1) Bus Voltage between 208V and 15kV.
   (2) Bolted fault current between 700A and 106kA
   (3) Bus bar gap between 13mm and 153mm.

vii) For cases where the voltage is over 15 kV or the bus bar gap is larger than 153mm, IEEE provides a different equation which is from a theory based model (Lee Model for Incident Energy).

$$E = 2.142 \times 10^6 \times V \times I_{bf} \left(\frac{t}{D^2} \right)$$

where:

E is incident energy (J/cm2)

V is system voltage (kV)

t is the time of arc exposure (seconds)

D is the worker distance to possible arc (mm)

I_{bf} is bolted fault current (symmetrical RMS) (kA)

3) Key NFPA Definitions

a) NFPA 70E-2004 Article 100©NFPA defines "Flash Protection Boundary" as: "An approach limit at a distance from exposed live parts within which a person could receive a second degree burn if electrical arc flash were to occur."

b) NFPA 70E-2004 Article 100©NFPA defines "Limited Approach Boundary" as: "An approach limit at a distance from an exposed live part within which a shock hazard exists". An unqualified person cannot cross the boundary unless escorted by a qualified person.

c) NFPA 70E-2004 Article 100©NFPA defines "Restricted Approach Boundary" as: "An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement for personnel working in close proximity to the live part."

d) NFPA 70E-2004 Article 100©NFPA defines "Prohibited Approach Boundary" as: "An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part."

e) NFPA 70E-2004 Article 100©NFPA defines "Electrically Safe Work Condition" as: "A state in which the conductor or circuit part to be worked on or near has been disconnected from energized parts, locked/tagged in accordance with established standards, tested to ensure the absence of voltage, and grounded if determined necessary."

f) NFPA 70E-2004 Article 100©NFPA defines "Qualified Person" as: One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved.

4) PPE
   a) When Required
      i) Adequate PPE for flash protection may be required during load interruption, visual inspection that verifies that all disconnecting devices are open, and during the lockout/tagout procedure.
      ii) Adequate PPE for flash protection is always required during tests that verify the absence of voltage after the circuits are de-energized.
      iii) Adequate PPE for flash protection is also required for applying or removing grounds.
   b) The garments selected must meet ASTM F1506-02a which says, among other requirements, that the label of the garment clearly state its arc thermal protective value (ATPV or EBT): (reference: NFPA 70E-2004 Table 130.7 (C)(8)).
   c) ATPV is the minimum incident thermal energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second degree burn based on the energy transmitted through the clothing.
   d) Flame resistance is characteristic of a fabric that causes it to not burn in air.
   e) Often confused with flame retardant which is a term used to describe a chemical substance that imparts flame resistance on fabric.
   f) Layering
      i) Layering significantly increases the level of protection.
      ii) Two thin layers are better than one thick layer.

iii) Layer of air acts as a “buffer zone” between layers of flame resistant fabrics.
iv) Any layer of cotton undergarment below the FR layer can be factored into the ATPV level.
v) Some multi-layer testing has been done by various fabric manufacturers and ASTM Task Groups).
vi) Currently, the ASTM Task Group F-18.65.01 is investigating the effect of layering and color on arc test results.

g) Protection is achieved when the ATPV of a material or system of materials is greater than the energy created by the arc.
h) 40 cal/cm2 limit due to excessive blast pressure, which peaks in ¼ cycle

5) Reducing Arc Flash Hazards
   a) De-Energize Equipment versus “Working It Live” unless increased hazards exist or infeasible due to design or operational limitations.
   b) Switching remotely (if possible)
   c) Closing and tightening door latches or door bolts before operating a switch.
   d) Standing to the side and away as much as possible during switching operations.
   e) Avoid leaning on switchgear or touching metallic surfaces in electrical rooms or outdoor substations.
   f) Use the proper tools and equipment for the job.
   g) Use new methods to perform the same job. For example, installing viewing windows or ports for IR scanning. See picture on the following page showing the SpyGlass™ lens from Mikron Infrared.
   h) Label electrical equipment with Arc Flash Hazard labels.
   i) Installation of Arc-Resistant Switchgear
   j) Application of current-limiting protective devices
   k) Application of current-limiting reactors
   l) Application of multiple settings groups
   m) Application of “maintenance switch”

n) Application of bus differential protection

6) Training

a) Eaton University

i) Understanding Arc Flash -- 8.0 hours, for engineers, safety managers, consultants and electricians.

ii) Arc-Flash Safety -- 4.0 hours, for electricians, technicians or equipment operators whose employers have already declared them to be "qualified" according to OSHA rules but need the new information contained in NFPA 70E-2004 Article 130.

iii) Electrical and Arc-Flash Safety -- 8.0 hours, for electricians, technicians and equipment operators who are not "qualified" but who might be exposed to arc-flash hazards.