Arc Flash Energy Mitigation Techniques

When short circuits occur on an electrical distribution system, an arc flash event usually forms. These arc flash events can cause dangerous and potentially fatal levels of blast pressure, excessive sound waves, toxic gases, vapors, heat, ultraviolet radiation, and flying shrapnel. Arc flash produces thermal, radiation, chemical, mechanical, and electrical energy.

The energy produced by an arc flash event is proportional to voltage, current, and the duration of the event (Volts $\propto$ Current $\propto$ Time) with the **duration time** affecting the energy levels the most. The working distance (distance from the arc flash location to the workers torso) also impacts the amount of energy that a person receives during an arc flash event. As the working distance increases, the arc flash energy decreases.

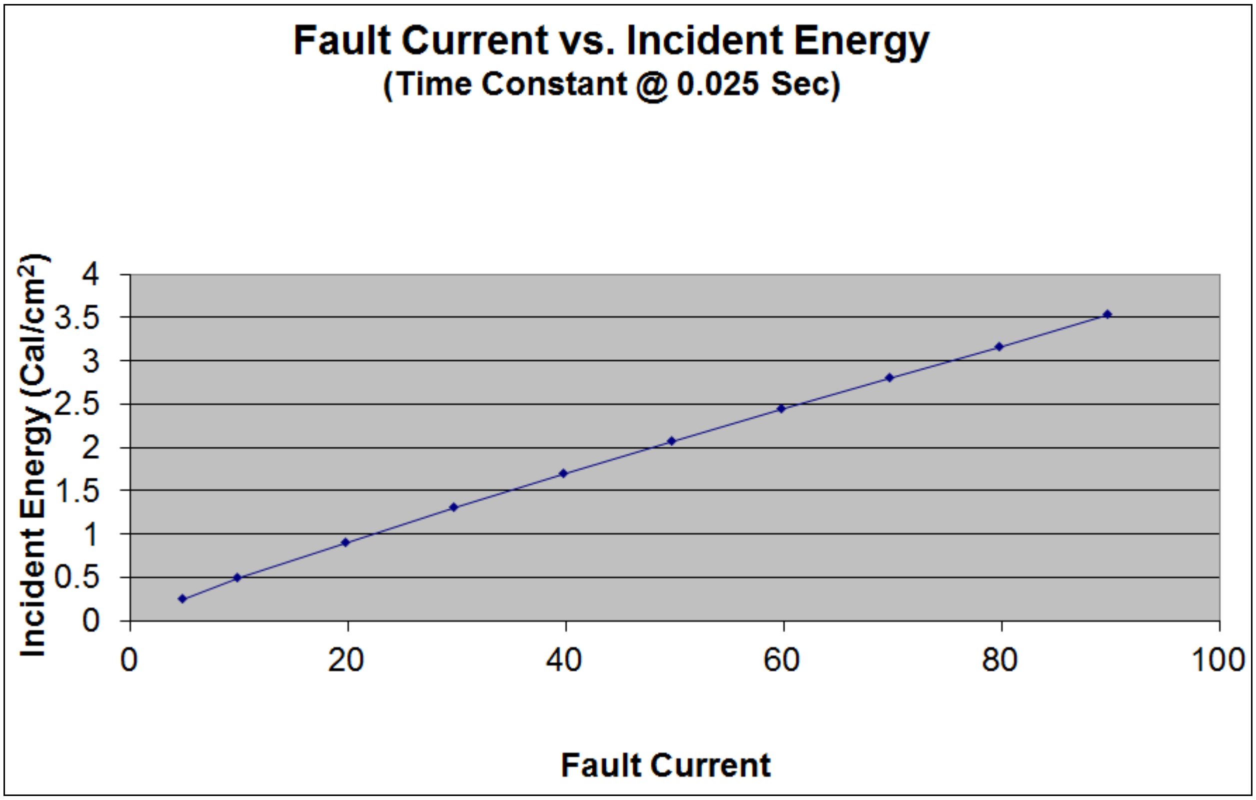
This paper will discuss how arc flash energy is calculated and what affects the calculations. There are several design, retrofit methods, and procedures that will reduce the arc flash energy. This includes the use of relays, detectors, and new types of equipment. Lowering the arc flash energy will decrease equipment damage and increase equipment and personnel protection.

Design engineers have a few options to reduce system voltage or fault currents. But, the best and most direct ways to reduce arc flash hazards are to **reduce fault-clearing times or increase the working distances**.

For this article we will focus on what affects the energy calculations and what a design or facilities engineer can do to reduce arc flash energy. We will use the IEEE 1584 equations to calculate the energy levels. The Arc Flash Energy Equations in IEEE 1584 require many variables that include equipment bolted fault currents, arcing fault current, and the upstream protective device clearing times. The calculations are also dependent upon operating voltage, gap length, and type of grounding. These last three items are very difficult to change in an existing facility. **The greatest effect on the calculations is time the upstream device operates**, followed by working distance, and then available fault current.

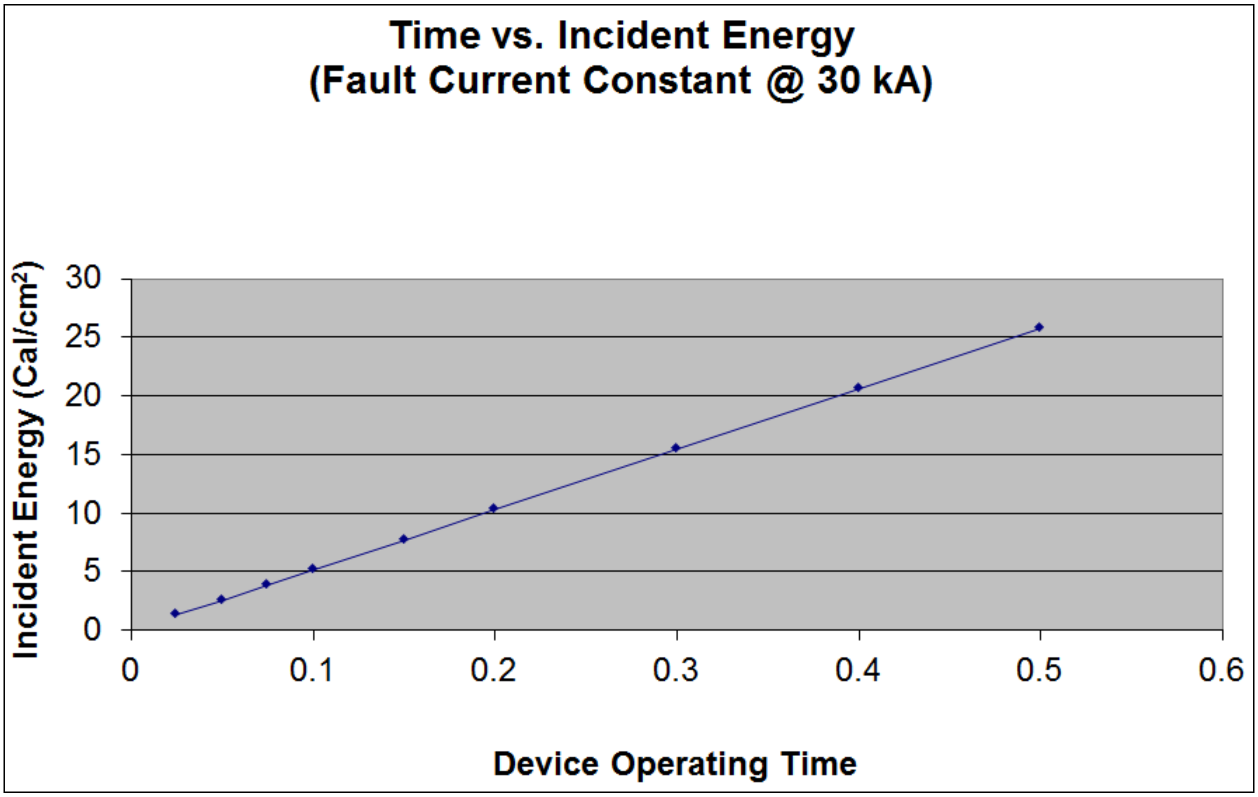
The three graphs below show just how much time can affect the energy calculations. For graphs 1 and 2, the working distance is held constant at 18 inches. Only in the last graph 3 is the working distance varied. Each graph shows the Arc Flash Energy on the vertical axis and is a blue line. The pink line shows the NFPA 70E Clothing Category.

Graph 1 below shows the effect of raising the fault current when the device operating time is held constant at 0.025 seconds. This is the typical clearing time of a molded case circuit breaker tripping instantaneously. As the fault current is raised from 5,000 amperes to 90,000 amperes, the required Clothing Arc Rating (AR) rises as well. ***The graph shows that if the device is tripping quickly, raising the fault current does not significantly affect the clothing AR***. The energy levels rise slightly. Although this graph is for low voltage equipment, the same applies to medium voltage equipment.



Graph 1 – Fault Current vs. Incident Energy Level

Graph 2 below shows the effect of changing the device operating times from 0.025 seconds to 0.5 seconds (0.5 seconds is the longest short time delay setting available for breakers with solid state trip units.) For these calculations, the fault current is held constant at 30,000 amperes. ***This graph clearly demonstrates that the device operating time has a huge impact on the calculations***. The NFPA 70E AR rising dramatically and approaches 26 cal/cm^2.



Graph 2 – Device Operating Time vs. Incident Energy Level

One of the least expensive ways to reduce arc flash energy is the modification of work procedures. The best and safest way is to de-energize the equipment. Although this may seem obvious, it is not always implemented. Before working on energized equipment, the personnel should consider all possible ways to shut the equipment down before working on it. Sometimes this may require working on the equipment during non-traditional working hours but, it is definitely the safest method. You should as, Is it inconvenient or infeasible to de-energize the equipment.

However, if de-energizing the electrical equipment is not an option, then consideration should be given to the items below as ways to reduce the arc flash energies:

- Reduce Device Clearing (Trip) Times by use of
    - High speed differential relaying
    - Maintenance switch to change the relay settings to lower trip times.
- Use photo optic sensors and relays to detect the arc flash and trip the upstream breaker.
- Use arc resistant switchgear (arc flash energies are redirected out of the top of the switchgear)
- Lower the Fault Current by using low resistance (Medium Voltage Systems) or High Resistance (Low Voltage Systems) grounding of the main transformer.
- Increase the Work Distances by using:
    - Use remote racking devices

- Remote Switch Operators or Actuators

Reduce Device Clearing (Trip) Times

As can be seen in Graph 1 above, reducing the upstream tripping time can greatly reduce the arc flash energy magnitude. The main and feeder breakers must be selectively coordinated during normal system operation and this requires a delay between the feeder, tie, and main relay/breakers ground and three phase relays. These delays drive up the arc flash energy and the main bus energy levels can be quite high.

Installing differential protection (IEEE Relay Function 87) is a way to detect faults within a zone (between the line side of the main and load side of the breakers) and quickly interrupt them. These sensitive and fast acting relays will greatly reduce the arc flash energy and damage to the equipment.

Another method to reduce the operating times is to install a maintenance toggle switch and use the relay or trip unit group functions. When work is going to be performed downstream from a breaker,the toggle switch is turned to “Maintenance Mode”. This forces the relay or trip unit to use a different set of pickup and delay settings which are set very low. The relay will trip fast which will reduce the arc flash energy should an arc flash or fault occur.

Photo optic sensors and Relays to Detect the Arc Flash

Several manufacturers have incorporated Arc Flash detection in their relays and switchgear. This involves using arc flash optical light sensors and fiber-optic cables. The relay is programmed to trip quickly if it detects (1) a light flash from an arc flash event and (2) a rise in current. If these two conditions are met, then the relay will send a trip signal to the upstream breaker. Because the relay operates quickly the arc flash energy is reduced.

Arc Resistant Switchgear

Arc Resistant Switchgear and Equipment is designed to re-direct the arc flash energy away from the operator. With normal switchgear and equipment, the cubicle doors are the weakest part of the structure. When an arc flash event occurs, there is an extreme buildup of pressure due to the rapidly expanding heated air. This pressure can cause cubicle doors to blow open, exposing the workers to the heat and blast.

Arc resistant switchgear is made to redirect the arc flash energy through the top of the equipment. Duct work connected to the top of the switchgear will redirect the heated gas and pressure wave out through the top of the building. If the doors are closed and all covers are installed, this new type of equipment is very effective and can reduce the arc flash energy to just a few calories/cm^2.

Grounding - Low Resistance (for Medium Voltage Systems) & High Resistance (for Low Voltage Systems)

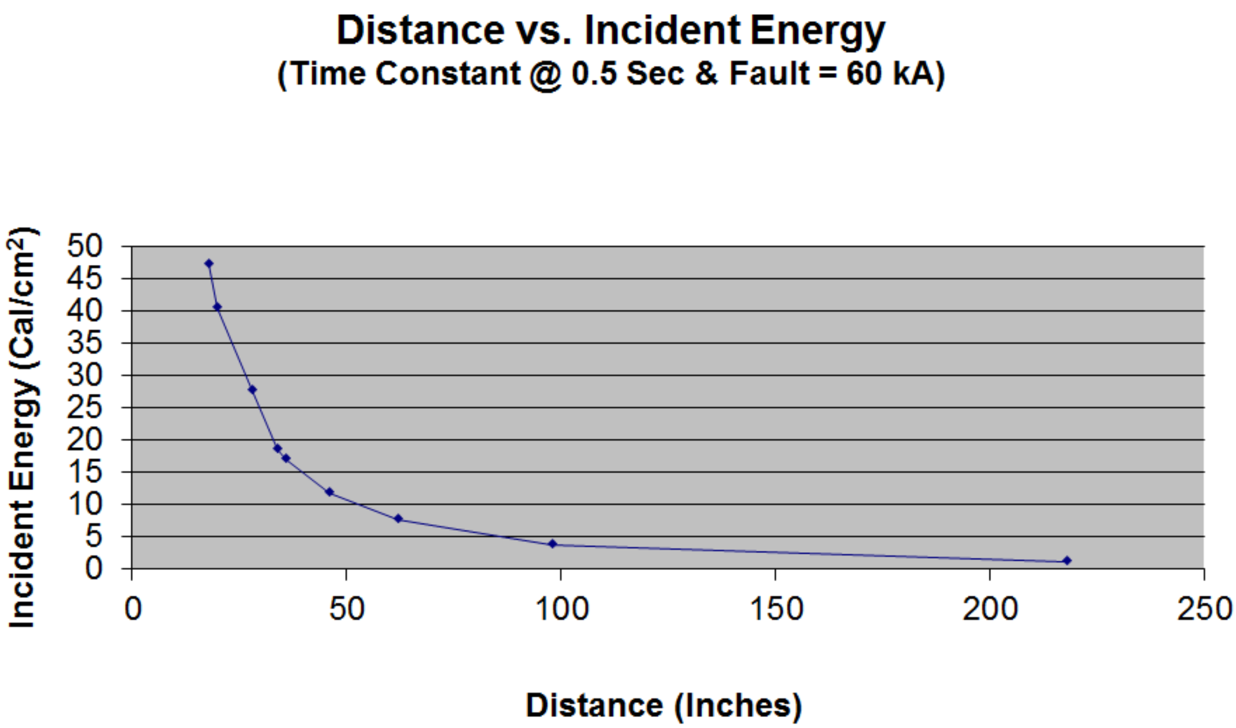
Most faults start out as a line to ground fault. On solidly grounded systems, this line to ground fault current magnitude can be as high as the three phase fault current if the fault occurs close to the main supplying transformer. These high line to ground fault currents can easily create such a large arc flash (plasma and heat), that the other two phases flash over and start a three phase arc flash event. A three phase arc flash event can have more energy than a single line to ground fault arc flash.

For medium voltage distribution systems, low resistance grounding reduces the line to ground fault current to much lower values of 200 to 400 Amperes. This is done by installing a resistor in the neutral of the transformer. This resistor lowers the line to ground fault current to a value that usually prevents the other phases from flashing over. Thus, the resistance grounded system will be more reliable and have less arc flash energy and equipment damage when a line to ground fault occurs.

For low voltage systems, the line to ground fault current is limited to less than 50 amperes. The results are similar to the medium voltage systems; the low level of line to ground fault current prevents the other phases from flashing over.

Increasing the Working Distance

Putting distance between the hazard and the electrician is also beneficial. The graph below shows how the energy decreases as the working distance increases. One way to reduce the hazards during infrared surveys is to use infrared windows. These windows are mounted at important locations that need to be inspected by infrared equipment such as the line side connections of the main breaker and load side connections for all feeder breakers. These windows allow the technician to scan the location to look for hot spots (loose connections) without removing covers and doors.



Graph 3 – Distance vs. Incident Energy Level

One of the most hazardous tasks to perform is racking in or out breakers. Many documented accidents have occurred during this operation. Recently, several manufacturers have been marketing remote breaker racking devices. These devices allow the operator to stand to the side while the machine racks in the breaker. Increasing this working distance reduces the arc flash energy at the operator's location.

Another way to get more distance between the potential arc flash hazard and the operator is to use remote breaker operating devices. This can range from a remote control panel that has open and close switches for each breaker or by use of Remote Switch Operators or Actuators. These Remote Switch Operators are attached to the breaker or on the pistol grip switch on the cubicle door using strong magnets. A remote control unit with a 20 foot cord then can control the breaker operation remotely.

Summary

We have looked at several ways to reduce the arc flash energy in a facility. Arc flash energy can be reduced by (in order of effect):

- Decreasing the Trip Times
- Reducing Fault Currents
- Increasing the Worker Distance

There are many methods and techniques that the technician or engineer can use to reduce the incident energy levels. Each location should be analyzed by an electrical engineer familiar with incident energy levels to see which solutions are most cost effective and beneficial. Working on the equipment when de-energized is the safest solution and it can be implemented at any location.

About the Author

Robert Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN.

After graduation, he worked for General Electric Company from 1980 to 1986 as a Field Engineer, performing commissioning and start up tests on many different types of power distribution equipment. Mr. Fuhr worked as a Senior Facilities Engineer at the University of Washington from 1986-1989. There he re-commissioned the electrical power distribution system for University Hospital.

In 1986, Mr. Fuhr established PowerStudies, Inc., a consulting firm that specializes in power systems studies, power quality services, and commissioning services. He also teaches classes in protective relaying, electrical systems, safety, power factor correction, harmonics and filter design. Mr. Fuhr is a Professional Engineer registered in Alaska, Arizona, California, Colorado, Delaware, Florida, Hawaii, Idaho, Iowa, Nevada, New Mexico, New York, New Jersey, Maryland, Oregon, Pennsylvania, Virginia, Washington, and British Columbia.

Mr. Fuhr has been actively involved in Institute of Electrical and Electronic Engineers (IEEE) and the Industrial Applications Society (IAS) since 1986. He served as an officer for IAS from 1988 to 1992 and was the 1991-92 Chairperson of IAS and was a Member-at-large for the Seattle Section of IEEE from 1992-93. Mr. Fuhr is an IEEE Senior Member, a member of the Building Commissioning Association, and a member of the Electric League of the Pacific Northwest. He is a member of the IEEE 1584 Working Group (Guide for Performing Arc-Flash Hazard Calculations)