For Greater Arc Flash Protection Think *"Outside the Box"*

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Summary

When an arc flash occurs, the severity known as incident energy, depends on many factors including whether it occurs in a box such as an equipment enclosure or in open air. If the arc flash occurs in an enclosure or box environment, the energy is concentrated by the walls of the box and focused out the door opening leading to potentially greater hazard and injury. However, if the arc flash occurs in open air, the energy is dispersed spherically in all directions reducing the amount of energy that can reach a person in close proximity.

A new design for the pad mounted transformer not only allows opening up the door, but also enables opening the top and sides as shown in Figure 2. With the more open design, incident energy from an arc flash could radiate away from the enclosure in multiple directions leading to a reduction in overall incident energy exposure. To compare the effect that the open enclosure has on incident energy, arc flash testing was conducted on both open and closed enclosure designs. The results of the arc flash testing indicates that there is a 55 percent reduction in incident energy when the enclosure's side and top are open compared to the same enclosure with only the door open.

The Arc Flash Hazard

All it takes is something as simple as the slip of a screwdriver to make contact between energized conductors or between a conductor and a grounded equipment enclosure, and the electric power system can act like a bomb. Known as an "arc flash", the result can be devastating. The severity of the arc flash is defined in terms of it's incident (thermal) energy which is measured as calories/centimeter^2 (cal/cm^2). Depending on the magnitude of available short circuit current that flows, as well as how long it takes the upstream protective device to operate, the arc flash can be anything from minor arcs and sparks to a massive explosion.

"Inside the Box" or "Outside the Box"?

The severity of the arc flash also depends on whether it occurs within a box type environment such as an electrical equipment enclosure or in open air. An enclosure (box configuration) can focus the arc flash energy out of the door opening. Anyone standing in front of the opening could experience a more concentrated energy, as if it was being shot out of a cannon. However, If the arc flash occurs in open air, the energy would radiate more spherically in all directions and anyone standing nearby would likely receive a much smaller "slice" of the total energy.

Figure 1 - Pad Mounted Transformer

Pad Mounted Enclosure "Outside the Box"

A standard pad mounted transformer enclosure as shown in Figure 1, is designed like a five sided box with a door that opens for access to the bushings and conductors. If the rare but dangerous arc flash occurs, the traditional box design could focus the arc flash energy out of the opening. However, thinking "outside the box" - *literally*, a new pad mounted transformer enclosure design has moved away from the traditional "inside the box" design.

Figure 2 - Open Box Configuration

By allowing the top and side of the enclosure to be opened, the open box design was originally developed to provide better access to the transformer's bushings for easier cable terminations. In addition it provides extra working space and better visibility for the worker.

By allowing not only the enclosure door to be opened but also the side and top, if an arc flash occurs, the enclosure would act more like open air rather than a confined box. The open box design shown in Figure 2 allows the incident energy from an arc flash to radiate in multiple directions and not be as focused towards the electrical worker.

The Comparison - Inside vs. Outside the Box

It is well understood that the incident energy from an arc flash should be less when using the open enclosure design. The real question is: how much less? Calculations using the IEEE 1584 equations were performed to test the concept of reducing incident energy by using an open enclosure design. In addition arc flash laboratory tests were also conducted.

For this evaluation, a 500 kVA three-phase transformer was used. The parameters of the transformer are listed in Table 1.

Table 1
Test Transformer Data

kVA rating	500 kVA
$Voltage_{secondary}$	480Y/277V
Percent Impedance	2.00%
Low Voltage Terminal Arrangement	Per IEEE Std. C57.12.34-2004 Figure 11(a) minimum dimension

Bolted Short Circuit Current

Both the arc flash calculations and laboratory testing were based on the arc flash occurring on the secondary side of the transformer. The calculated maximum bolted three phase short circuit current that could occur at the 480 Volt secondary bus of a 500 kVA transformer with a percent impedance of 2.0 percent was established as 30,000 amps. This value was derived from using the following "infinite bus" short circuit calculation.

$$SCA_2 = (FLA_2 \times 100\%) / Z\%$$
$$FLA_2 = kVA_{three\text{-}phase} / (\mathrm{Sqrt}(3) \times kV_{LL})$$
$$FLA_2 = 500\ kVA / (1.732 \times 0.48 kV_{LL})$$
$$FLA_2 = 601\ Amps$$
$$SCA = (601 \times 100\%) / 2.00\%$$

$$SCA_2 = 30{,}020\ Amps$$

Where:

SCA_2 = bolted short circuit amperes on the secondary bus
FLA_2 = transformer secondary full load current rating
kV_{LL} = line-to-line voltage in kilo-volts

Sqrt(3) = square root of three which is 1.732
Z% = transformer nameplate percent impedance

Arc Flash Duration

The maximum duration of the arc flash was established by determining the clearing time of the upstream protective device. Based on the transformer size and rating, it was assumed that a typical fuse such as a 353 C12 bay-o-net fuse would be used. The short circuit current that would flow through the primary fuse for the secondary short circuit was determined by calculating the secondary *arcing* short circuit current and reflecting it to the primary winding. This secondary arcing current was calculated using the IEEE 1584 equation for arcing currents on systems less than 1000 volts.

Using the calculated primary short circuit current and the manufacturer's published time current characteristic of the primary fuse, a clearing time of 0.214 seconds was established as the maximum arcing time. Since 0.214 seconds equates to 12.8 cycles, the clearing time of the test set up was rounded up to 13 cycles to account for the next zero current crossing.

Three Phase Configuration

Although most short circuits begin as contact between one phase and ground, it is widely recognized that the conducting plasma that is created from the arcing current can quickly escalate a phase-to-ground fault into a three phase event. IEEE 1584 addresses the potential for escalation by suggesting that only a three phase arc flash model should be used. Both the calculations and staged arc flash tests used the three phase configuration.

Arc Flash Calculation Methods

To predict the severity of an arc flash, the Institute of Electrical and Electronics Engineers (IEEE) has developed and published a document known as *IEEE 1584 - 2002 IEEE Guide for Performing Arc Flash Hazard Calculations*. This guide defines a series of equations that can be used to estimate the prospective incident energy. The equations include many factors such as the magnitude of available short circuit current, protective device clearing time, whether or not the system is grounded, the length of the gap that the arc jumps across and also the type of equipment. In addition, these elaborate equations also account for whether the arc flash occurs in open air, or is concentrated "inside a box" which is typical of enclosed equipment such as panels, motor control centers, switchgear and most pad mounted transformer enclosures.

Arc Flash Testing Methods

To validate the calculated reduction in incident energy using the IEEE 1584 equations, Tests were performed on a 500 kVA transformer enclosures to the high power laboratories of Ferraz Shawmut in Newburyport, MA for arc flash testing. This enclosure utilized the open box design so it was possible to open the top, front and side of the enclosure. It could also be configured as a standard enclosure with all sides closed and only the door open which is representative of the standard box design.

An array of six calorimeters were placed at a distance of 18 inches in front of the arc source to measure the incident energy during the test. The mean incident energy as well as the maximum incident energy from all 6 calorimeters was recorded and listed in Table 3. The 18 inch distance was used to represent at typical working distance as defined by IEEE 1584.

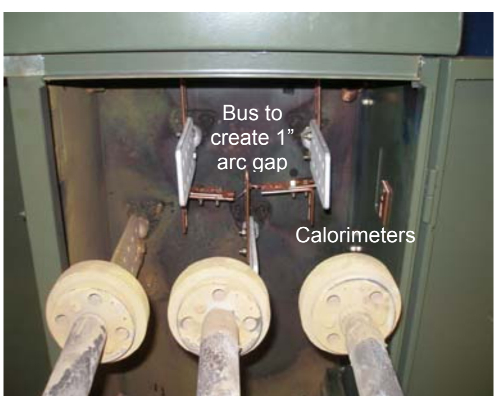

Figure 3 - Test Set Up

A series of additional bus work was attached to the transformer spades creating a 1 inch gap to match the IEEE 1584 parameters. To initiate the short circuit, an 18 AWG conductor was wrapped around each of the three phases connecting them together to create a three phase fault. Initially, when the test switch is closed, a bolted short circuit results. However the initiating wire instantaneously vaporizes and creates an arc that sustains itself across the gap.

Two different configurations were tested including the standard enclosure configuration "box" where only the door was open, and the open configuration where the enclosure door, top and side was open. The results of both tests are listed in Table 3.

Configuration One - "Inside the Box"
Standard Transformer Enclosure

The first test was conducted with the enclosure configured as a five sided box as shown in Figure 3. The second test was performed with the door, top and right side of the transformer in the open position as shown in Figure 2.

The first configuration that was evaluated was based on a standard pad mounted transformer enclosure where only the front door was open and all sides were closed. This is representative of the "box" type of configuration. The test parameters were based on the 30 kA bolted short circuit current with a clearing time of 13 cycles. Using this configuration for both the calculations and arc flash testing, the calculated value of incident energy was 11.87 cal/cm^2 and the actual maximum recorded incident energy during the test was 12.36 cal/cm^2.

Configuration Two - "Outside the Box"
Open Transformer Enclosure

The second configuration had the transformer enclosure placed in the open configuration. The calculations assumed the arc flash was in air and the actual test set up had the front, side and top of the transformer's secondary compartment open. This should allow the energy from the arc flash to diffuse and not be directly focused out of the enclosure door where a worker could be located. Using the IEEE 1584 model, the incident energy for the arc flash in air was calculated as 8.01 cal/cm^2. The recorded test results of the incident energy using the open enclosure configuration were 5.58 cal/cm^2.

Conclusion - Think *"Outside the Box"*

Comparing the results of the arc flash test using the same available short circuit current, clearing time, working distance and gap distance, there was a 55% reduction in the recorded maximum incident energy when using the open configuration compared to the box configuration. Although this test only represents one transformer enclosure, it does suggest there can be an appreciable decrease in incident energy when an open enclosure design is used.

Table 3
Summary of Arc Flash Calculations and Tests

Enclosure Configuration Box or Open	Predicted Incident Energy cal/cm^2	Recorded Maximum Incident Energy cal/cm^2
Box Configuration	11.87	12.36
Open Configuration	8.01	5.58
Percent Reduction in Incident Energy	33% energy reduction	55% energy reduction

NFPA 70E and OSHA both strongly advocate keeping energized work to an absolute minimum and equipment should be placed in an electrically safe condition. However, this is not always possible and sometimes energized work is unavoidable. In the case where energized work is to be performed, the requirements of NFPA 70E and OSHA must be strictly adhered to.

The “Outside the box” open design for pad mounted transformers can help reduce the amount of incident energy during an arc flash and potentially reduce the overall arc flash hazard.

Warning Note: An arc flash can cause serious injury and death. Strict adherence to proper regulations, codes and standards such as OSHA and NFPA 70E as well as being a qualified individual according to these standards is mandatory. This includes the use of proper personal protective equipment, clothing and safe work practices.