Arc Flash Hazards on Direct Current (DC) Systems

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Executive Summary

The most common concern when performing electrical work is arc flash hazards on alternative current (AC) systems. In fact, in the last 15 years, significantly more companies have acknowledged the importance of performing arc flash studies for AC-powered systems, in accordance with the CSA Z462 standard, to properly protect employees.

Although arc flashes hazards on direct current (DC) systems are just as real, they are often minimized or even ignored. Not only is it unrealistic to assume it is enough to take into account the incident energy in AC systems when assessing arc flash hazards, this in itself can be hazardous. For example, for a distribution panel that is fed by a battery room with a nominal capacity of 1000 ah, the level of calculated incident energy for the battery terminals would be 18 cal/cm^2. This high value requires protection with anti-arc coveralls for a standard work distance of 46 cm (18 inches). That's why assessing arc flashes for DC systems is just as important to ensure worker safety.

Remember that a risk assessment is intended to provide workers with a safe work environment. To do this, all businesses must properly train their staff and provide appropriate personal protective equipment (PPE) to perform tasks in accordance with Bill C-21 of the Criminal Code of Canada; otherwise, these businesses can receive hefty penalties and be held criminally liable in case of injury or death.

There are various ways to assess incident energy that can be caused by an arc flash on DC systems. In this document, we will introduce a quick and easy calculation to demonstrate how important it is to apply the methods indicated in the CSA Z462-15 standard. This standard is the benchmark in terms of assessing electrical hazards. Likewise, qualified experts must be mandated to adequately apply and obtain accurate and realistic calculations. After all, worker safety depends on it.

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Downtimes for DC-powered equipment

One of the biggest challenges that most companies face is obtaining enough downtime to complete maintenance on DC equipment. In fact, it is quite difficult for Operations to shutdown DC equipment that powers a facility's essential loads. Performing a preliminary risk assessment is critical in order to establish whether or not it is possible to perform tasks on energized electrical equipment while ensuring worker safety and to determine the proper personal protective equipment (PPE).

DC arc flashes can occur in various situations and for various types of installations, such as an uninterruptible power supply (UPS), a DC system powered by batteries or rectifiers.

The CSA Z462-15 standard states that arc flash hazards must be assessed for all systems of 50 V or greater, regardless of whether the voltage is AC or DC. This standard also proposes calculation methods to assess the energy level a worker can potentially be exposed to.

Because an arc flash can even occur on regular DC equipment (125 VDC), the importance of assessing risks is undeniable.

BBA has conducted many DC arc flash studies in the last three years. Our field experience and proven expertise allows us to confirm that the energy level observed in high-capacity DC systems is very high (30 cal/cm² or more) and to advise our clients properly.

Demonstration of the maximum power calculation method

During arc flashes on DC systems, the current never crosses zero. For arc flashes on AC systems, the arc extinguishes each time the current wave goes through a zero crossing and must reignite to maintain the arc.

In a DC system, there is no need to reignite the arc. That is why most 125 VDC systems used as control power sources in an electrical substation pose high arc flash hazards. Various studies show that a minimum voltage of 12 to 15 V/cm between the arc electrodes is sufficient to maintain the arc in a DC system. This value also depends on the arc current in question.

The form and length of an arc can vary considerably because of its dynamic nature. It is therefore difficult to quantify its physical behaviour. Also, other variables influence the total quantity of heat and energy a person working on equipment can be exposed to in case of an arc flash. Voltage gradients, the type of electrode material and current intensity are good examples. That's why it is difficult to measure hazards created by an arc flash—arc length being only one of the variables at issue.

BBA uses ETAP software from OTI Technology, which provides three different methods to calculate incident energy levels in DC systems:

1. Maximum power
2. Paukert
3. Stokes and Oppenlander

Recommendations in the CSA Z462-15 standard are based on "worst case" energy exposure. In 2010, the maximum power calculation method (method #1) developed by Doan1[1] was added to the CSA Z462-15 standard and the NFPA 70E -2015 standard. Below is an example of this calculation method for a basic circuit:

[1] Arc Flash Calculations for Exposures to DC Systems, Daniel R. Doan, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 46, N° 6, NOVEMBER/DÉCEMBER 2010.

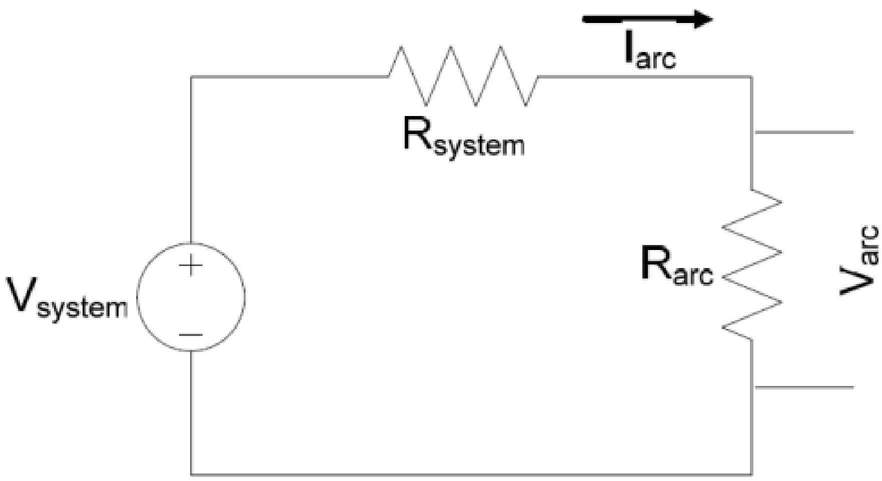

Figure 1: Basic representation of a DC arc

When only considering the resistive portions of impedance, arc power ($Parc$) can be calculated as follows:

$$P_{arc} = \frac{V^2{}_{arc}}{R_{arc}}$$

The maximum power ($Pmax$) released in the arc is reached when the resistance in the arc ($Rarc$) is equal to the resistance of the systems ($Rsys$) (Figure 1).

$$Rarc = Rsys$$

The current ($Iarc$) is therefore equal to half of the system's solid fault current calculated by hand or using short-circuit (Ibf) calculation software. The arc voltage ($Varc$) is, for its part, equal to half of the system voltage ($Vsys$):

$$P_{max} = \frac{\left(\frac{V_{sys}}{2}\right)^2}{R_{sys}}$$

When taking into account the nonlinear effect of the loads, it is easier to use the following equivalent formula:

By replacing $\frac{Vsys}{2}$ with

$$V_{arc} = I_{arc}\ x\ R_{sys}$$

So $Pmax = Rsys\ x\ I_{arc}{}^2$ is obtained.

To convert this last result into maximum power, we must take into account the arc time variable ($Tarc$).

$$E_m = R_{sys}\ x\ I_{arc}{}^2\ x\ T_{arc}$$

To convert joules into calories, we must multiply the above result by 0.239. Finally, for an open-air arc, this result must be divided by the surface of a sphere that is at the same distance as the worker (D) to calculate the estimative incident energy to cal/cm2.

$$Surface = 4\ x\ 3.14\ x\ D^2$$

The incident energy calculation using the maximum power method therefore becomes:

$$E_m \ = 0.02\ x\ \ Rsys\ x\ I^2{}_{arc} x \left(\frac{T_{arc}}{D^2}\right) cal/cm^2$$

The CSA Z462 standard also recommends using a conservative multiple of three, obtained using the maximum power calculation formula when the arc occurs in a contained enclosure. This allows us to take into account the reflection effect of the enclosure.

Determining arcing time

Protective devices in DC systems are affected by the L/R time constant, which is the result of the system fault inductance divided by the resistance. The current rise speed during a fault is based on this L/R time constant. When a time constant is below 10 ms, the trigger time for protective devices is not affected. When the L/R time constant is greater, which is often seen in long cable runs, it will take longer for the current to reach the trigger value for protective devices. These protective devices will also take longer to detect the fault current and open the circuit, which increases the incident energy.

Example of incident energy calculations

The following calculations are examples.

First, consider a battery system with the following characteristics:

- 129 VDC bus.
- 10,000 A short-circuit current
- L/R = 10 ms
- 400 A fuse
- Working distance of 18 in. (46 cm)

First, calculate the $Rsys$

$$R_{sys} = \frac{V_{sys}}{I_{cc}} = \frac{129}{10\ 000} = 0.0129\ \Omega$$

Then, $Iarc$ is equal to:

$$I_{arc} = \frac{V_{sys}}{2\ x\ R_{sys}} = \frac{129}{2\ x\ 0.0129} = 5\ 000\ A$$

In our case, $Tarc$ = 0.5 s, as determined by the TCC fuse curve (not shown).

$$E_m = 0.02\ x\ \ Rsys\ x\ I^2{}_{arc} x \left(\frac{T_{arc}}{D^2}\right)\ cal/cm^2 = 0.02\ x\ 0.0129\ x\ 5\ 000^2\ \ x \left(\frac{0.5}{46^2}\right) = 1.52\ cal/cm^2$$

In this case, the incident energy at maximum power is greater than 1.2 cal/cm2. The result would be around 1.52 X3 = 4.56 cal/cm², where the arc occurs in a contained enclosure.

Personal protective equipment

Here is a summary of the personal protective equipment (PPE) to use based on the incident energy at a given distance, taken from Appendix H of the CSA Z462 standard.

	Energy	Personal protective equipment (PPE)	Work assessment
1	Less than 1.2 cal/cm²	• Safety glasses • Hearing protection • Leather gloves or rubber insulating gloves with leather protectors, where required • Long-sleeve shirt and pants that do not melt or are made of untreated natural fibres, or arc-rated coveralls	Easy
2	Between 1.2 cal/cm² and 12 cal/cm²	• Arc-rated long-sleeve shirt with arc-rated pants or arc-rated arc flash coveralls • Safety helmet, arc-rated face shield and arc-rated balaclava or arc flash suit hood • Leather shoes *Arc-rated items must be greater than the determined incident energy level.	Average: Visibility is diminished, but work can be accomplished quite easily.
3	Greater than 12 cal/cm²	• Same equipment as in point 2 *Arc-rated items must be greater than the determined incident energy level.	Difficult: The arc-rated coverall is more cumbersome: only easy tasks can be achieved. Small tools can hardly be handled and visibility is greatly diminished. It increases risks of errors.

According to the CSA Z462 standard, PPE >1.2 cal/cm^2 and < 12 cal/cm^2 must be used to perform any task when not cutting power to the equipment studied in the previous example.

For circuits downstream from a battery in a DC distribution system, circuit breakers provide protection in case of a short-circuit, but if the circuit breakers are not properly adjusted, an arc flash can last over two seconds. In such cases, the level of arc flash incident energy can be considerably reduced by adjusting circuit breakers correctly.

In the previous example, replacing the fuse with a circuit breaker that has a correctly adjusted instantaneous element would eliminate the arc flash fault in less than 0.0167s. The energy level would therefore only be 0.05 cal/cm^2.

Sometimes, it is impossible to reduce the energy level. For example, battery rooms that feed a permanent DC source have no protection devices that can interrupt an arc flash right at the battery rack output. As a result, mitigating solutions must be applied to reduce the probability of an arc flash occurring.

It is the same for a distribution panel that is directly connected to a battery room. No protection device can eliminate the arc fault. Additionally in the standard, the time is maximized to two seconds in the calculation. This results in an increase in energy that can reach up to 18 cal/cm^2 in the previous example by using a two-second arcing time and multiplying the result by 3 for an arc flash in an enclosure.

In both cases, it is imperative to keep the energy level in mind when selecting PPE.

Such situations can only be mitigated by re-assessing the battery capacity, which is maybe oversized. The short-circuit level can be reduced by dropping the battery capacity. This will reduce energy levels proportionately with the square of the available fault current against what it was.

Benefits of mitigating techniques

There are three main benefits to applying mitigation techniques:

1. Improve worker safety by lowering arc flash hazard levels
2. Facilitate worker tasks by using appropriate PPE
3. Perform work more safely without cutting power and continuing the DC power supply

Recommendations

It is very important to be mindful of arc flashes in DC systems. As we have seen in this paper, arcing time has a direct effect on incident energy calculations. Protective devices adjusted to their maximum values may not sense the fault and can cause damage or even more serious injuries. This is why BBA recommends the following:

1. Perform an arc flash study on DC systems to assess arc flash hazards.
2. Determine what PPE workers must use within the arc flash boundary.
3. Identify critical work locations with high incident energy levels that could be lowered by applying various mitigation techniques, such as optimizing settings.

References

1. IEEE – Arc Flash Calculations for Exposures to DC Systems, Daniel R. Doan, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 46, N° 6, NOVEMBER/DECEMBER 2010.
2. DC-Arc Models and Incident-Energy Calculations, Ravel F. Ammerman, Tammy Gammon, Pankaj K. Sen, and John P. Nelson, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 46, N° 5, SEPTEMBER/OCTOBER 2010.

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