Concerned about arc-flash and electric shock?

White Paper

Safety technology

Want to comply with NFPA 70E CSA Z462?

How can IR Windows help?

Infrared thermography has become a well-established and proven method for inspecting live electrical equipment. To carry out tests, the thermographer usually works with live energized equipment and requires a clear line of sight to the target. Thermographers must therefore be especially aware of the hazards, the legislation and safety issues, and the techniques and equipment best suited to minimizing the risks when working in these dangerous environments.

Introduction

Electrocution is the obvious danger faced by anyone working on or near live electrical equipment and it is clearly important to understand shock hazards and wear appropriate protection. However, most electrical accidents are not the result of direct electric shocks. A particularly hazardous type of shorting fault—an arc fault—occurs when the insulation or air separation between high voltage conductors is compromised. Under these conditions, a plasma arc—an "arc flash"—may form between the conductors, unleashing a potentially explosive release of thermal energy.

An arc flash can result in considerable damage to equipment and serious injuries to nearby personnel. A study carried out by the US Department of Labor found that, during a 7-year period, 2576 US workers died and over 32,000 suffered injuries from electrical shock and burn injuries. 77 % of recorded electrical injuries were due to arc flash incidents. According to statistics compiled by CapSchell Inc (Chicago), every day, in the US alone, there are 5-10 ten arc flash incidents, some fatal.

NFPA 70E is the leading internationally recognized safety standard for electrical safety in the workplace. The Canadian Standards Association has developed its own set of standards based on NFPA 70E: CSA Z462.

These standards define a set of safe requirements for personnel working on electrical equipment. To comply with the standards, employers must carry out a hazard risk assessment and ensure that all employees working in a potential arc-flash hazard zone use appropriate equipment and wear the right protective clothing. Although it is not the responsibility of the thermographer to put in place the appropriate safety procedures, it is important to recognize and understand their need, and to ensure that the correct procedures, equipment and protective clothing are used.

The installation of IR windows, panes or ports allows a thermographer to inspect live electrical equipment without the removal of protective covers and the exposure of equipment. An arc-resistant window, unlike a port or pane, provides additional protection for the thermographer in the event of an arc flash resulting from unexpected component failures or work on other parts of the system. This substantially reduces the hazard rating for the inspections and, in most cases, may allow the thermographer to work more safely minimizing the need for excessively bulky and cumbersome protective clothing.

What is an arc-flash?

An electrical system can be subject to two types of shorting faults:
- Bolted faults
- Arc faults

Bolted faults
A "bolted-fault" is everyone's idea of a short circuit: such as energizing the circuit with a ground set in place. A bolted fault results in a very high current; it is a low impedance short because of the solid connection. Bolted faults behave predictably and so conductors can be rated to withstand the overcurrent for the time required for an interrupt device to operate. Bolted faults rarely result in an explosion.

Older switchgear which holds a "fault-rating" will usually be rated for its ability to withstand this high current for a particular time period. A bolted "fault-rated" piece of equipment will usually have a BIL (Basic Impulse Level) highlighted on the casing itself in the form of a fault current for a set duration. E.g 100 kA for 5 seconds.

Arc faults
The second—and far more destructive—fault is an arc-fault. This occurs when the insulation, or more specifically the air separation, between electrical conductors is no longer sufficient to withstand their potential difference. This can occur for many reasons. A dropped tool or any other conductive element (even rust), introduced between or near energized components may compromise the insulating clearances. Often, incidents occur when a worker mistakenly fails to ensure that equipment has been properly de-energized. Incidents can even occur when a worker is simply removing a cover from a piece of equipment. A significant proportion of arc faults occur simply due to some form of component failure and is not limited to human interaction alone.

In contrast to the low impedance required for a bolted fault, an arc-fault is a high impedance short because the discharge occurs through air.

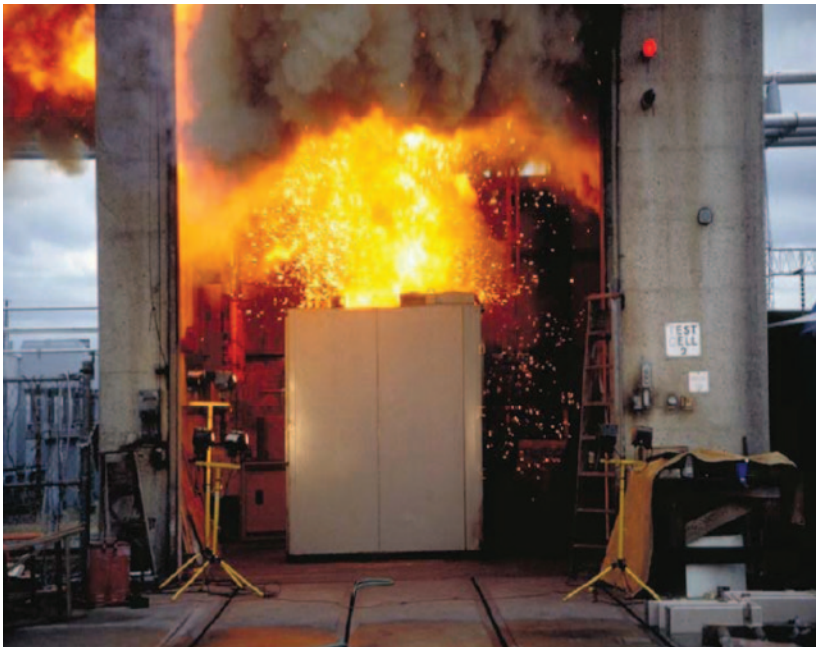

Figure 1. Demonstration of the power of an Arc Flash.
Photo courtesy of ewbengineering.

The current flow is therefore "comparatively" low but the explosive effects are much more destructive and potentially lethal. Unlike a bolted fault, it is difficult to predict exactly how much energy will be released by an arc fault. In particular, it is difficult to predict the duration of an arc fault as this depends on many factors, feedback mechanisms and the response of the over current protection devices.

When an arc fault occurs

NIOSH (National Institute for Occupational Safety and Health, Pittsburgh, USA) has published the results of a survey of electrical accidents reported by MSHA (Mine Safety and Health Administration, US Department of Labor) in the mining sector over the period: 1990-2001. In more than two-thirds of the cases of arc flash injuries, the victim was performing some form of electrical work such as troubleshooting and repair. More surprisingly, 19 % of the accidents arose from the direct failure of equipment during normal operation. Overall, 34 % of the accidents involved some form of component failure.

The key components involved in the accidents where: circuit breakers (17 %), conductors (16 %), non-powered hand tools (13 %), electrical meters and test leads (12 %), connectors and plugs (11 %). Of the cases that reported the arcing voltage, 84 % occurred with equipment at less than 600 V and only 10 % with equipment at more than 1000 V.

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Arc fault make-up

When an arc-fault is triggered, a plasma arc—the arc flash—forms between the shorted components. Once established, the plasma arc has a virtually unlimited current-carrying capacity. The explosive energy release causes:

- A thermoacoustic (dynamic) pressure wave
- A high intensity flash
- A superheated ball of gas

The thermoacoustic wave is a dynamic pressure wave caused by the instantaneous expansion of gas local to the fault. It causes panels to rupture, flying debris and barometric trauma. The wave front travels outwards, away from the fault, and as it impacts surfaces it increases in energy: an effect known as "pressure piling".

A common misconception is that an arc flash will always result in panel rupture. However, by incorporating high-speed interrupt devices and additional protection systems, an engineer can reduce the arc flash energy to a level where the thermoacoustic wave front does not have sufficient energy to rupture the panel.

Although the thermoacoustic wave resulting from an arc fault can be very destructive, it is not the only characteristic of an arc flash. Unlike a chemical explosion, the energy of an arc flash converts primarily to heat and light energy. Temperatures at the epicenter of an arc flash can reach 20,000 °C (four times hotter than the surface of the sun) within a millisecond. Such high temperatures are capable of explosively vaporizing metals such as copper. The presence of vaporized metal can then feed and sustain the plasma arc and exacerbate its power.

An arc flash essentially lasts until the overcurrent protective devices open the circuit. A fast-acting fuse may open the circuit as quickly as several milliseconds.

The consequences of an arc flash

Arc faults are potentially fatal to any personnel in the vicinity. The intense heat of the arc flash can severely burn human skin and ignite the clothing of anyone within several feet of the incident. Treatment for arc flash burns can involve years of skin grafts.

Without proper eye protection, projectiles and molten debris can cause eye damage. The intense UV radiation associated with the flash can cause retinal damage. Superheated vapors can injure lungs and impair breathing. The thermoacoustic blast can damage hearing with ruptured eardrums, cause collapsed lungs and damage other internal organs. The blast can knock personnel off their feet; falls may result in broken bones or lead to electrocution or further injuries on other parts of the system.

Inevitably, a serious arc flash will damage or even destroy the affected equipment. This leads to extensive downtime and expensive replacement and repair.

An incident may also represent a failure on the part of the employer to comply with industry guidelines and regulations. This could result in a fine, litigation fees, increased insurance costs, expensive legal actions and accident investigations.

Standards and guidelines

The potential dangers of an arc flash can be reduced by following the relevant safety guidelines and using personal protective equipment PPE.

In the USA, the following OSHA and NFPA regulations apply to personnel working with energized electrical equipment:

- NFPA 70 ("National Electric Code")
- NFPA 70E ("Standard for Electrical Safety in the Workplace")
- OSHA Standards 29-CFR, Part 1910 (S) 1910 333
- OSHA Standards 29-CFR, Part 1926 Subpart K
- IEEE Standard 1584-2002, ("Guide for Performing Arc Flash Hazard Calculations.")

Many other countries have their own broadly similar standards and regulations. For example, Canada's regulations can be found in CSA Z462. In the UK, compliance with EAWR (Electricity at Work Regulations) 1989, section 5 is required.

NFPA 70E—the safety standard

NFPA 70E defines the safe parameters for personnel working on electrical equipment. Although adherence is not a legal requirement, the standard provides a benchmark for most industries to demonstrate compliance with OSHA's General Duty clause. An employer adopting the guidelines offered in NFPA 70E demonstrates a clear commitment to safe working practices and the protection of employees from shock and arc flash hazards.

According to the standard, if personnel will be operating in the presence of energized equipment, then certain safety considerations are applicable. 70E recognizes that there may be the potential for arc flash and arc blast even when conductors are not exposed. Qualified personnel responsible for the work must:

- Conduct an arc flash hazard analysis
- Implement qualified and general worker safety training based on the results
- Establish shock and flash protection boundaries
- Provide protective clothing and personal protective equipment to ANSI standards
- Put warning labels on equipment
- Authorize the job with a 'live work' permit

Steps for an arc flash hazard analysis

Section 4 of IEEE 1584-2002 outlines a 9-step procedure for arc flash hazard analysis. The purpose of this analysis is to "identify the flash protection boundary and the incident energy at assigned working distances..."

The nine steps are:

1. **Collate system data.** Collect system and installation information for a detailed short circuit assessment. You will need to describe the system and the arrangement of its components in a one-line drawing with nameplate specifications for each device and the lengths and cross-sectional areas of interconnecting cables.
2. **Consider all modes of operation.** Examine the different ways that the system operates and how this may affect the risks and magnitudes of arc hazards.
3. **Calculate bolted fault currents.** Using the data gathered in the first two steps, calculate the highest bolted fault current expected to flow during any short circuit.
4. **Calculate arc fault currents.** During an arc fault, the current flow is normally lower than that of a bolted fault in the same equipment because of the added impedance of the arc. For example, for a bolted fault of 40 kA at 480 V the corresponding arc fault would be expected to yield about 20 kA. IEE 1584-2002 provides formula for estimating arc fault currents.
5. **Determine protective device characteristics and arc durations.** Estimate how over current protection devices will react during an arc fault. These may react more slowly, extending the duration and power of the arc flash. Through the analysis, it may be possible to reduce the arc flash hazard and lower the PPE requirement by replacing existing circuit breakers. For example, modern, current-limiting fuses may considerably reduce arc flash energies by reacting more rapidly and at lower over current values.
6. **Document system voltages.** Establish bus gaps and operating voltages.
7. **Estimate working distances.** Determine the distances from arc fault sources to a worker's face and chest. Although hands and arms may be closer to any incident, injuries are unlikely to be life-threatening.

8. **Determine incident energy.** Calculate the incident energy resulting from an arc fault at the working distance.
9. **Determine flash protection boundary.** Use the same calculations to estimate a 'safe' distance from the source of the arc hazard beyond which PPE is not required. This paper describes the Flash Protection Boundary in more detail later.

Shock hazard analysis

As the name implies, the determination of the shock hazard is an analysis designed to reduce the risk of electrocution. NFPA 70 recommends the identification of three boundaries to define the safe working limits for personnel working in an area with shock hazards. Each area is associated with a level of training and PPE.

NFPA 70E data (contained in Table 130.7(C)(2) allows you to calculate the boundaries using a formula based on the voltage of the equipment.

The limited approach boundary

This is the minimum permitted distance that unqualified and unprotected personnel may approach a live component. Before crossing the limited approach boundary and entering the limited space, a suitably qualified person must use the appropriate PPE and be trained to perform the required work. An unqualified person may enter the limited approach area if they are under the supervision of a qualified person.

The restricted boundary

To cross the restricted boundary and access the restricted space, personnel need to have been trained in shock protection techniques, be wearing the correct PPE and have a written and approved plan for any work in the zone. The plan must make it clear that the worker must not enter the prohibited space or cross the prohibited boundary either personally or by using any equipment or tool.

Prohibited boundary

No worker should cross the prohibited boundary and enter the prohibited area unless:

- The responsible authority has carried out a full risk assessment.
- The work has been documented and it has been fully established why it must be carried it out on live equipment.
- The qualified worker has been trained to work on live electrical equipment.
- The worker has been equipped with appropriate PPE. In terms of safety, any worker crossing the boundary must be equipped and protected as they would be for making direct contact with the exposed live equipment.

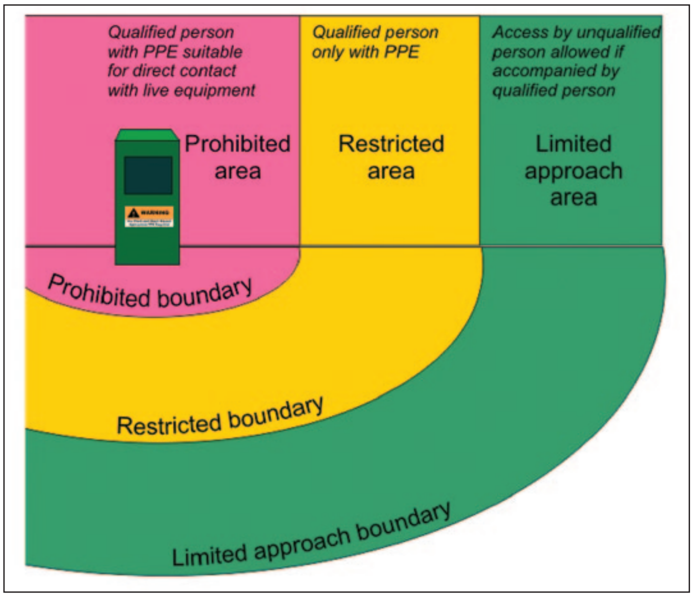

Figure 2. The shock hazard boundaries

Establishing these boundaries is an important step in protecting staff from the dangers of electrocution. It ensures that personnel use the correct equipment and procedures when in the proximity of live electrical equipment.

However, if the live equipment also poses an arc flash hazard, it is important to establish a 'safe' distance for this eventuality: the arc flash protection boundary.

The flash protection boundary

The arc flash protection boundary (FPB) is the minimum 'safe' distance from energized equipment that has a potential for an arc fault. It is defined as the distance at which, in the event of an arc flash, a worker would be exposed to a thermal event with incident energy of 1.2 cal/cm^2 for 0.1 second. With this exposure, a worker may receive a 2nd degree burn to exposed skin.

If it is necessary for workers to cross the flash protection boundary, and potentially be exposed to higher incident energies from any arc flash, they must be wearing appropriate PPE. For example, at an incident energy greater than 1.2 cal/cm^2, clothing could ignite and bare skin would sustain 2nd degree burns.

An important point here is that the flash protection boundary and the rules governing access within it take precedence over the shock hazard boundaries. So, for example, if the flash protection boundary is greater than the limited approach boundary then no unqualified person can be permitted in the limited approach area and even qualified workers must wear appropriate arc-resistant PPE here.

You can determine the flash protection boundary for an electrical system using the calculating methods contained in NFPA 70E and IEEE Std 1584. The equations are based on the voltage level, fault level and the trip time of the protective device.

The conditional flash protection boundary is 48 inches for low voltage (<600 V) systems where the total fault exposure is less than 100k amperes-seconds (fault current in amperes multiplied by the upstream device clearing time in seconds). On such a system, a qualified person who works closer than 48 inches from the live components must wear PPE for arc-flash protection including flame-resistant (FR) clothing. Of course, further PPE may be necessary for protection against electric shock according to the location of the shock protection boundaries.

Please refer to IEEE 1584 for comprehensive calculation methods for a wide range of electrical systems; the procedures describe calculation methods for equipment with voltages in the range: 208 V to 15 kV.

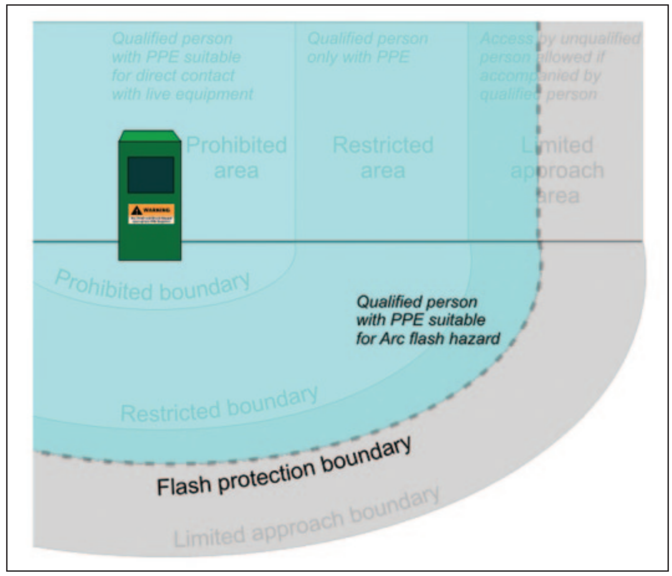

Figure 3. The Flash protection boundary takes precedence over the shock hazard boundaries.

Choosing the right PPE

As an option to incident energy analysis to assist in the choice of appropriate personal protection equipment for arc flash hazards, NFPA 70E defines five hazard risk categories (HRCs): 0, 1, 2, 3, and 4.

Hazard/Risk Category	APTV rating (cal/cm^2)
0	N/A
1	4
2	8
3	25
4	40

Figure 4. Category 4 PPE.
Copyright image courtesy of Salisbury by Honeywell

What is appropriate PPE?

Clearly, the potential injurious effects of an arc flash can be reduced by using a fire flame resistant (FR) suit of a suitable calorie rating to reduce the indecent energy on the body to an extent that the burns suffered are not life threatening.

Figure 5. Examples of PPE for arc flash protection. Copyright image courtesy of Salisbury by Honeywell

While safety is the paramount concern, it is important to select PPE appropriate for the task. It might seem a good idea to insist on category 4 PPE for all live work, perhaps to avoid a time-consuming arc flash hazard analysis, and this may outwardly appear to be a 'safe' policy for personnel. However, the use of restrictive or excessive PPE can also be hazardous: an over-heating worker struggling with poor visibility and restricted movement is more likely to have an accident. More accidents, more downtime.

In addition, there are scenarios where HRC may not be enough arc-flash protection. The HRC does not account for arc-blast.

NFPA 70E provides several tables listing the PPE appropriate for work within the flash protection boundary: clothing and equipment such as gloves, hats or hoods.

In addition to the HRC classification, PPE is often described by the arc thermal performance value (APTV). This corresponds to the capability of the garment to withstand a particular incident energy (in cal/cm^2).

As we have already discussed, the flash protection boundary defines the distance where an arc flash would produce incident energy of 1.2cal/cm^2: a level at which 2nd degree burns could occur. This corresponds to risk category 0. In practice, a worker will need to approach the electrical system much closer than the flash protection boundary. It is therefore important to calculate the likely incident energy for the working position and select PPE accordingly.

Most garments are tested and rated for incident radiation at a distance of either 18 inches or 24 inches. This roughly corresponds with the position of the head and chest when working directly on equipment. Of course, during an arc flash incident, the hands and arms may be much closer to the arc fault source and may need protective equipment with a considerably higher rating.

While NFPA 70E and IEEE 1584 cover the PPE requirements for arc flash protection, there are also other considerations and standards to include in any safety appraisal. Workers may require eye protection, insulating gloves, ear and hearing protection, head impact protection and reinforced footwear.

Heeding the warning signs

Equipment such as "Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers in other than dwelling occupancies, which are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment."

Although the basic requirement is for a sign warning of the arc flash hazard (see Figure 6) it is more helpful for engineers if the sign includes other useful information such as:

- Operational voltage
- Fault current
- Flash hazard boundary
- Incident energy at the normal working distance for the arc fault hazard.
- If this information is not present on the warning sign, it should be documented and accessible to all relevant personnel.

It is good working practice to make labeling clear and accurate; too much information is as bad as too little. If a system has several access points and arc flash hazards, label it with the parameters for the greatest hazard.

Figure 6. Energy level of 201 cal/cm^2 @7.2K V

The "live work" permit

Finally, before any work can commence, the responsible manager must generate and sign an energized electrical work permit. This describes the task and why it must be performed with live energized equipment, long with the shock and flash boundaries plus related PPE.

Arc flash hazards and the electrical thermographer

The goal of any electrical thermographer is to prevent unplanned shutdowns in a manner that is reliable, repeatable and above all safe. Since thermographers work with the target equipment online and on load coupled with the fact that IR Cameras cannot "see" through panel covers, thermographers face severe safety hazards when attempting to scan electrical distribution equipment.

Taking measurements with a cover removed is not a safe option.

The ideal solution is the provision of a permanent "access point" in the equipment housing

Leaving the cover closed:-

1. Increases safety.
2. Reduces the background reflection quotient and reduces the interference making readings more repeatable.

The safer alternative is the provision of a permanent "access point" in the equipment housing.

Ports, panes and windows

For infrared thermography, there are three types of access point:

- Infrared Port
- Infrared Pane
- Infrared Window

An IR port is simply a hole or series of holes; an IR pane is a thin polymer optic. Both limit physical access (human contact) to live equipment. However, in the event of an arc fault neither option provides a protective barrier between the thermographer and the exposed conductor and arc flash source. A pane affords little protection since it is a thin polymer with a low melting point.

How can infrared windows help?

An infrared window provides a solid barrier between the thermographer and the live conductors. By careful design, it is possible to not only to reduce the trigger effects of an arc but also provide the thermographer with a far safer working environment.

Thermography windows are relatively new technology, so there is no specific standard that relates to construction and testing. However, since they are invariably installed close to arc flash hazards, it is important that windows can withstand not only an arc flash incident but also the rigors of their environment and normal day-to-day operation.

In the United States, Canada and Europe, there are differing standards associated with testing equipment to be deemed "arc-resistant", specifically: ANSI C37.30.7 (North America), EEMACS G14-1 (Canada), IEC62271 (Europe). These standards are manifestly different and cannot be translated from one to another. For example, a product tested to IEC62271 in Europe cannot be claimed to be suitable for North American ANSI C37.20.7 nor Canadian EEMACS G14-1.

End-use requirements vary considerably so testing and certification needs to be generic in order to provide an all-round product suitable for use in most if not all applications.

Manufacturers tend to design viewing panes to withstand accidental impacts from untrained personnel in transit rather than the combined pressure piling and sudden temperature increase effects of an internal electric arc.

Infrared windows, on the other hand, are constructed of crystal optic materials designed to better protect the infrared thermographer under an arc-flash condition during scheduled, periodic inspection of the internal equipment.

Inspection devices may also feature locking security covers. This ensures only a trained and authorized person can remove and complete an inspection or scan. It also protects the optic material from day-to-day impacts and offers further arc-flash protection. Properly constructed cover designs are manufactured from materials that offer substantially similar properties as the original panel wall knock-out—National Electric Code 110.12(A).

Selecting the correct material

There are numerous materials that can "transmit" infrared radiation from low cost thin film plastics used for home intruder alarm systems to germanium optics for military imaging.

Unfortunately, there are not many materials suitable for the task of permanent installation into electrical equipment due to the combined temperatures and pressure experienced during an arc-flash.

Typically, infrared windows are manufactured from a crystal optic material that allows infrared and visual inspection via the same product. This material choice, if designed and implemented correctly, can withstand an electric arc and provide a measure of protection to the thermographer.

Conversely, thin film polymers can transmit IR in certain wavelengths—although actual transmission is poor—however the polymer itself cannot withstand the temperature and pressure of an electric arc and hence could become a dangerous molten projectile.

The most widely used optic material is that of crystal. A properly coated crystal optic can:
1. Maintain IR camera flexibility
2. Allow visual inspection
3. Enable corona inspection
4. Be arc-resistant

Understanding transmission

Infrared window transmission is a commonly misused term when it comes to obtaining a measurement. Since no material is 100 % transmissive, other factors come into play when attempting to correct for the apparent error.

As any good thermographer knows from training:

Reflection + **A**bsorption + **T**ransmission = 1

A thermographer must think of the window and thermal imager as an integrated system.

A little known fact is that the spectral range of an infrared camera varies from one model to the next. This is down to the individual "Switch-on, Switch-off" parameter of the infrared detector. For example, one longwave camera may have a working spectral response of 8.1 µm to 13.9 µm; the next unit to leave the line may operate at 7.9 µm to 13.5 µm. When this differing spectral response on the detector is mapped against an IR window product, the apparent "transmission" changes as a function of the detector/window relationship.

With a crystal window, this relationship is relatively straightforward to understand as the "route" through the optic is consistent. However, when mesh is introduced into the equation, the relationship becomes more complex still. The route through the combined polymer/mesh optic is confused and inconsistent resulting in a vignette problem (a vignette effect is known to photographers as the way a photograph fades towards its edges—often used for effect, it can be an unintentional result of the optical limitations of the camera's lens). Even obtaining a good image consistently is a challenge when attempting to scan through mesh.

Crystal windows

With a crystal infrared window, the R + A + T = 1 effects are multiplied with respect to the camera by a factor of two.

These additional signals can be simplified and compensated for by making some practical assumptions based on real life applications.

The first point to understand when investigating transmission is that the apparent error in the camera will not always be a negative, i.e. the camera may read LOW or it may read HIGH depending upon contributing factors.

Figure 9 shows an infrared camera scanning through a crystal window at a target. Let us assume that the emissivity of the target is 1. The camera shows a positive error: it is reading higher than the actual target temperature.

Figure 10 shows the same infrared camera scanning through the crystal window at the same target. This time however, the optic temperature is at the ambient temperature of 30 °C

The camera shows a negative error: it is reading lower than the actual target temperature.

At first glance, these two examples seem to indicate that the error associated with electrical inspection via a window cannot be compensated for:

- If the optic temperature is equal to or lower than the target temperature, the camera will read low.
- If the optic temperature is higher than the target temperature, the camera will read high.

However, by thinking in more detail about the application, we can make sensible assumptions that remove the latter.

Since unpowered switchgear is sitting at ambient temperature, the whole of the body and internals—including the window optic—is also at ambient temperature. When the switchgear is energized, current begins to flow through the internal conductors. This increases the temperature of potential targets above that of the original ambient temperature, leaving the casing (and window optic) at ambient.

Since scanning de-energized equipment will not provide meaningful results, it is safe to assume that the outer casing and hence the window optic is at a similar temperature or lower than that of the target.

Combined polymer and mesh windows

With a combination product such as a mesh/polymer optic, the mesh and polymer components have differing absorption and reflection coefficients. In this case, we can never account, in a repeatable manner, for the infrared radiation incident on the detector. The reflected quotient is multiplied many times over because of the mesh and polymer material reflectivity difference.

Another problem with scanning through mesh is the deflection angle. This term describes the inconsistent effect of the mesh with respect to reflected infrared radiation. Similar to the faceted faces used on modern stealth aircraft, combined mesh and polymer optics deflect infrared radiation in different paths that may or may not be detected by an IR camera.

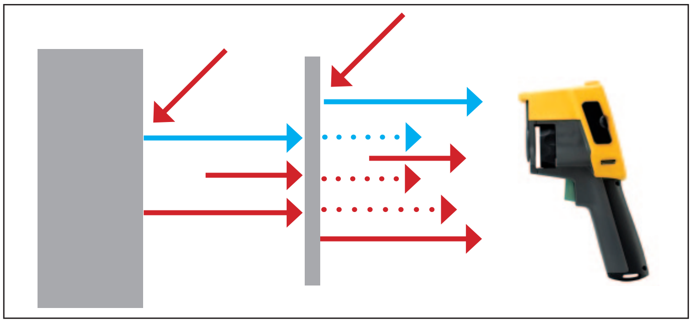

Figure 8. Additional signals resulting from the use of a window.

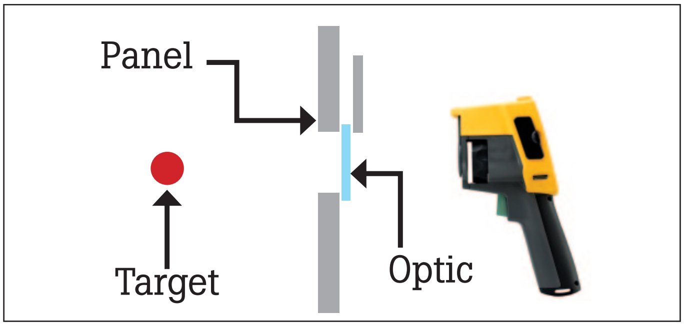

Figure 9. An infrared camera scanning through a crystal window at a target.
Target Temperature = 50 °C (122 °F)
Ambient Temperature = 30 °C (86 °F)
Window Optic Temperature = 60 °C (140 °F)
Indicated Temperature = 55 °C (131 °F)

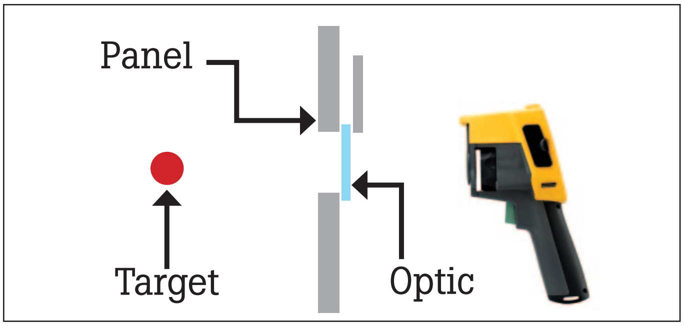

Figure 10. An example of negative error.
Target Temperature = 50 °C (122 °F)
Ambient Temperature = 30 °C (86 °F)
Window Optic Temperature = 30 °C (86 °F)
Indicated Temperature = 45 °C (113 °F)

These confusing effects are increased further when mesh is used on both sides of a polymer optic. The radiation from the target is not transmitted in a repeatable manner through the IR window; instead, the radiation is in part deflected back into the panel and in part transmitted through the first mesh, only to be absorbed by polymer and the remaining energy deflected again by the outer mesh.

The resulting signal registered by the camera may allow a thermographer to locate a hotspot BUT the transmission of the optic cannot be accounted for and modelled repeatably.

Window "Standards and codes"

An infrared window is first and foremost an industrial electrical component: electrical design and testing parameters must be applied.

Within North America, an electrical component must be recognized by a Nationally Recognized Testing Laboratory (NRTL) in order for that component to be acceptable to OSHA. Underwriters Laboratories (UL) are probably the most widely known NRTL although there are others.

UL have standards and codes that apply to differing electrical components and infrared windows are no different. Some of the requirements are material specific whilst others are functionality based.

For example, UL746C is a material standard that must be adhered to if a product destined for use as part of electrical equipment contains polymers. If the product has no polymers used in its construction, then UL746C does not apply.

UL50, by comparison, is a functional test that is denoted by a type number and is harmonized to the NEMA environmental test. In order to obtain a simple UL50 Type 1 (Indoor) certification, a product must show that it is manufactured from components that are non-corrosive. There are no environmental tests such as hose-down or dust applied to type 1 components. If a component is designed for outdoor equipment, it will have a UL50 Type rating higher than Type 1. A typical outdoor rating is Type 3/12. To achieve Type 3/12, a component is subjected to a series of vigorous tests to ensure that the sealing system and general construction are sufficient to maintain the environmental integrity of the component when put into service outdoors.

It is not possible to derive a North American (NEMA) type rating from European (IP) rating. Terms such as "equivalent to IP65" or "self-certified" are often used by other manufacturers whose product cannot pass the more stringent North American environmental testing.

In order to be sure that an IR Window installation does not lower a panel's environmental integrity, the original NEMA classification of the host equipment must be matched or exceeded by the NEMA/UL50 Type classification of the component. Reputable manufacturers will provide third party certification of the type rating of the component, to prove due diligence.

Arc-resistant windows

The strength of crystal infrared window optics has been increased to such an extent that they can withstand the effects of an arc fault.

With the adoption of NFPA 70E and the industry's focus on arc-flash safety, installing a product that can withstand arc-flash should be a primary concern for any end-user.

Finally, some arc flash myths

It is important to separate the truth from the myth:

- "99.99 % of arc-flash events occur with the cover removed".

This statement is untrue: as mentioned earlier, 19 % of failures occur because of component failures with equipment during normal operation.

A simple industry pointer would be the manufacture of arc-resistant switchgear. If arc-flash events only occurred with open covers, there would be no market for arc-resistant switchgear: it is only "arc-resistant" with the covers closed.

It is imperative that an infrared window product is designed to withstand the pressure and temperature of an arc-fault.

Conclusions

An electrical thermographer must work closely with live energized equipment and be aware of the dangers of this environment.

In addition to the obvious hazard of electrocution, workers must be particularly aware of the dangers of arc flash and arc blast events. Up to 77 % of all electrical injuries are caused by arc flash incidents. It is important to remember that NFPA 70E does not protect personnel against the effects of arc blast.

An arc flash is an explosive discharge resulting from a compromise of the insulation between two conductors or a conductor and ground. The event is characterized by its high temperature plasma and this can cause serious burns and other injuries to an unprotected worker several feet from the equipment.

NFPA 70E is the leading internationally recognized safety standard for arc flash prevention and protection. The guidelines recommend a thorough arc flash hazard analysis to establish the nature and magnitude of the hazard, calculate the shock and flash protection boundaries, and identify the appropriate protective clothing and personal protective equipment required for 'Live' work. Warning labels on the equipment must identify the hazard and summarize this information.

The use of windows can limit the exposure of a thermographer to energized equipment, reduce the hazards of both electrocution and arc flash and significantly reduce the need for bulky PPE. It is important that inspection equipment is constructed from suitable arc-resistant materials although there is currently no internationally recognized standard covering their manufacture.

For electrical inspections via a crystal window, the indicated temperature reading on the camera will almost certainly be lower than that of that target. Due to the consistent manner associated with the error, quantitative measurements are possible as long as the camera and crystal window are paired. This is generally a one-time requirement as window transmission is consistent for each model.

Conversely, a mesh/polymer optic cannot be used for quantitative inspection because of inconsistent transmission. This results from the mesh deflection angle and the differing reflectivity of the mesh material and polymer optic material. The thermographer may be able to correct for transmission in a lab using a one-time set of parameters but the poor performance of the mesh/polymer and lack of repeatability means that the this optic solution cannot be corrected for in a manner that is acceptable.

When selecting an IR Window, window or port an end-user must consider the electrical implications of the installation and insist on third party certification to back up any manufacturer claims. Potential mistakes such as installing a Type 1 component into a NEMA 4 panel could cost thousands of dollars in repairs due to leakage and equipment failure.

Finally, an optic material that may melt during an arc flash and cause contact burns could be more hazardous to a thermographer than simply having the panel open for the measurements. A true arc-tested optic should be used in order to demonstrate due diligence.

For more information please visit **www.fluke.com/irwindows** or call 1-800-760-4523.

Further reading

NFPA 70-2008. National Electrical Code.

NFPA 70E-2009. Standard for Electrical Safety in the Workplace.

IEEE Standard. 1584-2002. IEEE Guide for Performing Arc-Flash Hazard Calculations.

CSA Z462. Standard on Workplace Electrical Safety, Canadian Standards Association

"Protecting Miners from Electrical Arcing Injury" James C. Cawley, P.E., and Gerald T. Homce, P.E.; NIOSHTIC-2 No. 20032718, National Institute for Occupational Safety and Health.

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