INFRARED WINDOWS APPLIED IN SWITCHGEAR ASSEMBLIES: TAKING ANOTHER LOOK

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***Abstract* - Maintenance of electrical power distribution assemblies applied in industry has been critical in assuring facility uptime and reliability. One important metric in assuring reliability is electrical terminations of energized conductors. During normal energized service, terminations both at conductor bus joints and at cable terminations are subject over time to thermal expansion and contraction, ultimately resulting in loosened connections and excessive heat. Deteriorating terminations left unchecked will ultimately fail, resulting in electrical hazards for personnel and also costly loss of production. Infrared (IR) inspection has proved to be an excellent maintenance method used to identifying problems with loose electrical terminations. However, the design of Internal Arc Classified (IAC) switchgear assemblies to address arc-flash concerns has changed assembly designs that now limiting line of sight access necessary for IR inspection via windows. This paper will discuss global Standards, how they affect switchgear designs and application of IR windows, then present some alternative technologies that in some applications may be more suitable.**

Index Terms – Thermal Imaging, Infrared Camera, IR Windows, Arc-Resistant Switchgear, Thermal Sensors.

I. INTRODUCTION

Infrared inspection has proved to be an excellent maintenance method used to identifying problems with loose electrical terminations. As shown in Fig. 1, an infrared camera can effectively survey energized systems and provide a thermal image that identifies a potential problem, in this case a loose terminal at the line side of the molded case circuit breaker at Phase A. This method can be used to pinpoint a potential problem and remedy this issue before a hot spot becomes an equipment failure.

Many industrial manufacturing facilities have effectively used infrared scanning of both medium-voltage and low-voltage switchgear and motor control assemblies as a means of predictive maintenance. Thermal imaging for electrical systems will be performed on a rotational basis for the entire facility and maintenance outages are scheduled on an as-needed basis only after an electrical problem has been identified. Some industry standards including IEEE Standard 1458 “Recommended Practice for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications” [1] actually recommends the use of infrared scanning as a means to detect issues such as the

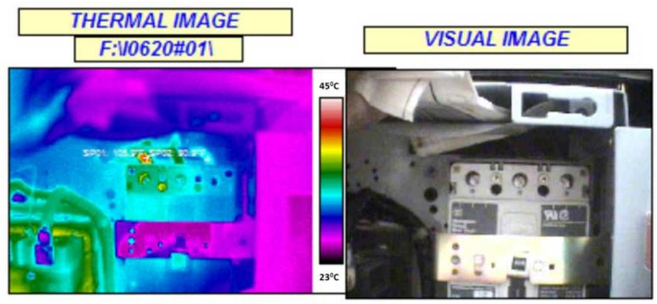

Fig. 1: The thermal image at left shows an elevated temperature and possible loose connection at the Phase A line terminal of the circuit breaker

one illustrated above. Fig. 2 shows a plant thermographer conducting a routine thermal scan using a hand-held camera, in this case inspecting a low-voltage motor control center unit with the door open. This method although effective, can present some risks to the person conducting the infrared (IR) scan. The emerging understanding of arc-flash hazards of energized electrical systems has changed the way maintenance personnel perform IR scanning of electrical systems. New globally accepted and applied standards such as IEEE Standard 1584 “Guide for Performing Arc-Flash Hazard Calculations” [2] now have clearly defined the hazards associated with working on or around energized conductors. Application of this Standard includes calculations that determine the magnitude of incident or potential heat energy should an arc flash event occur.

Fig. 2: Thermographer conducting an IR scan of a low-voltage motor control center unit with the unit door open.

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The thermal energy calculation is performed for each point of the electrical system and this energy is measured in calories per centimeter squared (cal/cm2). A safe working distance referred to as the Flash Protection Boundary is defined and working inside of this calculated distance required that the IR camera operator wear appropriate Personal Protective Equipment (PPE). So referring back to the image in Fig. 2, if the thermographer is standing outside of the Flash Protection Boundary, then conducting the thermal scan is considered a low-risk activity. In higher voltage systems, and low-voltage systems that are becoming ever larger, often times the Flash Protection Boundary is ten meters or more from the energized conductor. Simply opening a door or removing a cover from energized equipment presents a risk to the worker.

II. Review of Infrared Windows

To solve these issues, several manufacturers have introduced IR Windows. As shown in Fig. 3, there are two basic configurations of IR window media, crystal optics and polymer/mesh optics. Crystal optics employs a broadband media which allows thermal infrared inspection. Polymer/mesh IR windows include a metal or plastic grid work this is only suitable for qualitative non-measurement based thermography. Both media are supplied with a protective cover, designed to shield the crystal or polymer/mesh from impact. The two designs offer different performance characteristics in measuring thermal energy via non-contact imaging. Introduction of the window media between the target and the camera introduces some error, as the total energy measured is that which is transmitted and reflected from the target plus the energy emitted from the media itself. This is discussed further in [3].

Fig. 3: Two different types of infrared windows including crystal optic at left and polymer/mesh at right.

Problem solved? Well in many cases, this is in fact a valid approach. As a result, many engineers now specify addition of IR windows as a requirement for both low-voltage and medium-voltage switchgear assemblies. However, there are some technical considerations that need to be reviewed and addressed. In a few instances, evolution of switchgear assemblies tested to the latest Standards may be rendering this “new” IR window approach obsolete.

III. Looking a Little Closer

One recognized limitation of IR windows and periodic thermal scanning is the intermittent nature of his maintenance discipline. Although hot spots at electrical terminations typically change gradually over time, some can elevate to critical levels within just a few weeks or even days. Scheduled thermal imaging using equipment mounted IR windows on an annual basis leaves the facility vulnerable to changes that occur between scheduled IR surveys. Another issue centers on the switchgear assemblies themselves. Changes in global standards for both power distribution and motor control assemblies has resulted in design requirements for both medium-voltage and low-voltage systems that are “arc resistant” rated or tested for arc containment. In North American markets, this typically means the switchgear manufacturer tests to a special American National Standard Institute ANSI C37.20.7 Standard for Arc-Resistant Switchgear [4]. Similarly, for International Electro Technical Commission IEC assemblies markets, this means the assemblies are designed and tested for arc containment, either IEC Standard 62271-200 for medium-voltage switchgear assemblies [5], or IEC Standard 61439-1 [6] coupled with IEC Standard 61641 [7] criteria 1 through 7 for low-voltage assemblies.

Fig. 4 shows the image of these assemblies, medium-voltage switchgear tested to IEC Standard 62271-200, including details on the unique construction. Note from the assembly side view in Fig. 4 that the switchgear design is “compartmentalized” meaning that the low-voltage control section, the breaker compartment, main bus compartment and cable compartment are all separated by steel barriers. This is necessary as the IEC arc containment test standard requires that initiation of an arc in one section while the equipment is energized cannot propagate to another section. The entire

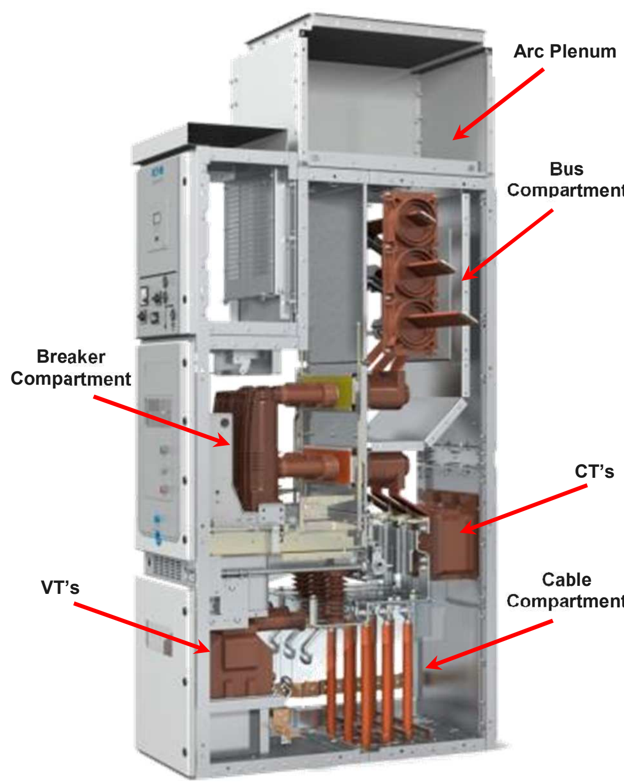

Fig. 4: Typical internal arc classified MV IEC switchgear assembly. Each section is compartmentalized leaving few locations where IR windows could be effectively applied.

assembly is designed to direct the arc-flash blast energy from the compartment where it is initiated up into the arc plenum mounted at the top of the enclosure, above the height of persons near the assembly. With this arc rated design, there are really no reasonable places that an IR window could be mounted in order to inspect live conductors. Perhaps an IR window could be installed in the lower front of this section to inspect the outgoing cable terminations, but in this case, the optional VT drawer restricts the line of sight necessary for inspection with an IR camera leaving no practical way to scan these load cable terminations. A window could also be mounted at the lower rear for visible access to cable terminations, but this assembly is designed to be mounted against the wall. There also is no reasonable place to locate IR windows for visible access to the breaker or main bus compartments. The low-voltage assemblies are similar as are the IEEE/ANSI assemblies applied across North America and arc containment tested to IEEE/ANSI C37.20.7.

Another concern is the integrity of the IR window mounted in an arc rated switchgear assembly. In order to offer switchgear assemblies that are certified and tested to arc rated standard, the manufacturer is required to conduct an arsenal of tests that assure an arc flash event will be successfully redirected away from the enclosure front, rear and sides and channeled to the top-mounted plenum. These tests include initiating an arc flash event in each compartment, resulting in extreme temperatures and pressures. The test standard requires that pressure and heat from the arc be channeled 2 meters above floor level, up and out the top of the enclosure, away from persons standing around the perimeter of the assembly. If IR windows are to be applied in the assembly, it is incumbent on the switchgear manufacturer to conduct arc tests with these mounted on the assembly during the tests. Therefore, it is important when specifying IR windows in switchgear assemblies that the user verifies arc testing has been performed with IR windows installed. Reputable switchgear manufacturers will publish IR window make and model numbers that have successfully passed type testing. Fig. 5 shows the results on one arc test where the crystal optic failed after an arc was initiated in the panel. In this case, the protective cover was closed during the test, but the crystal was shattered due to the extreme pressure and heat.

Fig. 5: IR window failure occurring during an arc test of a MV motor control center incoming line compartment.

One additional consideration is concerning the protective cover for the IR window. The cover is designed to protect the crystal optics or polymer/mesh element and is closed and secured during the switchgear assembly arc testing. Of course, thermal inspection with and infrared camera requires that the cover be removed or opened. Since the arc testing is only conducted with the cover installed, there is really no way to verify that the integrity of the IR window crystal or polymer/mesh will survive an arc event with the cover removed. Following completion of an arc flash hazard assessment, what would the calculated incident energy be at this electrical point in the system with the cover open or removed? What personal protection equipment would the thermographer wear during inspection with the camera to assure safety from an arc flash event?

While taking a closer look at IR window application, let’s also consider some issues around application of IR windows in existing panels. Here, the user must also carefully consider some technical areas of concern. IR windows installed as a retrofit in an existing arc classified or arc tested panel have obviously not been subjected to the testing criteria defined by the standards for that existing panel. Users can install IR windows in existing equipment that will function well as a predictive diagnostic tool for thermal imaging; however this will likely compromise the arc rating of the assembly. In some cases, IR window manufacturers will offer test data to prove the component has “survived” and arc flash event as defined by the test standard. This must be validated to show testing was performed in the specific panel and mounting location where it is proposed to be installed. It is often impossible to prove such testing, unless the IR window supplier has worked directing with the switchgear manufacturer when the defined battery of tests was performed. For assemblies that are not arc resistant or internal arc classified, there is generally not an application problem with IR windows. Test requirements for these assemblies focus on interrupting and withstand ratings that are typically not associated with the enclosure structural integrity during the interruption of an arc fault.

IV. Alternative Technologies in Thermal Imaging

Most certainly, IR windows offer unique advantages in thermal imaging. In an environment where there is increased knowledge and awareness of arc flash hazards, IR windows offer a true advantage in assuring a thermographer is not exposed to energized conductors while conducting a thermal survey. That said, there are some applications where IR windows have limitations and alternatives should be considered.

Most low-voltage motor control center assemblies include multiple starter modules in each panel. The individual modules typically include an incoming overcurrent protective device (fuse or circuit breaker), a motor contactor and protective relay, a control power transformer and other various other electrical components. Each module is separated from the other by steel barriers and includes a front mounted hinged door. Referring to Fig. 2 as an example, a thermal survey of this subassembly requires inspection of line and load power terminations at up to fifteen electrical points (3-phases of the protective device and motor starter line & load, plus 3-phases a the motor load terminals). Although the field of view for IR windows would allow for inspection of multiple terminations using a single window, several windows would be needed for each starter module. It is easy to see due to both space and cost that choosing an IR window here would not be practical. Most industrial users conduct this type of inspection with the unit door open. Depending on the connected system, maintenance personnel may need to wear appropriate PPE while opening the unit door with the circuit energized. However, thermal imaging can be safely performed without PPE if the thermographer is some distance way, outside of a zone referred to as the arc flash protection boundary. In this application, the author recommends additional protection through the use of an upstream incoming circuit breaker with an arc flash reduction maintenance setting [8], similar to would be applied when electricians are performing energized work such as testing or troubleshooting.

Arc rated low-voltage and medium-voltage switchgear assemblies also present a challenge for application of IR windows as discussed in previous sections. The balance of this paper will focus on three alternative thermal measurement technologies which may be better suited, in light of these limitations.

A. Thermal Monitoring via Infrared Sensors

One technology that looks promising which addresses some of the IR window issues for arc rated assemblies discussed previously is a miniature infrared thermal sensor as shown in Fig. 6. Note that this device mounts inside the switchgear assembly and can be positioned within the various compartments, eliminating the line of sight requirement necessary for an infrared camera inspection through an IR window. The sensor can be focused on bus joints and terminations that are likely to present the most problems. A companion thermal monitoring device shown in Fig. 7 is designed specifically for sensing of cable temperature for terminations at terminals, bus bars or circuit breakers. Both devices are self-powered and produce a millivolt output proportional to temperature rise over ambient. The device twisted-pair cable millivolt output signal connects directly to a data card which converts the millivolt signal to Modbus RS485 where the information can be connected to a network. Real-time temperature data can then be monitored from a local personal computer using the manufacturer's standard software or connected to a host supervisory system such as a SCADA or DCS. With the advent of 24 X 7 X 365 monitoring in lieu of periodic scheduled inspection via an infrared camera, temperature data can be trended and system alarms can be set should temperatures exceed pre-set critical levels.

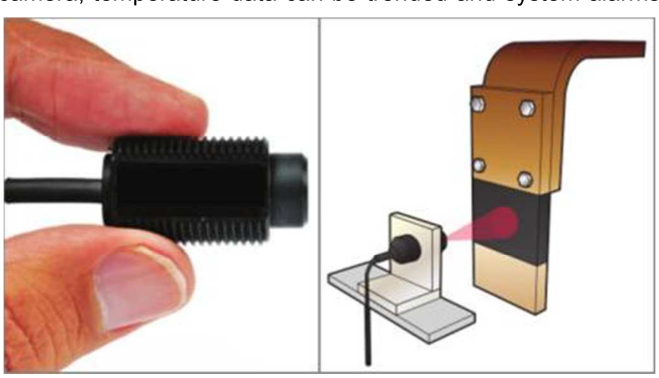

Fig. 6: An infrared non-conductive, non-contact sensor can be mounted inside a switchgear panel offering 24 X 7 thermal monitoring.

These miniature infrared thermal sensors are commercially available and typically are offered at a slightly higher price point than their IR window counterparts. Because the IR sensor component has a very narrow field of view, one sensor is required for each bus connection that is to be thermally interrogated. So, unlike IR windows where one device can often be mounted on an exterior panel in a location where multiple phases are in the field of view, a single IR sensor device is required for each phase conductor. All the same, there are advantages when applied to interrogate temperature of bus joints that are not easily accessible using an external camera to record a thermal image via and IR window. The IR sensor can be mounted virtually anywhere in the assembly and unlike IR windows, it does not require mounting on an external cover so testing as a part of the assembly arc certification is not an issue (albeit the device would likely be destroyed during an arc event that occurred in close proximity).

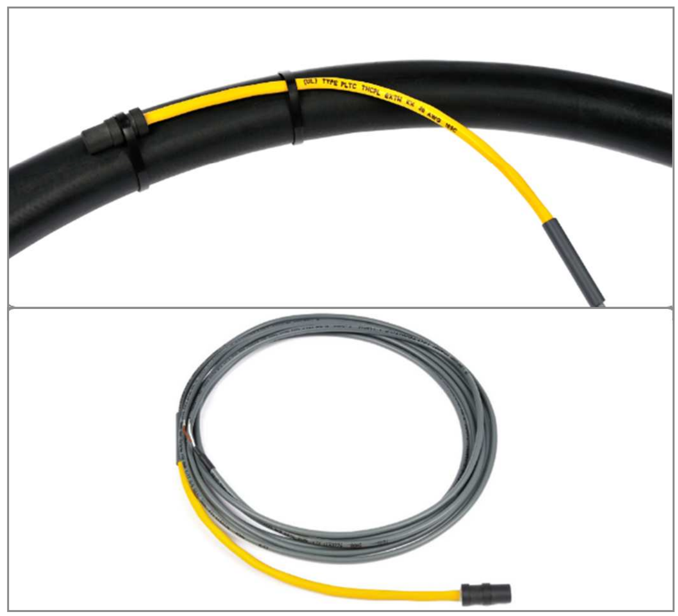

Fig. 7: A sensor with a millivolt output is used for temperature detection of cable terminations.

There are some challenges when applying the IR sensor or cable sensor millivolt devices in existing panels. As previously discussed, assemblies designed and tested to arc classified standards have compartmentalized sections, so adding sensors to areas such as the main bus compartment would be fairly difficult. Installation in new switchgear is a better application; understand again that due to limited access, maintenance or replacement of a failed sensor may prove difficult.

B. Thermal Monitoring via Piezoelectric Acoustic Sensor

Similar to the infrared sensor used to measure the bus temperature, another sensor product that makes contact with the energized bus in switchgear assemblies is also in stages of early development. This sensor detects loose bus joints and loose connections via measuring an acoustic "signature" which occurs as microscopic particles of the bus conductor melt and then cool. Thermal cycling of molten metal delivers a reliable and repeatable acoustic signal that can be measured and continuously monitored. A relatively small piezo acoustic sensor as shown in Fig. 8 can be connected directly to the bus conductor and an Event Time Correlation (ETC) algorithm is used to confirm a bus overheated condition. The non-metallic sensor makes contact with the energized bus at a single location; however the measured acoustic signal is able to travel for some distance away from the sensor. This distance is typically from 5 to 10 feet, dependent on the conductor geometry. At the time of installation a calibration device connected to the switchgear bus determines the required sensor spacing. The on-board electronics in this sensor derives power parasitically from the energized bus based on continuous currents in the range of 100 amperes through 5000 amperes.

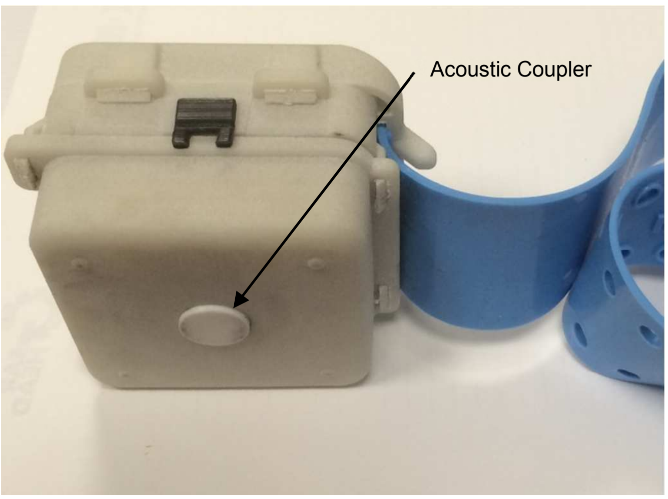

Fig. 8: Piezoelectric Acoustic Sensor with mounting strap and acoustic coupler.

The sensors operate independent of bus voltage and can be applied on any type of bus material including epoxy insulated for both new and existing switchgear installations. A wireless transmitter in each of the sensors communicates status to a central receiver so temperatures across an entire switchgear assembly line-up can be trended over time via any standard industrial network, most typically Modbus Transmission Control Protocol/Internet Protocol (Modbus TCP/IP) or Ethernet Internet Protocol (Ethernet IP). The piezoelectric acoustic sensor would perhaps be a better choice for retrofit in existing switchgear assemblies than the infrared sensor discussed previously. An industrial facility could schedule installation of the sensors during a scheduled rotational outage when the bus covers were removed while the main us bars are inspected. At this time, the wireless receiver would also be installed and communications with each device established before replacing the bus covers. Similar to the infrared non-conductive, non-contact sensor, the advantage using this technology versus IR windows is that real-time bus temperature can be monitored and trended over time, offering a continuous predictive method the identify possible hot spot failures before they occur. The non-metallic sensor is connected or strapped directly to the energized conductor as shown in Fig. 9

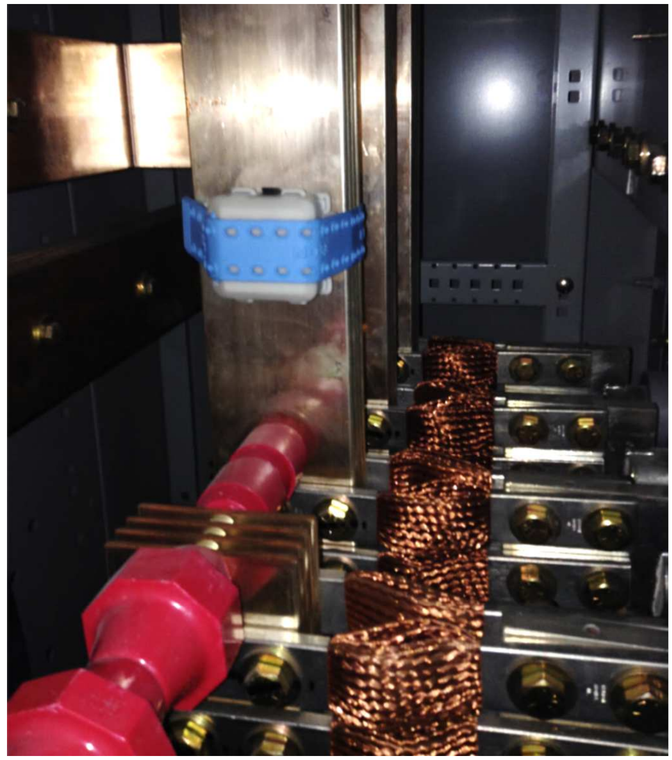

Fig. 9: Acoustic sensor attached to energized bus bar in low-voltage metal-enclosed switchgear.

C. Thermal Monitoring via Conductor Resistance

Recently another thermal detection solution [9] was revealed that also looks to be an alternative to infrared thermal imaging. This approach continuously measures the resistance of the conductors using normal load current. In effect this method converts the conductor itself into an RTD sensor. Using voltage, current and phase angle data collected from a group of metering devices, the per-phase resistance between each metered point is calculated. When a termination or junction (e.g. shipping split splice) degrades, a detectably larger voltage drop develops across that junction. This appears as an increase in that conductor's point-to-point resistance. By trending this calculated per-phase resistance and normalizing to current (since the balance of the conductor itself changes with temperature as a result of current changes), anomalous deviations in phase conductor resistance are detected.

Similar to a differential relay protection scheme where multiple protective devices are sensing voltage and current to protect the distribution system, this method uses metering and other devices such as solid state motor overload protective devices to measure temperature via impedance. Use of a typical 1.0% accuracy class meter offering time stamped voltage, current and phase angle or power factor allows real-time measurement of conductor temperature. It is important to note that application of this approach will most typically include an energy management system and accompanying software to perform the calculations and deliver reliable temperature trending. With the advent of lower cost electronic metering and a drive toward energy management including sub-metering for downstream loads, many new industrial systems will already specify this system capability. Similar to the permanently mounted infrared sensors described above, this method does not require periodic thermal scanning and resolves the issue of locating IR window in metal-clad or arc resistant power distribution assemblies. Both offer a predictive maintenance platform with a capability to trend elevated thermal activity, warning the user to intervene before the measured hot spot results in failure. Fig. 10 shows a simplified single-line diagram illustrating this impedance sensing method.

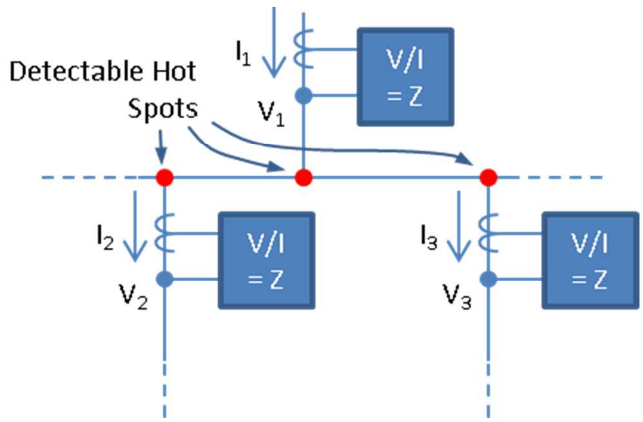

Fig. 10: Measurements of V, I and ϕ at each of these three meters provides sufficient data to detect hot spots on the bus interconnecting these meters.

V. Conclusions

Thermal imaging via infrared cameras and sensors of any type has greatly improved the reliability of electrical power distribution systems around the world. With the advent of an enhanced focus on electrical arc flash hazards, it has become untenable for maintenance personnel to open doors or remove covers to conduct thermal surveys using an infrared camera. Introducing the hazard of exposed energized conductors and the possibility of an arc flash event has ruled out this option in many applications.

Infrared windows are often the best choice for thermal imaging and predictive diagnostics in industry, but there are limitations in some applications. One such limitation is in low-voltage motor control center applications. Often times, individual compartment doors offer limited space for IR windows, as control devices occupy much of the available door area. Because these assemblies typically include many power connections where a thermal survey would be required, it is often a better choice to open the starter module door (after darning appropriate PPE) and then conducting thermal imaging while standing away from the energized conductors, outside of the flash protection boundary. Another limitation involves application in arc rated low-voltage and medium-voltage assemblies. Arc testing as defined by global standards requires that the arc blast pressure and thermal energy be redirected above 2 meters from the panel base. IR windows must be tested in the specific arc rated panel as a part of the standard to assure compliance with the specified standard. Retrofit applications are more problematic as the IR window manufacturer must have test data that proves the device has passed the tests in the specific switchgear already installed. In some cases, other thermal detection technologies available today and/or in the near future offer a better alternative to IR windows. The right solution should be selected based on the application.

The intension of the authors is not to dissuade the use of infrared windows, but instead to provoke thought in consideration of alternative approaches for applications discussed here. In some cases, an IR window is not the best choice. It depends on what you are looking for!

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