Inspecting Electrical Vaults Using Infrared Thermography

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ABSTRACT

Electrical vaults are key to power distribution. They may contain switchgear, transformers, fuses, potential transformers, current transformers, and circuit breakers. Underground vaults are subject to a variety of adverse environmental factors inherent to the location, including flooding, pests, and toxic or explosive gases. Problems in vaults that are allowed to go to failure can pose severe safety hazards and be quite expensive to repair. A component failure can interrupt power to customers for hours and severely damage other equipment in the vault. Repairs may require excavation, and the sound of jackhammers breaking up sidewalks, streets and curbsides is an audible reminder to the neighborhood that the electric utility has a problem. Citizen and power company employee safety is of considerable concern. A failure of an oil-filled transformer bushing or load-break elbow in a vault can cause an explosion and fire. Arc flash of failing components while linemen, electricians or thermographers are working in a vault can be devastating. All these factors compel us to do what we can to protect the equipment and keep it in good repair. Infrared (IR) thermography is a valuable tool for monitoring the condition of vault electrical components, and finding and documenting dangerous and unsafe conditions. This paper discusses IR surveys of vaults and includes infrared thermograms of suspected problems and visual verification photos of actual problem components.

Keywords: Electrical vaults, infrared surveys, infrared thermography, load break elbows, circuit breakers.

INTRODUCTION

Progress Energy has been using infrared thermal imaging for several years. One of the most beneficial areas to inspect has been our transformer vaults. With over 180 vaults, this is a significant task. There are many components in a vault that lend themselves well to IR surveys. The thermographer needs to be well-trained in both direct and indirect infrared measurement, as both types of components exist. Load break elbows are a good example of indirect measurement, with uninsulated bolted plate connections an example of direct.

Routine infrared camera surveys of vaults are crucial to electric system reliability. A service interruption in a vault will not generate headlines like an extensive grid failure, but those important customers whose service is interrupted are just as seriously affected. And the vault is often close to populated areas with high “visibility”.

Vault real estate is dear, and so there is not a lot of room to maneuver in the vault. Safety is of primary concern, as the space is confined and access limited. There is danger of toxic or explosive gases, electrocution, arc flash and fire. All these must be mitigated to the extent possible when performing vault infrared surveys.

VAULT DESIGN

Transformer Vaults are designed to meet Progress Energy's and the customers' needs. The KVA size of the load would be the biggest factor in properly sizing the vault. Transformer KVA determines the
physical size of the transformers which in turn drives the space requirements for transformers, fuses, and switchgear. The next design step is determining the primary feed. The customers’ secondary buss, number of conductors, load and distance from the main switchgear room further drive space requirements. Vaults can have two types of access openings as shown in Figure 1. The most frequent type is a grate section, or a hinged access lid in the covering of the vault. The second is rare, but in some vaults there is a steel door at the same level as the floor of the vault. Other factors are the location, aesthetics, ventilation, and drainage.

![Figure 1. Typical vault entrances.](image)

Vaults are usually below ground level. A pump system is designed to remove ground and rain water from the vaults. These pumps are usually a sump pump design that requires space and regular maintenance to ensure proper working order.

Transformers are sized for the customer’s secondary voltage needs, KVA Load, as well as the primary voltage available. Progress Energy has two main primary voltages (12kv system and a 23kv system). Progress Energy also supplies customers with high voltage by using step down transformers for the requested voltage. In the vaults, the 12kv or 23kv voltage is transformed to a customer requested secondary voltage. Secondary voltage may be delivered to one or more customers from a common vault. Secondary voltage usually ranges from 120 to 600 volts. Early design of vaults used overhead transformers with live primary connections. Over time, these were redesigned to a dead-top bushing well, insulated primary connection. Now when a vault is designed or redesigned a dead-front vault type transformer is installed.

**SAFETY**

Safety is a very important and mandatory action while inspecting vaults. It all starts at the top of the vault. A visual inspection of the covering and entrance of the vault would be the first area inspected. The vaults history should be reviewed to help with the safety as well as the inspection before entering the area of the vault. Once an overview of the vault location has been inspected, we have a job briefing before the vault is opened. Some reasons of concern are entering a new vault for the first time, differences of vault design, changes that may have happened between vault inspections, clearance to energized equipment, ladder design, opening design, proper or improper lighting, gas detection, slippery surfaces, wet surfaces, holes or uneven surfaces, etc. We also do an overview infrared camera inspection to the extent possible prior to entering the vault. A critical problem can preclude entry! Progress Energy safety rules state that a person will be left at the opening for traffic safety, public safety, as well as safety for the personnel entering the vault. This person should never enter the vault for any reason. In the event of an emergency this person’s role would be to call for help. This person may become a victim by entering the vault.
Most vaults are 15 to 20 feet below grade. Ladders are installed for easy access. The air must be tested with an air quality meter before entering a vault as shown in Figure 2. If any toxic or explosive gases are detected, the vault should be flushed with fresh air, and tested again before and while occupying the vault. This is another reason vaults should be properly maintained. When a vault is properly maintained there is a less chance of contamination. Vaults should be inspected regularly to ensure that they are in proper working order.

The importance of making repairs as they are found is to ensure continuity of power delivery, avoiding an unscheduled outage, minimizing repair costs and above all having a safe work environment. When an anomalous condition is found, an inspection report is created. The report includes a visual and infrared image, description of the component and suspected problem and a problem severity level. The latter is based on severity criteria which are different for direct and indirect measurements. All abnormalities should be considered at a higher degree of importance in a vault or any area with difficult accessibility. Repairs can range from a quick fix to a couple of days. An example is a heating load-break elbow with a minor heat problem and repairing it with minimum cost or finding the same elbow with a minor heat problem and not making the repair in a timely manner. A minor heating problem could become a critical problem if not repaired. An un-repaired critical problem can result in a catastrophic failure. A catastrophic failure can result in explosion and fire, causing a transformer failure, unscheduled outage, and multiple opportunities with the damage to other equipment in the vault. A catastrophic failure would likely severely injure or kill anyone in the vault when it happened.

VAULT COMPONENTS

Vaults serve a variety of purposes from electric power distribution line feed-throughs to multiple transformer enclosures. In addition to transformers, equipment inside a vault may includes switches, fuses, pumps, lightning arrestors, fans, and fault indicators. Figure 3 shows a modern 12kv to 480 v transformer with a wall-mounted vacuum switch on the far left and current limiting fuse bank in between. The protective boots on the secondary side of the transformer are removed by properly protected and trained support personnel prior to shooting with an infrared camera. There are numerous connections to survey in a vault. This is a simpler one.
Figure 3. Typical vault with a transformer and associated components.

SEVERITY CRITERIA AND REPORTING

Component severity criteria are based on temperature rise above a normally operating component under the same conditions. Ensuring electrical system reliability is risk management. The risk is the probability of failure times the consequences of the failure. Lucier\(^1\) has proposed a matrix approach to severity using this definition. One side of the matrix is the probability of failure; the other side is the consequences. The higher the consequences of failure, the more critical the component. In a vault pretty much everything falls into the critical category. What we are left with is probability of failure. Temperature rise found using infrared thermography is a key indicator of this probability. Other factors include load, ambient conditions and thermal insulation level. Electrical insulation is also thermal insulation. The temperature rise seen on the surface of an insulated conductor is substantially less than the internal hot spot. The thermal gradient depends on the amount of thermal insulation and how hot the internal problem is. In a load-break elbow, the internal temperature rise can be 6 to 10 times higher than the reading seen by the IR camera on the surface. We call such measurements “indirect”. For a given load condition, the higher the temperature rise, the worse the problem. We have used the load correction software\(^2\) from the Infrared Training Center to estimate how hot a problem will get with increasing load\(^3\). This software also allows us to have a rule-of-thumb when in the field: The temperature rise increases by a factor of 3 when the load is doubled. Temperature rises (delta-T’s) for 200 amp load-break elbows have ranged from 12 \(\text{F}\) to 72 \(\text{F}\) without showing external signs of failure. When a load-break elbow is found with an elevated degree of heating, it is recommended in the report that a “Do Not Operate” tag be attached. This load-break
equipment still may be operated until it is de-energized, but should not be operated as load breaking equipment. When this equipment is found with a severity criteria of "serious", load breaking components are damaged and therefore should not be operated and will not break the load safely.

![Image](progress_energy.png)

**Figure 4.** Sample IR Report showing problem insert bushing on an SF$_6$ fuse.

The Progress Energy thermographer generates a written report using FLIR Systems Reporter software that includes an infrared and visual image together with enough information for lineman to find and repair the problem as shown in Figure 4. Severity is estimated and action recommended. The loop is only closed when the problem has been fixed and the thermographer has returned to verify the temperature has returned to normal operating levels. The report format used by Progress Energy highlights the delta $T$. Progress Energy thermographers use the max temperature in the area to get the hot spot. This is a great time saving technique, as you don't have to chase the hot spot with the spot cursor. The software does it for you. It also improves reporting accuracy as the computer is usually better at this than the thermographer. The spot mode is used to ensure the measured target is large enough for the infrared
camera optics and working distance. It is often not shown on the report as it can cover up thermal details. The area mode leaves room for viewing the thermal patterns in the hot spot.

For vaults, postponing repair of even a minor problem can create a major time and expense. If the problem is not properly monitored and evaluated, the problem will start to grow. When the variables are not properly managed, the opportunity will manage itself by evolving into a high level of concern. As a problem starts to grow, the opportunity of a catastrophic failure grows as well. An hour scheduled outage is far better than the unscheduled catastrophic failure. The scheduled outage is less minutes out, less expense, less time to repair, less customer inconvenience, and less of a safety concern, less, less, and less. When a problem found by infrared is not properly evaluated and repairs performed, it could escalate into a major problem. Safety First!

VAULT IR SURVEY EXAMPLES

Figure 5 shows a load break elbow with a thermal anomaly on the insert bushing taken with a FLIR Systems PM695 infrared camera. This bushing is the feed-through to the oil-filled transformer. It is well insulated and thermally connected to a large thermal mass. So a surface temperature rise of over 64 °F means the internal temperature is quite high. An indirect target, this problem has an internal temperature somewhere between 440 °F and 740 °F. Mineral oil flash-points range from 305 °F to 370 °F. This is a critical problem, “freeze and leave” situation. Repair ASAP.

Figure 5. Load break elbow showing a 64 °F temperature rise.

Figure 6 is a visual photo of this load break elbow after removing from service. It is badly damaged. The thermographer made a good call on this one.
INFRARED SURVEY SCHEDULING

Progress Energy schedules inspections for two significant load seasons, winter and summer. One is scheduled for the winter load, the other for the summer load. One of the challenges of infrared surveys is to perform the work when the equipment is under significant load, then to get a scheduled outage to do the necessary repairs. The two are often incompatible time wise. Seasonal scheduling is but one of the challenges. Inspection time of day is another. The thermographer must consider vault accessibility and load. In downtown areas, accessibility may be limited during normal working or retail hours. But after hours, the load may not be enough to do a good IR survey. Vault access can also be a challenge, as the vault must be secured from entrance by non-authorized personnel. Sometimes they are secured so well not even authorized personnel can gain access without significant effort. Some lids and external entrances can be locked from the inside with bars and deadbolts. Some have been found welded closed.

It is very important to get "The Big Picture" before entering. After the visual inspection is preformed, use your infrared camera to gain a second opinion before entering a vault. To the extent possible from outside the vault, look for exceptionally hot spots prior to entry. Figure 7 gives an example.
Figure 7. This problem was found prior to entering the vault.

For security reasons, time is a factor. Time to gain access is one part of the equation and time to perform the vault infrared inspection the other. After entering the vault, a visual inspection is performed to ensure proper footing, and to get an overview of any safety concerns that may lie in your path.

**SUMMARY**

Vaults present some unique challenges for the infrared thermographer. The components must function in a rough environment that includes large ambient temperature changes, moisture and flooding, dirt and debris, and pests. Often the equipment is aging and hasn’t been looked at for years. This combined with the austere environment make vaults “low hanging fruit” for IR surveys, at least in the onset of an infrared program. As equipment gets repaired and upgraded, the number of finds will decrease over time. This doesn’t mean we can cut back on IR surveys, as such a reduction would mean an eventual unacceptable increase in problems.
Vaults are confined spaces that must be entered only after gas analysis, visual inspection and preliminary infrared inspection from the outside. Safety procedures must be well thought out and strictly followed. There are numerous indirect targets in vaults including load break elbows, fuse holders, or any insulated cable or connection. The thermographer must be aware of the very different severity levels indicated by indirect targets as opposed to directly viewed targets. Just about everything in a vault is critical equipment. The temperature rise is a good indicator of severity level provided comparisons are made under similar load conditions. System reliability doesn’t stop at the end of the transmission line, substation, distribution line or vault. System reliability means the customer’s electrical equipment works when the switch is thrown. Electrical vaults are an important element of a good infrared thermography program.

REFERENCES


2) Madding, Robert P.; Infrared Training Center IR Utilities CD; Load Correction Excel® Spreadsheet Software.