Substation inspection guidelines

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ABSTRACT

We need to better understand what our infrared camera is really showing us. Without guidelines, we may not understand how serious a "ΔT" may be. At TVA, we have established "ΔT" limits to guide us in our substation thermographic surveys.

This paper deals with problems in a Power Utility's substation. It describes a wide variety of equipment with different temperature limits for designating findings as "intermediate", "serious", or "critical" problems.

These designations help us set priorities for maintenance and relate directly to cost, reliability and safety.

Keywords: predictive maintenance, substation limits, small detail

1. INTRODUCTION

For many years Tennessee Valley Authority (TVA) has performed substation inspections. The use of infrared began in the late 1980s. By 1991, we had four infrared cameras for substation use. The most value was thought to be in finding hot disconnect switches. In 1991 we had a bushing fail violently. This caused us to dig through old test records. An infrared report showed an image of a hot bushing connection. We did not have any guidelines at the time telling what was a problem and what was normal. From that point, the infrared reports got much more attention.

2. SUBSTATION PdM PROGRAM DEVELOPMENT

Early in 1993 we purchased our first Focal Plan Array infrared camera. This allowed us to have a much sharper image. Later that year TVA's Transmission Support and Technology Advancement departments teamed up with the EPRI M&D Center to start a Substation Predictive Maintenance Program. It seemed we had the equipment, but we were missing two key elements of communication and documentation. We started with an entrance meeting before a substation survey. This allowed the people doing the inspection to get a closer look at known areas of concern. After the substation survey, an exit meeting was held to discuss the problems found and help decide what work needed scheduled. We started communicating across TVA on problems and looking at small detail. The motto became: "Watch Small Detail - Avoid Big Mistakes".

In 1998 the TVA Transmission Support Department started the Level 2 Inspection (L2i) program as a pilot. Seven teams were selected. Each team was composed of an electrician from the maintenance side and an engineer from the test side. This turned out to be a great idea, the whole being greater than the sum of the parts. In six months 106 inspections took place, with $4.3 million avoided costs. Biweekly telecons helped promote findings of smaller detail and teamwork. Now TVA has 18 teams to cover the system. Each substation is on a yearly L2i inspection schedule.

2. EXAMPLES OF FINDINGS AND ESTIMATED COST AVOIDANCES

There are two ways to look at an infrared image: Qualitative and Quantitative.

1. Qualitative: The following examples are qualitative images in which the actual temperatures are not as significant as the relative temperatures of similar targets for purposes of comparison:

Image only

- Compare images of all three phases
- Image profile across the apparatus
- Similar devices with similar conditions

Note: Direct vs. Indirect Images:

- Direct view of a current carrying connection is when the current carrying connection is directly viewable.
- Indirect view of a current carrying connection is when the current carrying connection is not directly viewable but covered in some way. One example would be a connection inside an oil circuit breaker. This connection is immersed in a tank of oil.

The thermograms of Fig. 1 illustrate the different thermal appearance of two oil-filled transformers. The transformer on the left is filled adequately. The transformer on the left has a low oil level. Fig. 2 is another example of normal oil level.

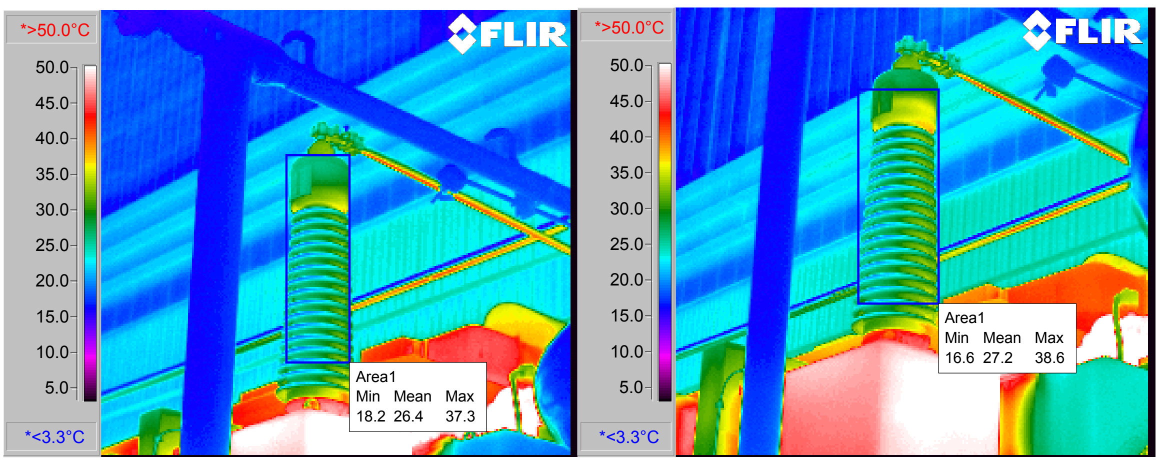

Figure 1 Transformer with low oil level (left) compared to a similar transformer with normal oil level (right)

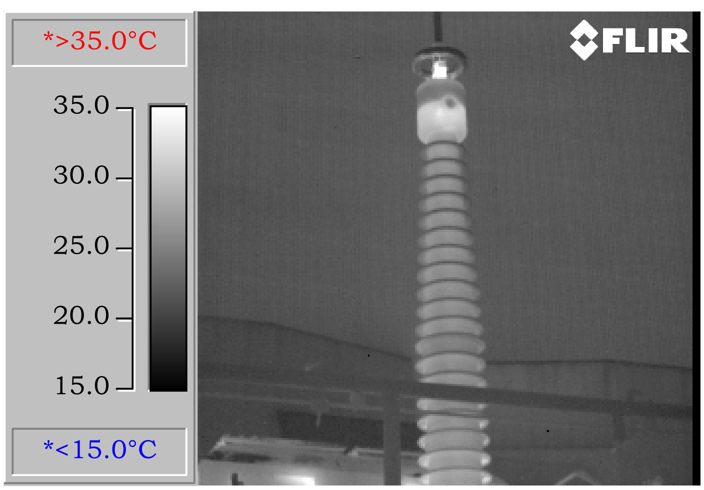

Figure 2 A different transformer with normal oil level in the bushing

Avoided Cost estimates for this type of finding are:

- Low Oil -- $1,000
- Pegged Low (oil gauge reading below scale) -- $2,000

The thermogram of Fig. 3 shows a radiator section at the left that was closed-off at the valve and appears substantially cooler than the other sections.

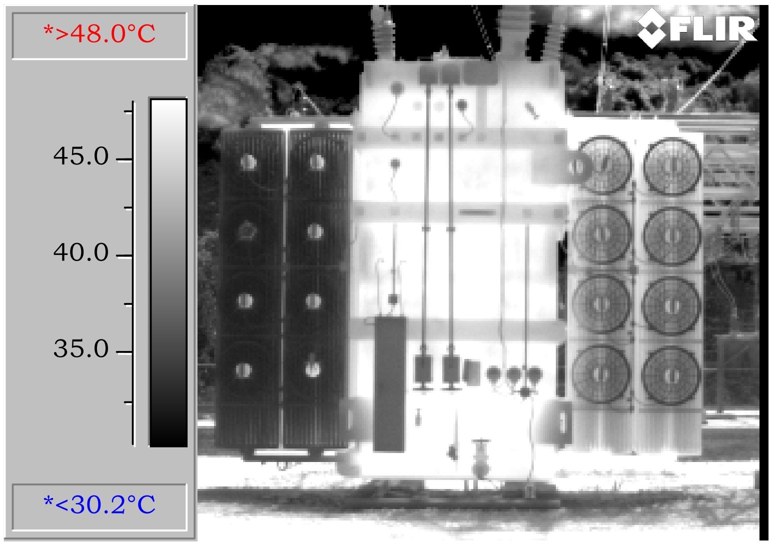

Figure 3 Radiator section at the left appears substantially cooler than the other sections

Another example of inadequate cooling is illustrated in Fig. 4. Here the cooling pump on the right is not running and appears substantially cooler than the adjacent pump.

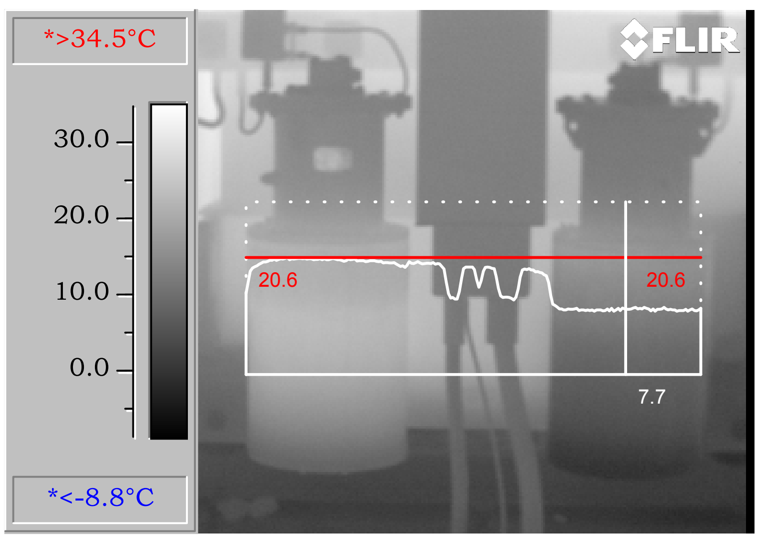

Figure 4 Pump on the right, not operating, appears cooler than the other pump

Avoided Cost estimates for this type of finding are:

- 10% -- 25% cooling not functioning -- $1,000
- 25% -- 50% cooling not functioning -- $2,000
- > 50% cooling not functioning -- $3,000

(The % cooling not functioning equals the number of radiators or pumps not running or blocked off divided by the total number of pumps.)

2. Quantitative: The following examples are quantitative images in which the actual measured temperatures are significant:

Image with temperature measurements

- Compare Temperature of all three phases
- Temperature profile across the apparatus
- Similar devices with similar conditions

The metal to metal connection illustrated in Fig.5 (left) is a connection from a wave trap (large inductor) to the 500 kV bus. The thermogram (right) shows extreme overheating at the connection

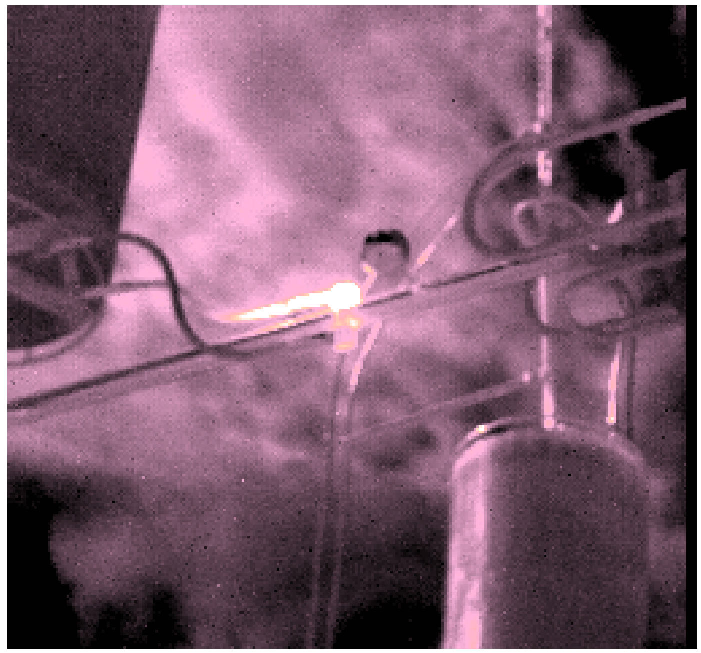

Figure 5 Photograph (left) and thermogram (right) of a severely overheated metal-to-metal connection

The avoided cost estimates for this type of finding depend on the severity rating which is, in turn, dependent on the measured temperature rise as follows:

Severity Rating	Avoided Cost
Critical -- > 75° C rise	$ 5,000
Serious -- 35° C to 75° C rise	$ 2,000
Intermediate --> 10° C to 35° C rise	$ 1,250

Definitions of Severity Rating Limits

Critical -- Immediate investigation with the possibility of removing the equipment from service depending upon the investigation

Serious -- Investigate as soon a possible and increase the frequency of scanning, depending upon the investigation

Intermediate -- Trend at regular scanning frequency

Any discrepancy in a Fossil or Hydro switchyard causes the avoided cost to be multiplied by 4 due the cost of replacing generation and possible damage to the generator itself. Any discrepancy in a Nuclear Switchyard causes the avoided cost to be multiplied by 8 due to the extra reports and procedures needed if we lost a piece of equipment.

Fig. 6 is a thermogram of an overheated bushing cap (center, left) with a maximum measured temperature exceeding 65°C.

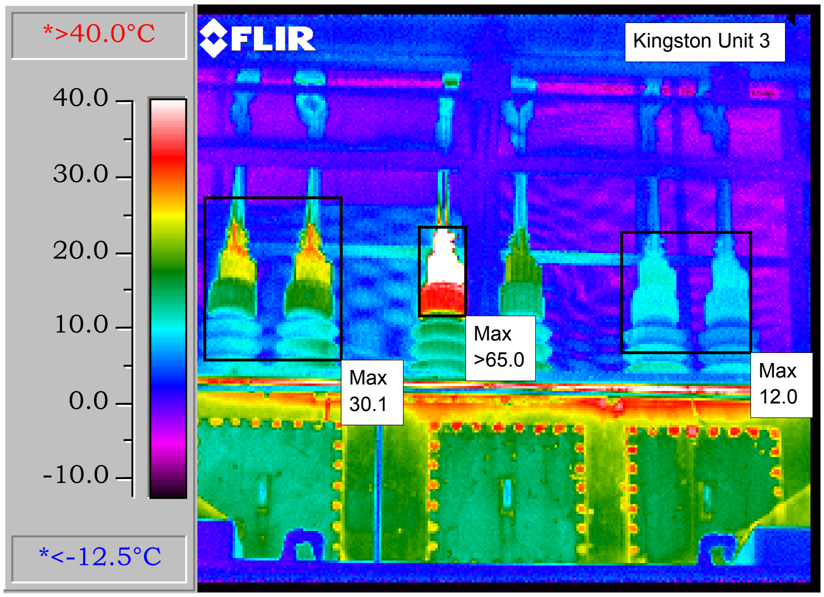

Figure 6. Overheated bushing cap at left center with a measured temperature rise of 43°C.

The avoided cost estimates for this type of finding depend, again, on the severity rating as follows:

Severity Rating	Avoided Cost
Critical -- > 35° C rise	$ 20,000
Serious -- 10° C to 35 C rise	$ 10,000

The overheated live tank breaker head shown to the right side of Fig.7 shows a rise of just over 10°C compared with the other side. Avoided cost estimates for this type of finding are shown below.

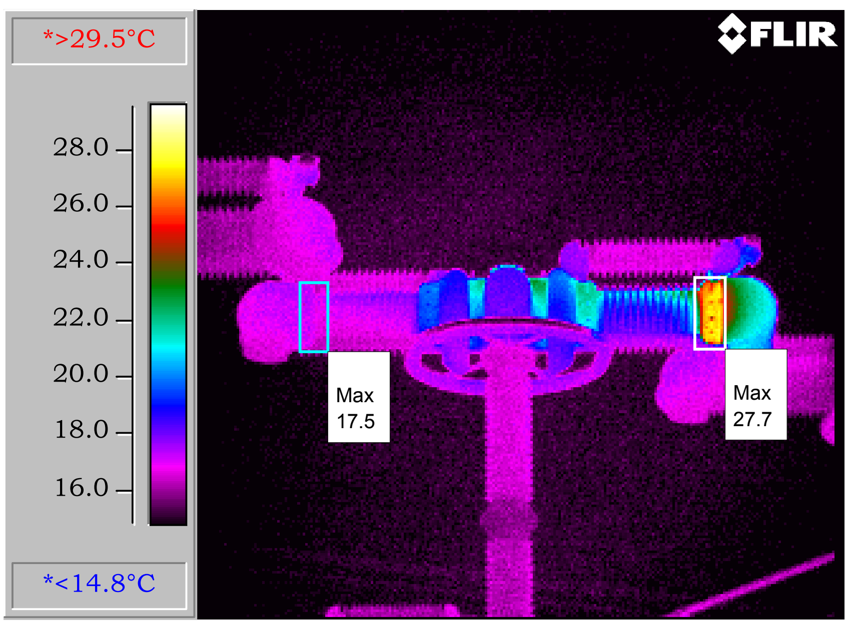

Figure 7. The temperature is 10°C higher on the air blast circuit breaker head (right side).

Severity Rating	Avoided Cost
Critical -- > 35° C rise	$ 20,000
Serious -- 10° C to 35° C rise	$ 10,000

The overheated coupling capacitor illustrated in the thermogram of Fig. 8 shows a serious, but not critical severity rating by the criteria shown below. The avoided cost estimates are again dependent on the severity criteria.

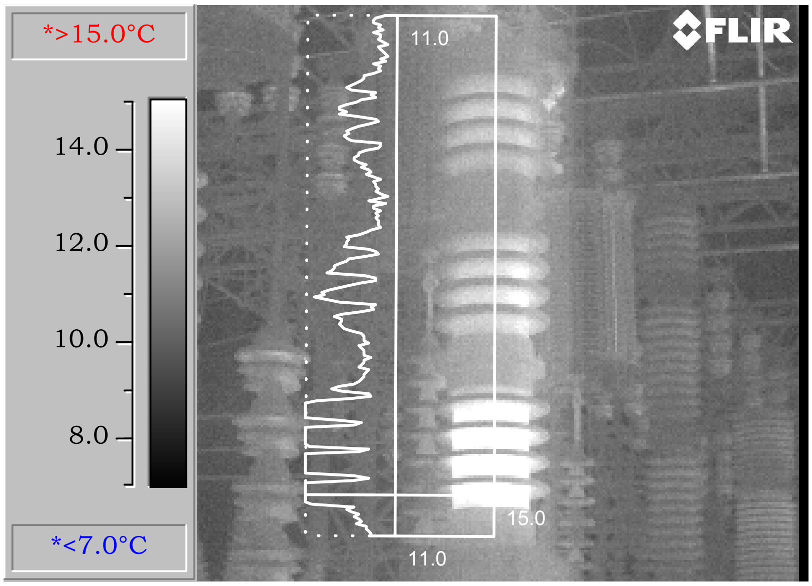

Figure 8. Overheated coupling capacitor exhibits a temperature rise of about 4°C.

Severity Rating	Avoided Cost
Critical -- > 7° C rise	$ 5,000
Serious -- 2° C to 7° C rise	$ 2,000

Fig. 9 shows overheated PK studs (left thermogram) and Osc blocks (right thermogram). These are break points for control voltage and currents to relays or other instrumentation. The avoided cost estimates are again shown below.

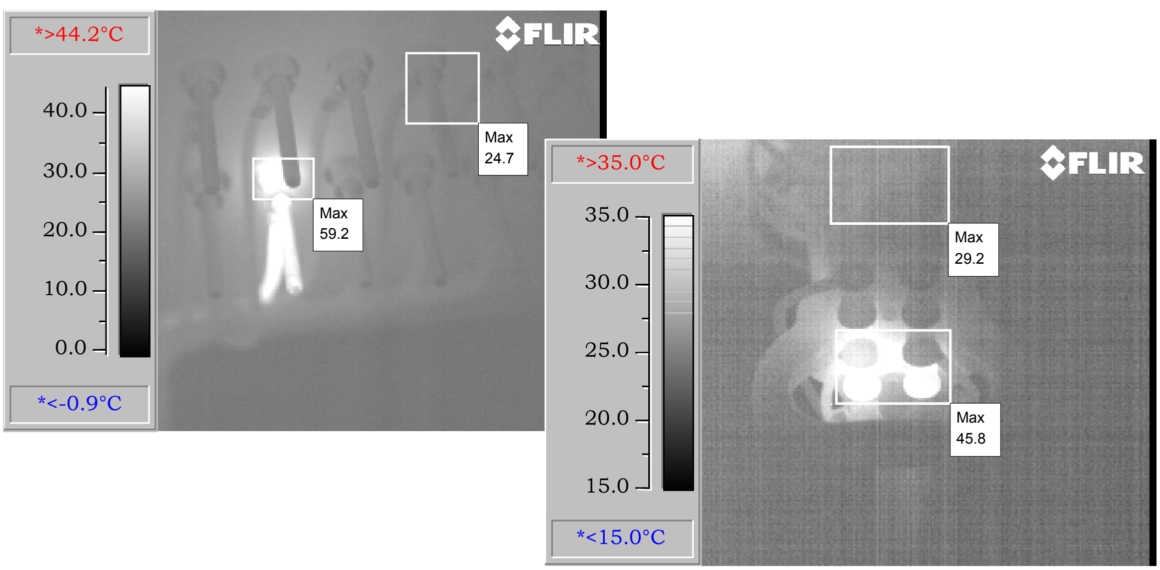

Fig. 9 Overheated PK studs (left thermogram) and Osc blocks (right thermogram)

Rating	Avoided Cost
Critical -- > 10° C rise	$ 5,000
Serious -- 5° C to 10° C rise	$ 2,000

Overheated fuses shown in the thermogram of Fig. 10 appear at the left and center of the thermogram. According to the criteria shown below for this type of finding, one finding is "serious' (center) and the other is "critical" (left).

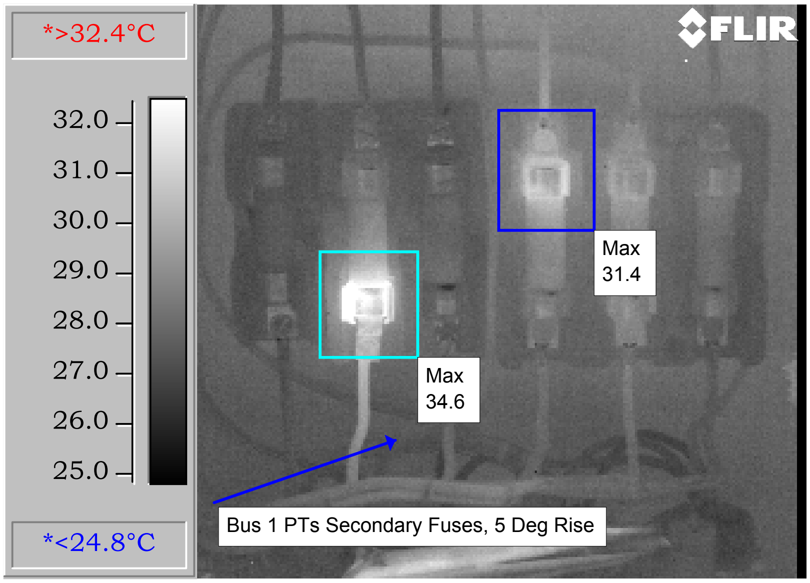

Fig. 10 Overheated fuses at left (critical) and center (severe)

Severity Rating	Avoided Cost
Critical -- > 5° C rise	$ 5,000
Serious -- 2° C to 5° C rise	$ 2,000

Two examples of overheated potential transformers are shown in the thermograms of Fig. 11.

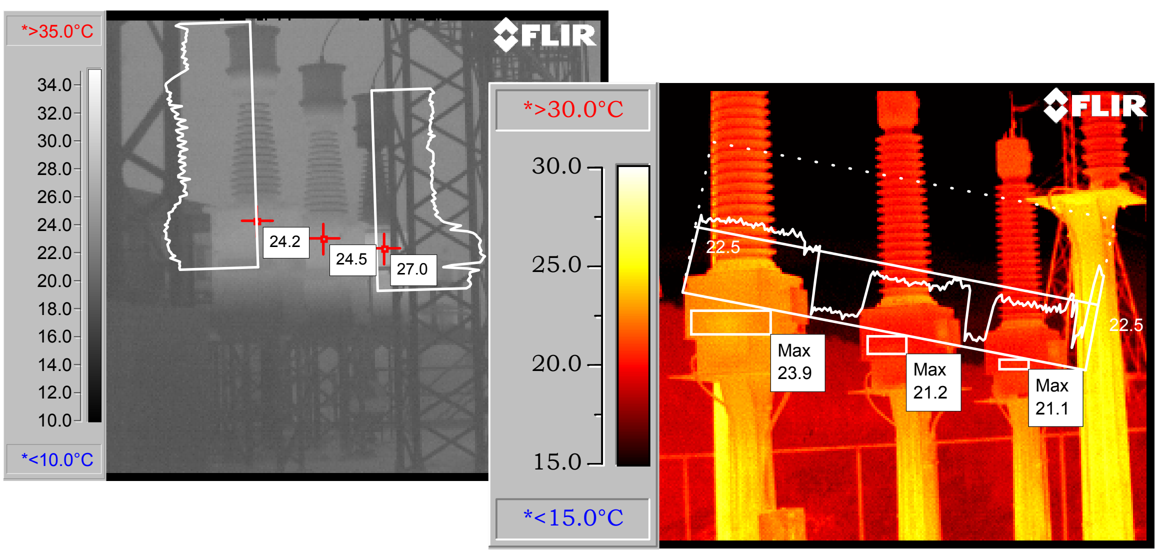

Figure 11. Two examples of overheated potential transformers

Here relatively small temperature rises can result in great expense if left uncorrected as shown below.

Severity Rating	Avoided Cost
Critical -- > 5° C rise	$ 5,000
Serious -- 2° C to 5° C rise	$ 2,000

The lightning arrestor depicted in the thermogram of Fig. 12 is considered critical since its measured temperature exceeds a rise of 10°C. Severity ratings and corresponding avoided cost estimates are shown below.

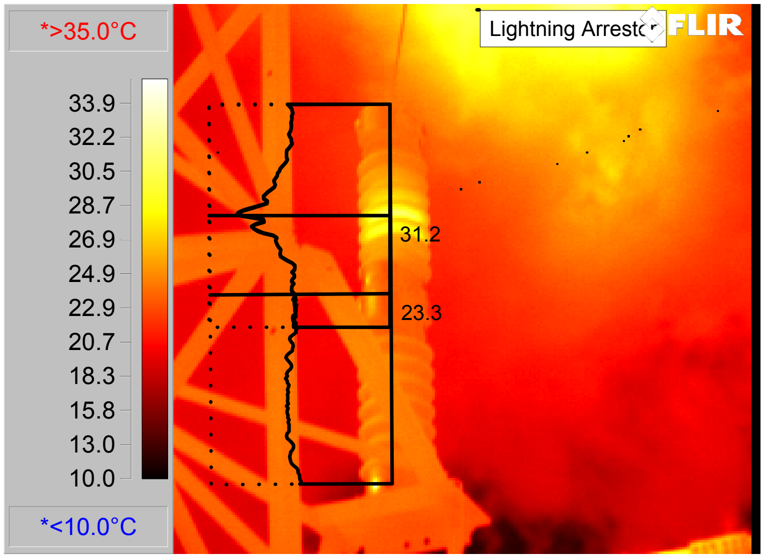

Figure 12. Overheated lightning arrestor is rated as "critical"

Severity Rating	Avoided Cost
Critical -- > 10° C rise	$ 5,000
Serious – 5° C to 10° C rise	$ 2,000

The warm breaker tank depicted to the left of the thermogram of Fig. 13 can also be considered as a "critical" finding, since the measured surface temperature is about 10°C warmer than the adjacent breaker tank. The cost avoidance estimates are shown below.

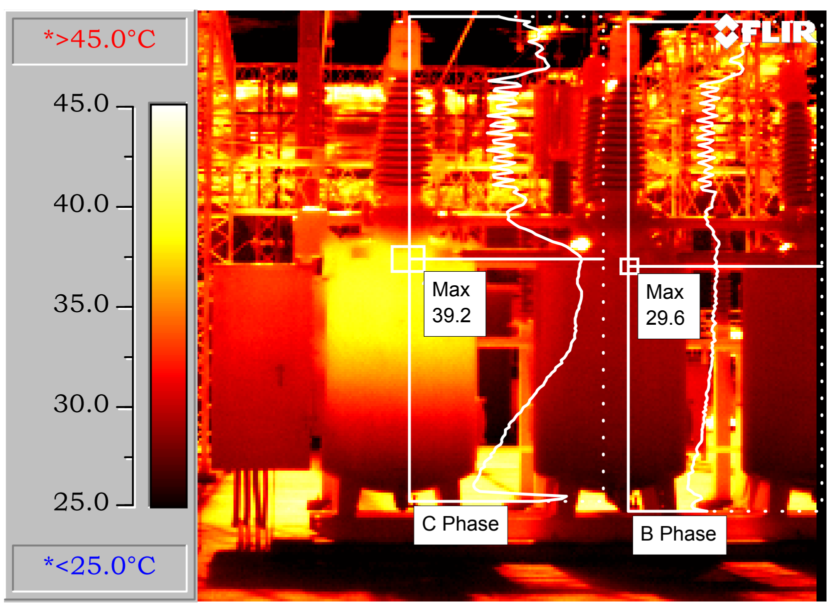

Figure 13. Overheated breaker tank is more than 10°C warmer than its neighbor and is rated as "critical"

Severity Rating	voided Cost
Critical -- > 10° C rise	$ 20,000
Serious – 5° C to 10° C rise	$ 10,000

Cool spots on breaker tanks can also be indicative of failure mechanism. In the thermograms of Fig. 14, for example, Breakers 924 (left thermogram) and 928 (right thermogram) were in parallel from a 700 MW unit. Note that 924 C-phase is carrying all of the current. Breaker 928 C-phase was open and showed cool. This was verified by reading the current in the current transformers. Had the hot breaker been switched, as one may first think, the generator would have tripped off line and possibly caused 928 C-phase to fail.

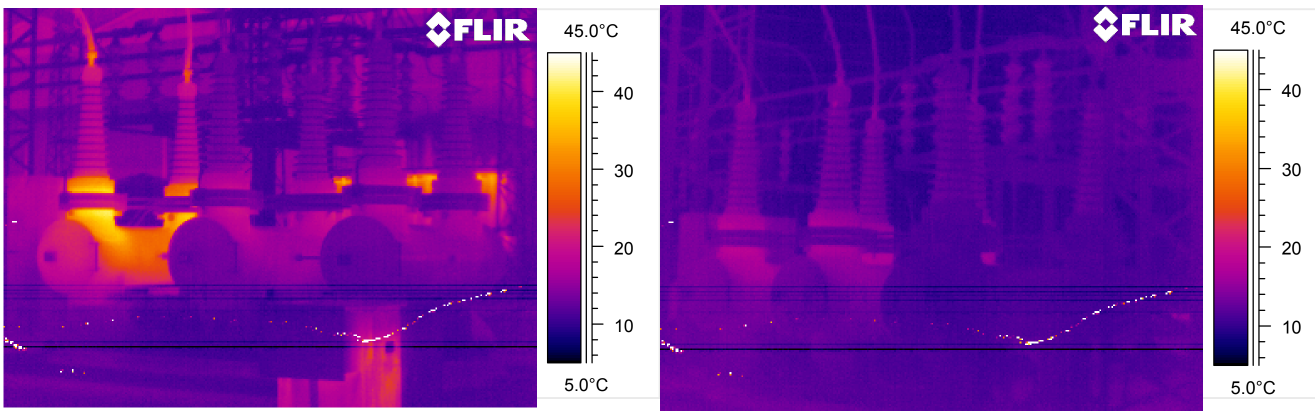

Figure 14. 20° C rise on 924 C phase breaker tank (left) is matched by a 5° C drop on 928 C-phase (right)

Avoided cost estimates for breaker tanks are as follows:

Severity Rating	Avoided Cost
Critical -- > 10 C rise	$ 20,000
Serious -- 5 C to 10 C rise	$ 10,000

3. CONCLUSION AND SUMMARY

From our past experience and through root cause analysis, we have developed a set of temperature rise guidelines for infrared inspections. This list continues to grow and evolve as more root cause and corrective maintenance activities are performed. Also, the avoided cost figures we use are refined and updated by virtue of our contacts with EPRI M&D Center and through our own continuing experience.