Substation Equipment (Bushings)

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ABSTRACT

Bushings provide a point of interface such that electrical current can pass to and from an electrical apparatus. Much like bridges on the highway, they are very critical and the weakest link. The integrate design and high areas of stress makes monitoring a vital part of any maintenance program.

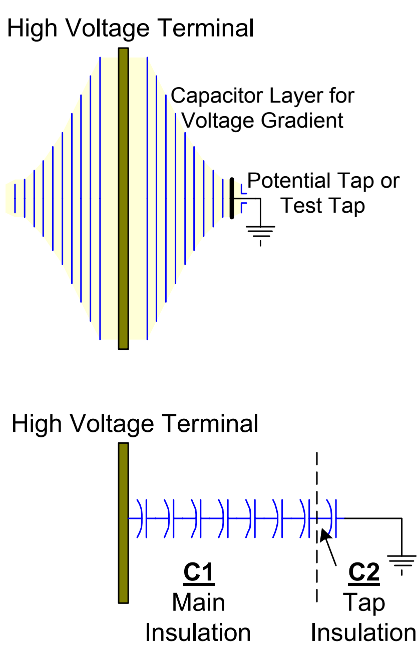
This paper discusses how to use infrared to examine such critical pieces of electrical equipment. It also describes the two key elements of stress on the bushings. By knowing the key elements, temperature limits and profiles, a maintenance program can be established.

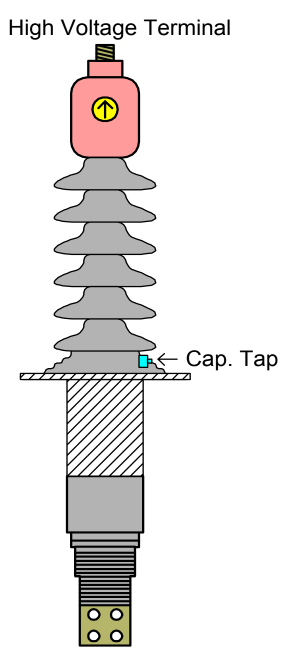
After reading this paper, one will see how a good bushing monitoring program should include infrared as one of the key elements.

Keywords: bushings, electrical equipment, predictive maintenance, temperature limits, temperature profiles

1. INTRODUCTION: WHAT IS A HIGH VOLTAGE BUSHING

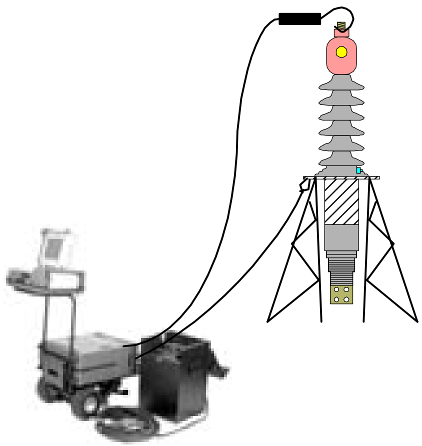
Bushings provide a point of interface such that electrical current can pass to and from an electrical apparatus. The current is at some potential above ground and must be electrically insulated from the tank walls which are at ground potential. It can be thought of like a bridge where the potential is the length of the bridge and longer the bridge the more support it must have such that it will not come in contact with the ground. The current path is the number of lanes. If the number of lanes are reduced on part of the bridge under heavy traffic flow, a multi-car pile up will occur. The two key factors are: 1) Insulating System - to prevent a failure mode of over voltage. 2) Conductor Path - to prevent a failure mode of over current. Over voltage will cause a flash over in the insulation and over current will cause overheating in the conductor due to I^2 R losses.





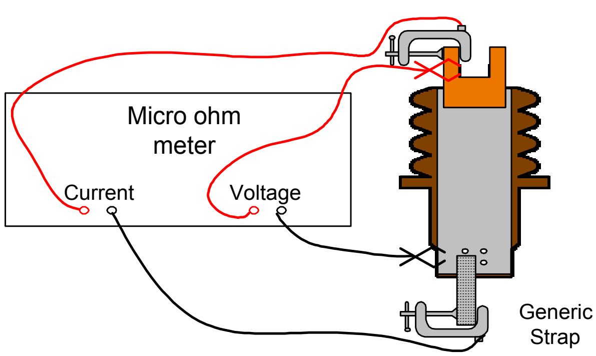
Inside Pictorial **Outside Pictorial**

How does the bushing withstand the voltage stresses? The bushing must contain many layers of capacitors to grade the voltage down evenly from the potential at the center conductor to ground potential. These capacitors are made up of many layers of paper and foil and usually filled with an insulating fluid such as oil. The main insulation system is known as the C1 insulation and the last few layers near ground is known as the C2 insulation. The Tap Electrode is at the junction point between C1 and C2. The tap electrode is referred to as the "Potential Tap" or "Test Tap." These layers of insulation can be checked by measuring the powerfactor of the bushing when the parent apparatus is out of service or when a bushing is sitting in a bushing stand. While the parent apparatus is in service, an infrared camera can be used to check for low oil levels. The oil level relates to the insulation quality of the grading capacitors. Infrared method will only work when the parent apparatus produces heat because it relies on the thermal mass difference between the fluid and the void at the top of the bushing. Bushings in transformers are ideal examples due to the heat produced by the losses in the windings and core.



Powerfactor testing of a Bushing which checks the insulation integrity

How does the bushing withstand the current stresses? The bushing must have a conductor in the middle of the insulating jacket that is sufficient to carry the rated current of the parent apparatus. This core is usually made of Copper or Aluminum. Sometimes this conductor is not a solid piece, but may consist of a cap adapter, a multi-piece stem, and/or bottom bolted connector, depending on the design. Loose or deteriorated connections can be checked with Micro-ohm test set when the parent apparatus is out of service. An infrared camera can be used when the parent apparatus is in service if the problem is in the bushing cap or in an external connection. Bottom connection problems will not usually show up using infrared, but is better found using dissolved gas-in-oil analysis.



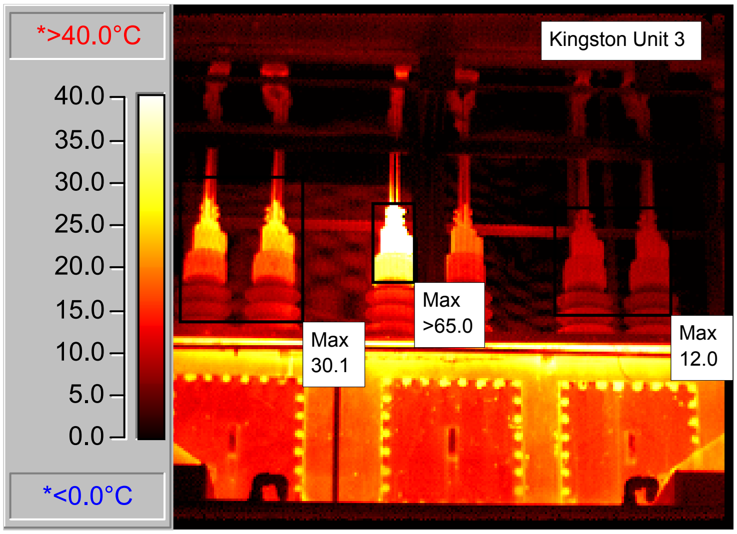
Micro-ohm testing of a Bushing which checks the conductor integrity

2. TESTING WHILE IN SERVICE

Infrared is a great tool because it allows for equipment to be viewed under operating conditions and at any frequency desired. One item to note is the fact that the apparatus should be running at least 50% of normal load for meaningful results.

Connection problem example:

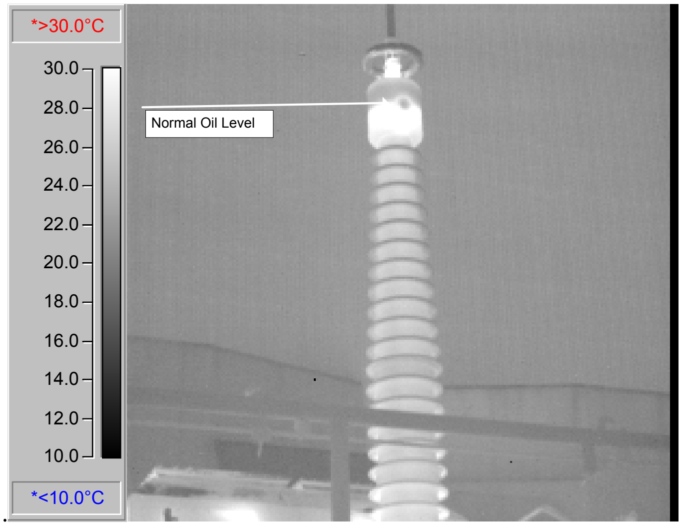
Generator Step-Up Transformer:



During an infrared scan it was noted that three bushing caps were hot. Bushings caps are rated critical if greater than 35 C rise over another bushing under like conditions. Bushing caps are rated serious if the rise is greater than a 10 C. One had a temperature rise of greater than 53C, which put it in the critical category. An investigation found that aluminum bolts were used instead of stainless steel. Over time the connection became loose, thus creating an overheating condition.

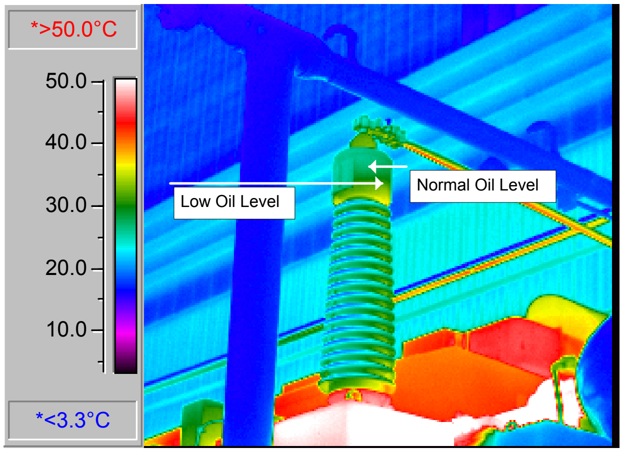
Low oil Level Examples:

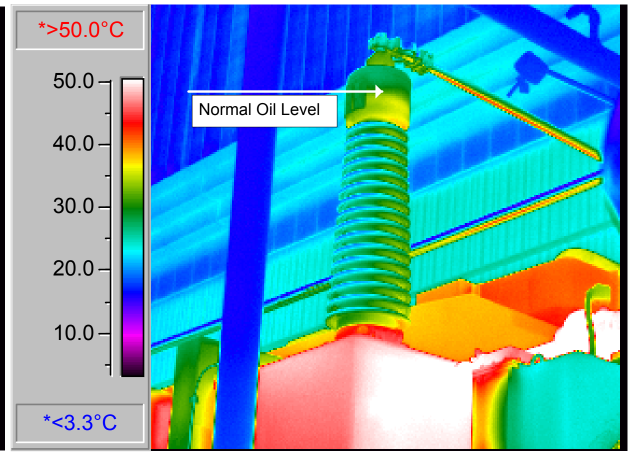
Generator Step-Up Transformer:



Oil level can be detected on transformer bushings because the windings produces a heat source that heats the oil in the main tank and the bushings. The bushings have an oil expansion chamber at the top. Since the oil has a higher thermal mass than the void, the expansion chamber temperature profile shows the oil level. This is then checked to see if this matches the gauge or site glass.

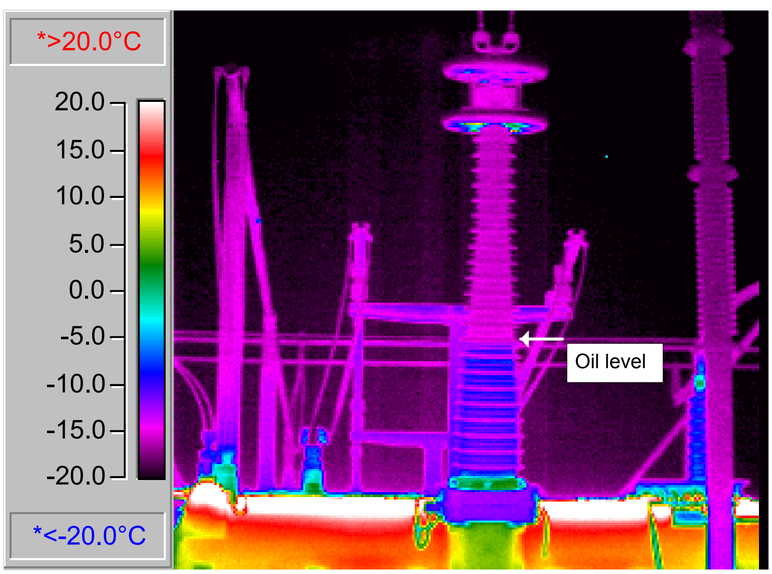
Generator Step-Up Transformer:





The generator step-up transformers had an oil sheen coming down the side of the transformer. All oil levels looked normal, including the oil level in sight glass of the bushing above the oil sheen. An infrared camera was used to look for low oil levels. It was noted the Neutral Bushing on the 500 kV Winding appeared lower on one phase when compared to the other two phases. The bushing was scanned daily until a patch was applied to the leaking cap tap. IR scan continued until the bushing was taken out and replaced. The site glass on the leaking bushing had become stained and was not showing the true level of the oil.

Intertie Transformer:

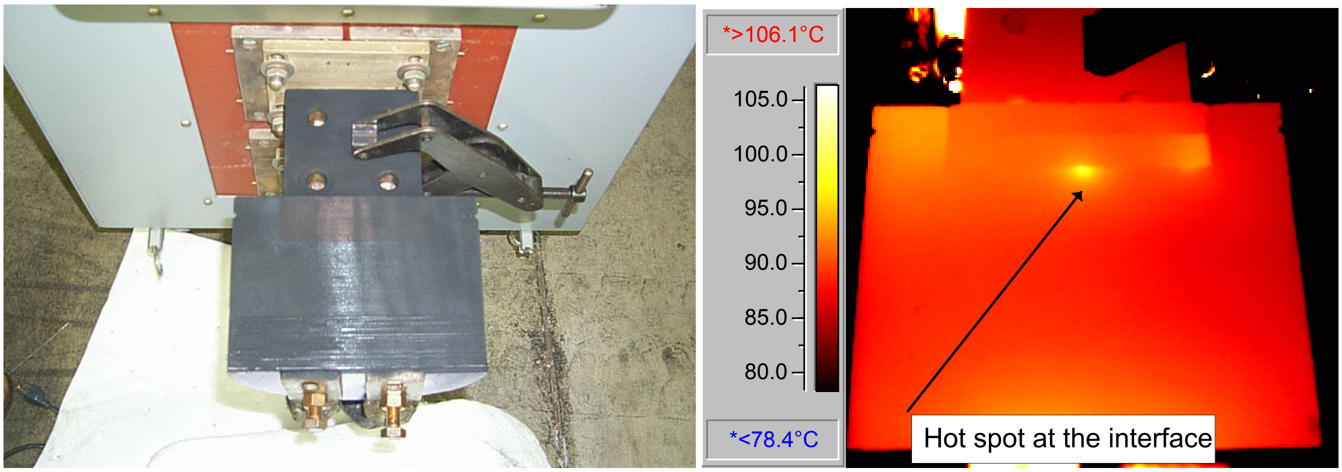


During an infrared scan it was noted that this 500 kV bushing had a low oil level. The oil was leaking from the bottom of the bushing into the tank and was not visible from the outside. The low oil reduced the insulating ability of the bushing. If this had not been found, the bushing would have lost more oil until the point when the insulation would have flashed over. This would have destroyed a 4 million dollar transformer.

Failure Analysis Example:

Some bushings have internal connections or joints. A recent failure of a ASEA GOH 150 bushing lead to testing of several bushing with a micro-ohm meter. One bushing was found with a high internal resistance. To analyze this bushing, the top portion of the bushing, containing the Aluminum to Copper interface, was sliced in half. 50% of rated current was passed through the test specimen. The interface was observed using an infrared camera. Note the hot spots at the Aluminum to Copper interface. This was the area that was producing the higher than normal resistance.

15kV 12,500 Amp- ASEA GOH 150 "Copper Top"



3. SUMMARY

- Bushings are subject to two types of stress
    1. Voltage
    2. Current
- External loose connections or high resistance points will show up on an infrared scan if the bushing is carrying at least 50% nominal current
- Bushings oil level can be seen in energized transformers
- Infrared is a great tool for failure investigations

4. CONCLUSION

Finding problems in bushings is only one aspect of what infrared can do for an inspection program. TVA performs a Level 2 inspection (L2i) once a year on every substation. All major power equipment outside and control equipment inside is inspected. The inspection includes an Infrared scan, Detail Visual inspection, Ultrasonic scan, and Dissolved gas-in-oil analysis. Generating stations are scanned with infrared cameras twice a year. Infrared is a key part to an over all predictive maintenance program.

During our L2i pilot program in 1998, TVA inspected 106 stations and had an avoided cost of 4.3 million dollars. This lead to implementation of L2i throughout TVA. Now the L2i program consists of 18 teams. One team in each Service Center and each team has two members - an Electrician and an Engineer. Each team has their own infrared camera and set of inspection tools.