Criticality of oil level of power transformers and regulators

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ABSTRACT

Knoxville Utilities Board (KUB) is a company that has continually had customer satisfaction as the driving force for its preventive maintenance program. KUB's System Operations Department has a group known as Station Management Services (SMS), and their primary duties are to test and maintain the electric substations and remote site facilities. Our goal in SMS is to minimize equipment failure, and our efforts have been rewarded with a failure rate far below the national average.

To continue this mindset, we incorporated thermal imaging into our program in 1990. This service was provided by local and regional contracted vendors, and its main purpose was to locate overheating disconnect and air-break switches.

In the fall of 2000, budget allowances were made to purchase an infrared camera for our department and also train and certify two employees in its operation.

This paper reviews the incorporation of infrared thermography into our scheduled maintenance plan. It also describes how critical the temperature of power equipment can become with slight variations in the oil level and how IR thermography has been used to monitor these variations.

Keywords: Migratory oil, expansion tank, load cycle, and radiators.

1. INTRODUCTION

As of January 2001, infrared thermography was incorporated into our scheduled maintenance plan. I was given the task of developing the program: planning, scheduling, and setting priority levels for equipment based on system importance, and once these tasks were completed, to perform the IR scan. It was quite an undertaking just to get the program off the ground.

Knoxville Utilities Board consists of the four main utilities:

1. Electric
2. Water
3. Wastewater
4. Gas

The system covers approximately 750 square miles and provides services to all, or part of, a seven-county region. The electric system has six infeed substations and 54 distribution substations, with one infeed and two distribution stations under construction at this time. The water system consists of two plants and 22 pump stations. The wastewater system has four plants and 45 pump stations, and three gate stations and 53 regulator stations support the gas system.

The initial plan is scheduled to take three years to complete, and the guidelines are as follows:

1. Initiate the program January 2001.
2. Create a three level priority list of all facilities.
3. Schedule all infeed electrical substations within six months.
4. Schedule infeed substations on an 18-month rotation allowing for more frequent inspections and for inspections during different climate conditions.
5. Incorporate time for flexibility to provide services for key account facilities and to allow for any contingency that arises.
6. Test all facilities within 36 months.
7. Scan switch-gear of all electric substations on an annual basis after the initial plan is completed.

2. CLASSIFICATION OF THE PROBLEM

The regulators described in this paper are located at one of KUB's six infeed substations. This station serves primarily the downtown area of Knoxville, Tennessee, and is considered to be our largest electrical substation, based on overall energy demand.

During the infrared thermal inspection of the substation, several problems were located. Before the purchase of the FLIR ThermaCam 695 in the fall of 2000, contractual support for this type of inspection was used, mainly to locate overheating air-break and disconnect switches.

We had been aware of a problem with migratory oil within these types of regulators for some time, but did not realize the thermal effects on the winding compartment.

To define what is meant by migratory oil, let me describe the scenario:

There are three (3) compartments within these regulators. The first compartment houses the tapchanger, the second houses the regulator windings and the third is an expansion tank. The compartments are separated by a connection barrier made of a dielectric composite material, commonly called Micarta board, or a wood laminate, which is supposed to prevent oil movement from one compartment to the other. The top of the winding compartment is filled with nitrogen, a nonflammable, inert gas. This pressure is usually less than 2 PSI, but is necessary to provide a moisture free environment. The configuration of the regulator is illustrated in **figure 1**.

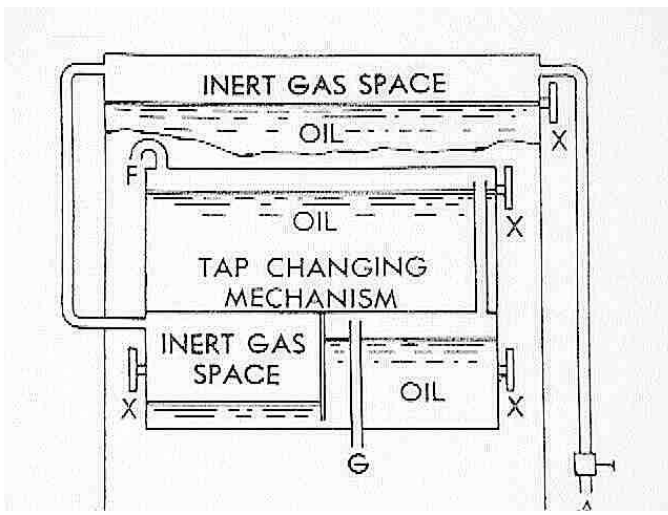


Figure 1. Configuration of the 3 chambers of a typical regulator

Regulators of this type are transformers in their own right, but they are used primarily as secondary voltage regulators to support fixed winding infeed transformers.

Under loading conditions, heat is generated based on the magnitude of electrical current (or load, as we call it) as it is in all electrical power equipment. As the current demand increases, so does the heat generated within the windings. This effect is caused primarily by two conditions: vibration and the winding resistance to current flow. All windings are manufactured to be as efficient as possible to control these effects, but no unit is without some amount of internal loss due to heating.

The nitrogen blanket applied to the winding compartment serves two purposes:
1. To prevent combustible gases from accumulating.
2. To prevent moisture from entering the unit by means of atmospheric air.

This is where our problem exists. The Micarta board is allowing oil to pass from the winding compartment to the tapchanger. As the load fluctuates, the regulator temperature increases and decreases. This fluctuation depends on the type of customers served and their energy needs. Normally, industrial or commercial customers' energy demand increases during the daytime hours and decreases during the evening and night hours.

The opposite occurs if the primary customers are residential: Demand decreases during the day and increases in the evening and night. Either load condition will cause the same effect, just at different times of the day.

This heating and cooling of the oil within the winding compartment causes the oil to expand and contract.

During lightly loaded periods, the contraction of the oil within the winding compartment reduces pressure on the barrier board, thus limiting oil transfer to the tapchanger compartment. During heavily loaded times, however, the expansion of the oil overcomes the poor seal of the barrier, allowing winding oil to migrate to the tapchanger. This condition overfills the tapchanger and reduces the volume of oil in the winding compartment. **Figure 2** is a cutaway view of the winding compartment.

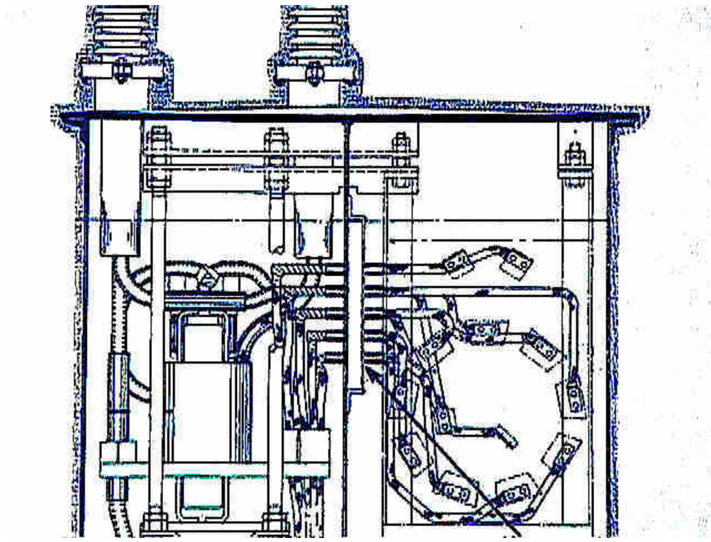


Figure 2. Cutaway view of the tapchanger and winding compartment

The repetitive nature of the load cycle allows the oil to migrate until the level is reduced to the point at which the increase in pressure within the winding compartment is not sufficient to overcome the pressure established within the tapchanger compartment. This is the point of pressure balance or equilibrium.

As illustrated by the thermal images in the next section of this paper, the level at which the oil ceases to migrate is below the level at which the radiators can cool the windings effectively. The radiators are manufactured to have accurately vertical veins and horizontal flow pipes. To ensure this during the construction, the veins are inserted into the flow pipes at different depths. These variations will not affect the temperature of the unit if the oil level is above the upper flow pipe, but if the level falls below full immersion, proper oil flow is not guaranteed. This is illustrated in **figure 3**.

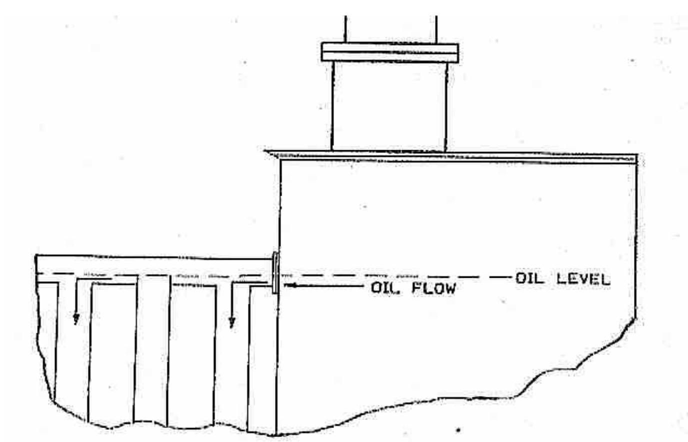


Figure 3. The oil level must be above the upper flow pipe for proper cooling.

3. THERMAL IMAGES, BEFORE AND AFTER LEVEL CORRECTION

The thermograms of **figures 4a through 4f** illustrate the difference between the thermal distribution of the radiator sections of three regulators before and after filling.

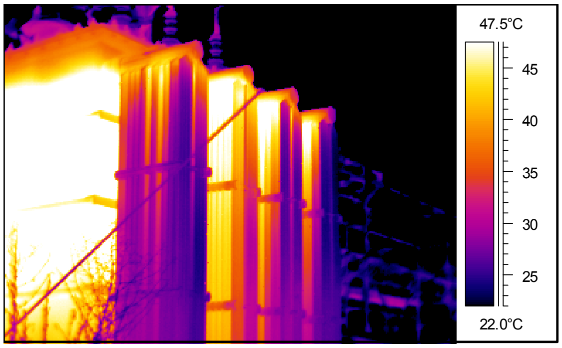


Figure 4a. LN Regulator No. 1 radiators before filling

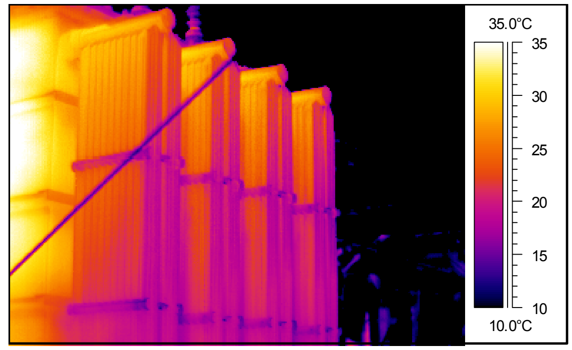


Figure 4b. LN Regulator No. 1 radiators after filling

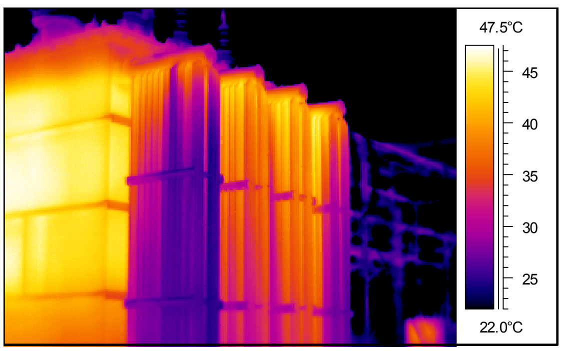


Figure 4c. LN regulator No. 2 radiators before filling

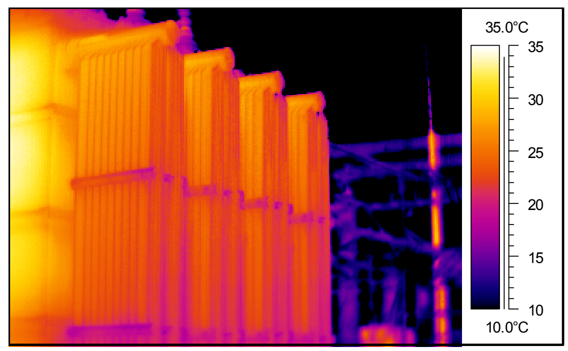


Figure 4d. LN regulator No. 2 radiators after filling

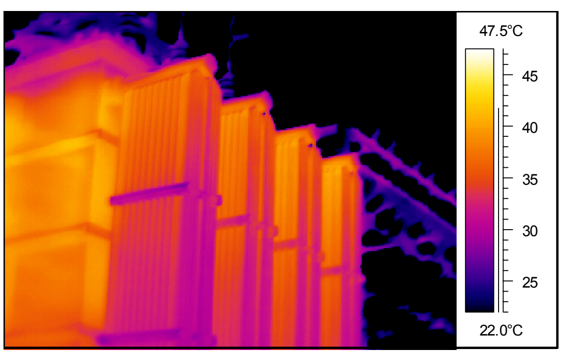


Figure 4e. LN regulator No. 3 radiators before filling

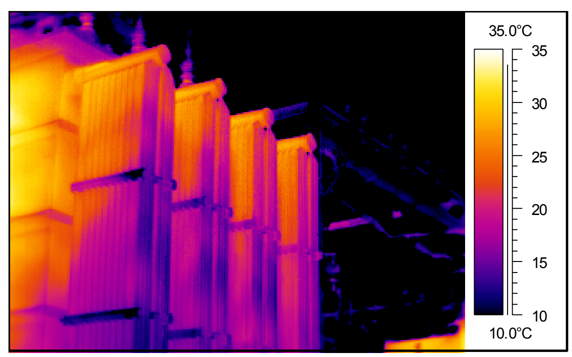
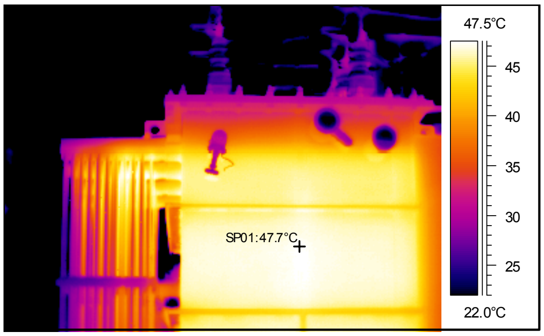


Figure 4f. LN regulator No. 3 radiators after filling

The thermograms of **figures 5a through 5f** illustrate the difference between the thermal distribution of the winding sections of three regulators before and after filling.

The maintenance performed and the thermal differentials observed are documented below:

Approximately 100 gallons of oil were added to the winding compartment of LNR1 regulator, and the temperature reduced by 28.5 percent, or from 47.7 degrees C to 34.0 degrees C (**figures 5a and 5b**)



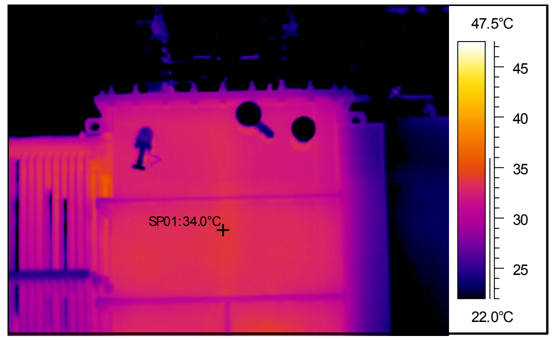
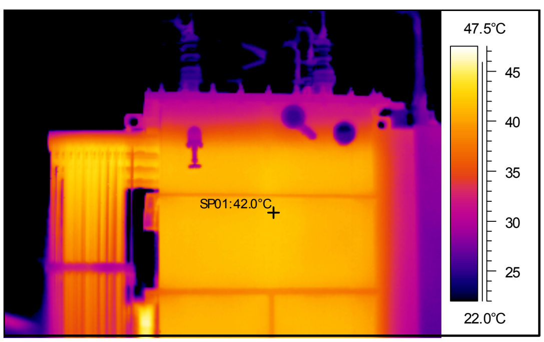


Figure 5a. LN Regulator No. 1 winding section before filling **Figure 5b. after filling**

Approximately 50 gallons of oil were added to the winding compartment of LNR2 regulator, and the temperature reduced by 22.0 percent, or from 42.0 degrees C to 32.4 degrees C (**figures 5c and 5d**).



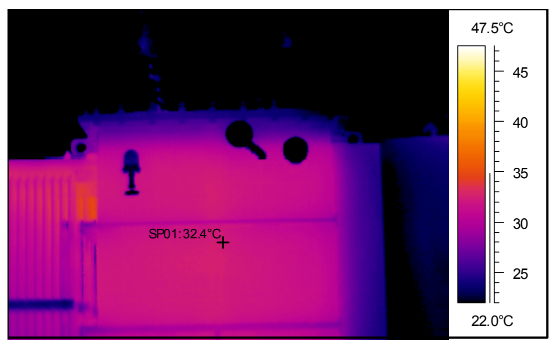
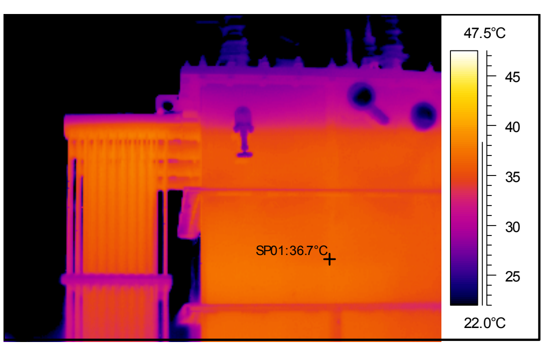


Figure 5c. LN Regulator No. 2 winding section before filling **Figure 5d. after filling**

Approximately 30 gallons of oil was added to the winding compartment of LNR3 regulator, and the temperature reduced by 8.0 percent, or from 36.7 degrees C to 33.7 degrees C (**figures 5e and 5f**). Notice that the oil level allowed proper convection flow, but the additional volume allowed for better radiation of generated internal heat.



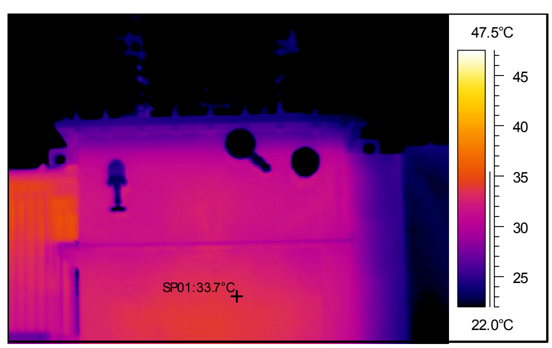


Figure 5e. LN Regulator No. 3 winding section before filling **Figure 5f. after filling**

4. CONCLUSIONS

To control the overheating as the oil migrates, maintenance crews must remove the units from service and add new oil to the winding compartment. In addition, oil must be removed and filtered from the tapchanger. Carbon deposits are inherent to tapchangers due to the arcing during tapchanging operations, requiring filtering during the procedure. This process has become both costly and time consuming.

Unfortunately, eliminating the problem completely would require extensive work, including physically removing the regulators from the substation and transporting them to our transformer warehouse. The tapchanger and winding compartments would have to be completely separated electrically to replace the barrier board and seals. This level of repairs is not possible on site because of weather exposure. Also, these units are approximately 50-60 years old, (54 years, to be exact), and parts for equipment of this vintage are almost impossible to locate, so fabrication is inevitably necessary.

It was decided that, at this time, the process of monitoring temperatures and correcting the oil levels would be continued.

The equipment on which these measurements were taken is identified as follows:

Manufacturer: Allis Chalmers

Regulating Transformer Type OAT-TLF

25,000 KVA 13,800 Volts +/- 5%

1046 Amps 3 Phase 60 Cycles

Serial Numbers:
2-0110-8118-1 (LNR1) C/N 17211
2-0110-8118-2 (LNR3) C/N 17210
2-0110-8008-3 (LNR2) C/N 17212