Generator step-up transformer, low voltage bushing overheating event

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ABSTRACT

On Tuesday, November 10, 1998, personnel from the Component Engineering Department and CSI Services conducted a self-assessment of Seabrook Station's Infrared Thermography Program. While performing the self-assessment, a high temperature on the Generator Step-Up Transformer (GSU) was discovered. One of six low voltage bushing enclosures was found to be much hotter than the other five. Peak housing temperatures were approximately 250º F as compared to 110º F for like enclosures. An infrared inspection through a 3/8 inch bolt hole identified temperatures in excess of 540ºF. The plant immediately commenced shutdown. Subsequent inspection of the transformer/bus connection revealed significant overheating damage to the 25 kV connection. Melted aluminum, copper and even a 304 SS bolt was discovered.

Root cause analysis concluded that a complete connection failure would have occurred within 2 weeks.

This paper describes the event and demonstrates how the cost benefit analysis for this Infrared discovery, using the EPRI cost-avoidance model and industry experience, is estimated to have saved over $32 million.

Keywords: IR thermography, electrical survey, transformer

1. INTRODUCTION - INFRARED THERMOGRAPHY (IRT) CASE HISTORY

North Atlantic Energy Service was performing a routine thermographic inspection as part of the self-assessment program at Seabrook Nuclear Station, a 1200 megawatt nuclear power generating facility in New Hampshire. What appeared to be a serious temperature rise was detected on a 25kV to 345kV Generator Step-up "A Phase" Transformer. The location was on an Isophase-to-Low-Side bushing where an apparent temperature rise of 150°F was detected on the surface of the bushing compartment.

Fig.1 is a visual image of the "A" Phase Generator Step-Up Transformer, Low Side Bushing Compartment. Fig.2 is the corresponding thermal image. The 250°F temperature measured on the surface of the bushing compartment exists because of heat being generated inside the compartment. The source of the heat was suspected to be a high resistance connection between the low side bushing and the isophase. Recognizing that a significant heat source would be needed to raise the surface temperature of the compartment to 250°F, it was suspected that there was potential for a catastrophic transformer failure.

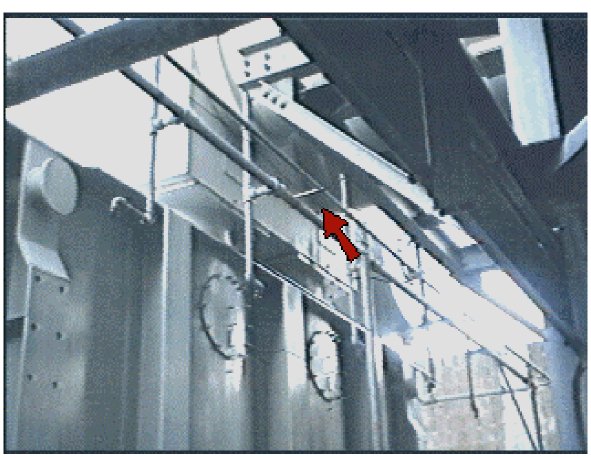

Figure 1 Visual image of the "A" phase generator step-up transformer

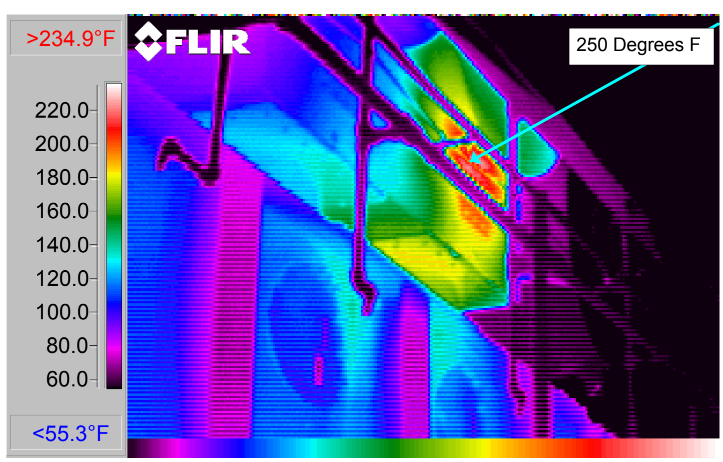

Figure 2 Corresponding thermal image of the transformer

2. CONCERNS:

The finding prompted immediate concerns as follows:

Safety - A catastrophic failure of the transformer could have devastating safety consequences for plant personnel.

Environmental - It is assumed that fire resulting from a transformer explosion could be controlled, however, an adjacent salt marsh could be contaminated.

Lost Power Generation - Loss of the "A" Phase Generator Step-Up Transformer requires a forced plant shutdown.

Component Damage - Component damage is expected.

3. INITIAL RECOMMENDATIONS

Initial recommendations based on the above concerns were:

Remove the unit from service.
Inspect the low side transformer bushing and all other associated components.
Make repairs as necessary.

4. RESULT OF INITIAL RECOMMENDATIONS:

An inspection of the inside of the bushing compartment revealed significant damage, including substantial melting and deterioration of the bushing and surrounding components. These components had been exposed to extremely high temperatures. The melting temperature of aluminum is approximately 1220°F. Fig.3 illustrates some of the damage sustained by the transformer bushing links.

Figure 3. Photographic illustration of some of the damage sustained by the transformer bushing links

5. CONCLUSION

A non-intrusive diagnostic test, using infrared thermography, exposed a situation where an incident would have certainly occurred. By detecting this situation, an opportunity was created for operations and maintenance personnel to take appropriate action. The station was able to avoid a catastrophic failure, and the associated issues and costs.

6. COST AVOIDANCE BENEFIT ANALYSIS:

If a Predictive Maintenance (PdM) program is working, and equipment failures are detected in their incipient stages, maintenance can be performed to correct problems before the equipment fails. This is the premise upon which PdM philosophy is based. Unfortunately, this situation makes the computation of cost benefit (dollar savings) attributable to a particular PdM finding somewhat difficult to quantify. The event that would have taken place, had diagnostic testing not been available, is uncertain. Proposed scenarios of what could have taken place, based upon knowledge of equipment functionality and its maintenance history, must be relied upon.

By proposing three, or fewer, general failure scenarios, and applying a probability of occurrence to each of them, cost benefit can be reasonably estimated. These scenarios could be classified as “Most Severe”, “Medium Severity” and “Least Severe”. The cost avoidance benefit for this case is calculated by estimating the cost for each scenario, subtracting the actual cost from each of the estimated costs, weighting each net cost by the likelihood of its occurrence and adding the results as follows:

- Scenario #1 Most Severe Event - There is no PdM program. The situation goes undetected. An explosion destroys the transformer and bus ducts. Damage is sustained by the turbine building. Burning oil contaminates the adjacent salt marsh. Industry averages for these catastrophic failures indicate that there would be 72.2 days of plant shutdown. Root cause analysis of this event concluded that there is a 50% chance that this catastrophic scenario would have taken place.

- Scenario #2 Medium Severity Event - There is no PdM program. The situation goes undetected. The resultant fault causes protective relays to trip the plant. The “A” Phase low voltage bushing, duct links and bus duct are destroyed. There is no further transformer damage. The plant would be forced to shut down for approximately 15.2 days. Root cause analysis of this event concluded that there is a 50% chance that this medium severity scenario would have taken place.

- Actual Event - In actuality, the situation was detected by a PdM diagnostic program and repairs were made. The unit was put back into service after an outage of 12.2 days.

Costs attributable to:

Scenario #1	
Lost Generating Revenue & Associated Penalties	$43,320,073
Replacement Power Costs	7,220,000
Parts & Labor	21,660,010
Replacement Transformer	1,900,000
Total Costs Scenario #1	**$74,100,083**
Scenario #2	
Lost Generating Revenue & Associated Penalties	$9,123,831
Replacement Power Costs	1,520,000
Parts & Labor	4,559,985
Total Costs Scenario #2	**$15,200,125**
Actual Event	
Lost Generating Revenue	$7,320,028
Replacement Power Costs	1,200,000
Parts & Labor	3,660,005
Total Costs Actual	**$12,180,034**

	Scenario #1	Scenario #2
Proposed Costs	$74,100,083	$15,200,125
Less Actual Costs	(12,180,034)	(12,180,034)
	$61,920,049	$ 3,020,091
X % probability of event	X 50%	X 50%
Sub-Totals	$30,960,025	$1,510,046
COST AVOIDANCE BENEFIT	$30,960,025+$1,510,046	**$32,470,071**