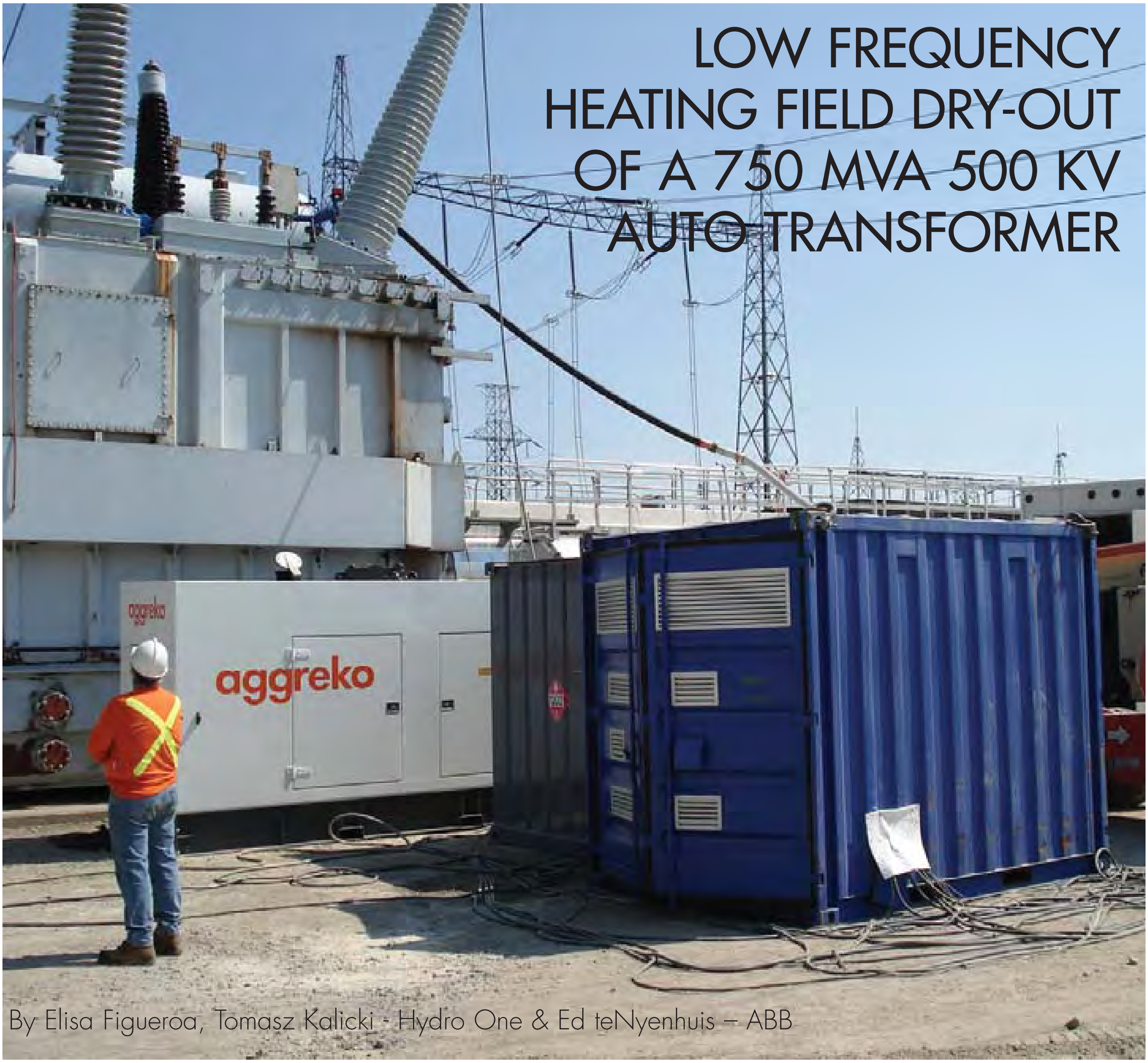

LOW FREQUENCY HEATING FIELD DRY-OUT OF A 750 MVA 500 KV AUTO TRANSFORMER

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Recently, two 30-year-old EHV 750 MVA 500 kV GE autotransformers were dried in the field using the Low Frequency Heating (LFH) process. It is generally difficult in the field to achieve acceptable dryness for wet EHV transformers using the traditional hot oil cycling method.

The LFH process applies near DC current to the windings allowing uniform winding temperatures progressively and safely up to 110°C.

The LFH drying process was completed for both units in two weeks with significant water removal and the moisture in cellulose brought down to below one percent.

These are the largest field applications of the LFH drying process.

Based on the limited number of measurements, it has already been concluded by Hydro One that the Low Frequency Heating (LFH) method is superior to the methods used previously. The results of less than 1.0 percent remaining moisture allow Hydro One to restore the transformers' overload capabilities without fear of bubble formation.

INTRODUCTION

The primary purpose of performing site dry-outs of power transformers is to reduce the moisture content in the cellulose. Moisture comes from the aging process of the cellulose (it is a byproduct) or externally from the transformer (gasket, breather, leak, etc). Moisture deteriorates the electrical and mechanical properties of the transformer and can limit the allowed overload due to risk of water bubble formation.

Hydro One recently investigated a failure of an important system autotransformer which led it to invest in a program of site drying its fleet of 500/230 kV autotransformers. This group of autotransformers is the backbone of the transmission network in Ontario. One of these units, a 750 MVA 500/230/28 kV three-phase autotransformer, underwent a failure only hours after a sister unit at that station had been removed from service due to a high moisture alarm from an on-line monitor. The resulting investigation showed that moisture was a main contributing factor to the failure. It was estimated that the moisture level in the failed unit was approximately 1.5 percent. Further analysis indicated that similar moisture content existed on other units within that fleet of installed transformers. As a result, many of the units in service were de-rated and an extensive dry out program was initiated to reduce the risk of further failures.

Site dry-outs for this drying program were performed using a Hot Oil Circulation plus Vacuum (HOV) method, which is standard practice for smaller units. Due to the size of the units and the deep penetration of the moisture in the cellulose, numerous hot oil/vacuum cycles were required. This resulted in lengthy transformer outages. To improve moisture removal effectiveness, a diffusion pump was used to achieve a very deep vacuum - 50 microns. With all this, the final moisture results indicated that the effectiveness of HOV was marginal. While the surface moisture dropped, the average moisture levels hardly budged. The target level of less than one percent moisture content was not achieved. Furthermore, the outages lasted over two months due to the large size of the units and the consequently large volumes of oil. This effort also tied up significant resources (staff and equipment) and subsequently other transformer projects were also impacted. The deep vacuums required to extract moisture also caused new leaks to spring up due to aged component stress. At times the process had to be stopped before reaching target vacuum levels because of concerns regarding the structural integrity of the tank. A new method had to be found for the large transformers which led to the application of the Low Frequency Heating (LFH) technology on two 750 MVA, 500 kV autotransformer with much better results.

LOW FREQUENCY HEATING OVERVIEW

With the LFH method, current is applied to the windings in order to heat the transformer more effectively at a higher temperature. The current is applied at 1 - 50 mHz that has two critical advantages.

First, the impedance voltage is much reduced with low frequency meaning the required applied voltage is low. The LFH is applied when the oil is removed from the unit but the applied voltage is thus low enough to eliminate any risk of flashover.

Second, the leakage flux is negligible so the temperature across the winding is uniform. Under normal AC operation, leakage flux causes uneven winding heating. Thus, the low frequency current allows higher temperatures to be safely achieved across the entire winding during the dry out.

The current is applied to the HV winding and is typically 20 - 50 percent of the rated current. The applied current is limited by the temperature of the winding and the induced windings. The frequency can be varied slightly to control the amount of transformation to the LV winding, which is short-circuited during the dry-out. Winding temperatures of up to 110°C are permitted during the LFH dry-out process and are monitored by constant winding resistance measurement. This peak winding temperature of 110°C has a negligible effect on the paper aging of the transformer.

The LFH unit has power converters to change the current from 50/60Hz AC to the desired low-frequency current. The control system monitors the winding temperatures, applied voltage & current, frequency, thermocouples (placed inside the transformer) and vacuum. The safety protocols ensure maximum individual winding temperatures are not exceeded and low vacuum is not used when LFH voltage is applied.

During the heating of the windings, a hot oil spray is applied over the core/coils to additionally heat the external insulation. Temporary spray nozzles are installed beneath the cover. The hot oil spray allows external insulation temperatures above 90°C.

A typical LFH process would be as follows:

- Initial heating/circulation of core/coils using hot oil and with LFH current applied to the windings
- Drain the oil and pull vacuum to remove moisture
- Break vacuum; apply LFH current and hot oil spray follow this with vacuum. Repeat this process and progressively raise the temperature to 110°C
- Pull final vacuum
- Break vacuum to remove temporary spray nozzles
- Vacuum fill the transformer with dry degassed oil

Due to the much higher achieved temperatures compared to traditional hot oil treatments (110°C versus 80°C) the moisture removal with LFH is more effective and is done in a reduced amount of time.

HYDRO ONE SITE DRYOUTS WITH LFH PROCESS

Hydro One performed site dry-outs in 2007 using the LFH technology on two 750 MVA 500 kV autotransformers. The first dry-out was performed for a unit being repaired in a Hydro One facility. The second unit was dried in the field during an outage. Both units were 750 MVA 500/230/28 kV three-phase autotransformers and were 33 years in age. The moisture content in each unit was estimated to be 1.5 percent prior to the dry-out.

Since both units were autotransformers, the LFH unit injected current into the series/parallel windings and current was induced in the tertiary winding. The LFH unit monitored the winding temperatures (constant resistance measurement) since the windings did not each heat at the same rate. When required, the frequency was reduced so that current was not induced in the tertiary winding (since the tertiary winding heated faster). Thermocouples were placed on the core, windings, lead structure and in the drying tank to closely monitor the process. Oil spray nozzles were temporarily installed under the cover via a modified manhole cover.

A total of 11 LFH/vacuum cycles were performed for each dry out. Hot oil was initially circulated to remove the surface moisture. This hot oil was heated together with external equipment and the LFH, which raised the oil and windings to a temperature of about 80°C. This was followed by vacuum. At this point the 11 cycles of LFH current/hot oil spray followed by vacuum were done. The winding temperature was increased from 85°C to 110°C over the 11 cycles. The oil spray was raised to a temperature of 95°C during the LFH cycles.

Thermocouples confirmed that insulation external to the windings reached 95°C and that the temperature was uniform from the top to bottom. The injected current for these transformers was limited by the tertiary winding rating. Thus, the tertiary winding current was limited to 70% of rated current. The frequency of the injected current was 0.05Hz for when all windings were being heated and 0.0015Hz when only the series/common windings were being heated. The first dry-out took a total of 12 days while the second dry out was done in 11 days.

The water removed was calculated to be 150 liters for the first dry-out, and 160 liters for the second dry-out. Insulation samples were also taken from both units after the dry-out, which showed average moisture in cellulose result of 0.7% for the first unit and 0.3% for the second unit. The 150 liters and 160 liters of water removed during the two dry-outs translates to approximately one percent reduction in moisture content in cellulose. With an estimated pre-dry-out moisture in cellulose of 1.5 percent, the one percent reduction implies a final average moisture in cellulose of 0.5 percent, which is consistent with the sample block results.

DISCUSSION OF LFH SITE DRY-OUT PERFORMANCE

The two dry-outs performed showed that the LFH method of site drying has a number of advantages compared to the traditional HOV method. The primary advantage is the superior drying effectiveness. As shown above, the final average moisture in cellulose result was less than 0.7 percent. Previous HOV dry-outs have not achieved results even less than one percent and the removed water has been less than 100 liters.

The duration of the LFH dry-out was about two weeks compared to up to eight weeks for the HOV dry-outs. This is a huge benefit considering the importance of these autotransformers for system operation and the severe difficulties in obtaining extended outages. Furthermore, the LFH dry-outs tied up fewer resources, as well as being required for a shorter time. The LFH dry-out requires less oil handling equipment and reduced personnel. Only two operators are required for the oil degasser/vacuum pumps and one LFH operator when LFH current is applied. HOV dry-outs typically require more personnel due to the extra equipment and the numerous hoses, valves and pumps to be operated and monitored during extended hot oil circulations.

Lastly, since the LFH vacuum requirements are not as low as those required by the HOV method, the stress applied to the transformer tank is reduced. Even if a transformer tank can sustain a deep vacuum (which is questionable for many older units), significant effort must be exerted to locate and eliminate all leaks.

A summary of the advantages of LFH compared to HOV is shown in Table 1.

TABLE 1
Comparison of HOV Drying Method versus LFH

Method	Drying Effectiveness	Duration	Tank Stress	Resources
HOV	at best 1.1%	4 to 8 weeks	Moderate to Severe	100%
LFH	comfortably <1%	< 2 weeks	None to Minor	75%

CONCLUSION

Although the number of confirmed measurements is limited, it has already been concluded by Hydro One that the Low Frequency Heating (LFH) method is superior to the previously used methods. The results of less than one percent remaining moisture allow Hydro One to restore the transformers' overload capabilities without fear of bubble formation.

It is believed that future dry-outs will give Hydro One more evidence to support the previous statement. More data, combined with the on-line monitoring of the moisture activity inside the transformer returned to service after the dry-out will further prove the effectiveness of this method.

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