IMPROVED ACCESSIBILITY AND COOLING OF UNDERGROUND TRANSFORMER VAULTS

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ABSTRACT

Large underground transformer vaults in urban areas are critical components of distribution networks. The transformers and switches located inside these rooms are usually down-rated due to the enclosed area that reduces the heat dissipation, and consequently, increases the oil and winding hotspot temperature at a given load. On the other hand, water and dirt tend to accumulate inside these vaults, hindering in case of emergency the access to the low and medium voltage components which adversely affect the continuity index of energy supply to customers. Moreover, galvanic corrosion is very likely to increase in submerged vaults and consequently, reducing the life expectancy of the equipment present. At Hydro-Québec, a major North American utility with 35000 MW network, a great effort and money have been spent in the few past years to design new generation vaults and upgrade the existing ones (nearly 2000 at term) by preventing water accumulation on the floor and improving air circulation for better cooling. First, we have worked on reducing the spillage by reducing significantly the exposed ventilating area and by controlling water infiltration through the ducts connecting the vault to low and medium voltage cable duct banks. This was accomplished by blocking the free space between cables and ducts with a special injected silicone material. Also, sump pump was installed to insure a complete dry environment. To counter the adverse effect of reduced ventilation surfaces at grade level, a thermally insulated duct was installed in the middle or at the extremity of the vault that extend from the ground level to the bottom. This device improves substantially the air circulation due to chimney effect. In other existing vaults with heavy load, ventilator is installed to increase the air circulation. This paper shows the various methods adopted and outlines their thermal effectiveness with respect to accessibility of maintenance crew and load ability of transformers inside.

1. INTRODUCTION

Underground vaults represent an essential component of a distribution network in urban areas where the transformers and switches are hidden from public view. These structures should ensure safe working environment for the maintenance people and rapid intervention and accessibility to the electrical equipment in case of emergency. At the same time, they should provide good heat dissipation in order to minimize the down rating of the equipment inside that normally occurs when installing these equipments in closed areas compared to open air. The former requirement implies a significant reduction of the exposed openings for ventilation that invite littering and waste spilling. Unfortunately, this adversely affects the load capability of the transformers because reducing the openings leads to a reduction of the outside air flow rate that carry away a large part of the heat generated inside the enclosure. At Hydro-Quebec, where nearly 2000 of these urban vaults are already in use and for the new design of vaults, we tried to strike a balance between these two opposing criteria by reducing the ventilation openings and by improving the chimney effect that compensate for the adverse effect of this reduction. In some case where the load is too high, forced air cooling was considered necessary in order to satisfy the above mentioned requirements.

2. PROBLEMS WITH UNDERGROUND VAULTS

An underground vault is a large concrete structure (typically 8mL x 2,9mW x 2,6mH) built underground to lodge the transformers and switches of a distribution network in downtowns or urban areas. Many of these enclosures lie below the natural water table. Most of them are flooded a few weeks each year and others most of the time, mainly because of cracks in the city water system. Moreover, water can leak in mostly from the conduits of medium and low voltage cables that enter and exit these vaults and also through the ventilation openings normally located on the sidewalk. Also, human waste spilling is a major factor that adds to the problems afflicting these structures that complicate the regular maintenance and prolong the duration of outages in case of emergency situation.

Based on these facts, Hydro-Québec management has decided several years ago to design and install new generation vaults and upgrade existing ones to a new standard that ensure dry and clean conditions and better ventilation for the equipment inside.

3. NEW VAULT DESIGN

The new vault design was made with several goals in mind: first make sure the equipment will be operating in completely dry conditions. And second, obtaining maximum cleanliness by minimizing the possibility of natural and human spillage (dirt, leaves, sand and illegal motor or vegetal oil discharges) into the vault and by improving the ventilation.

The first goal was accomplished by blocking any water leakage from the cables' conduits into the vault and installing a sump pump below the floor level. The second one was obtained by moving side way the ventilating openings normally located above the two access chimneys at the sidewalk level. Those ventilation openings were incorporated in two rain water drain connected to the sewage system as shown in figure 1. First, the cold air migrates inside the vault from the left water drain which is also connected to the insulated duct (figure 2) in the vault to improve the chimney effect. The warm air exits at the other water drain on the other end of the vault following a directional flow. The covers over the access chimneys were redesigned with no vent areas and new marking on the covers specifies the electrical function of the structure below.

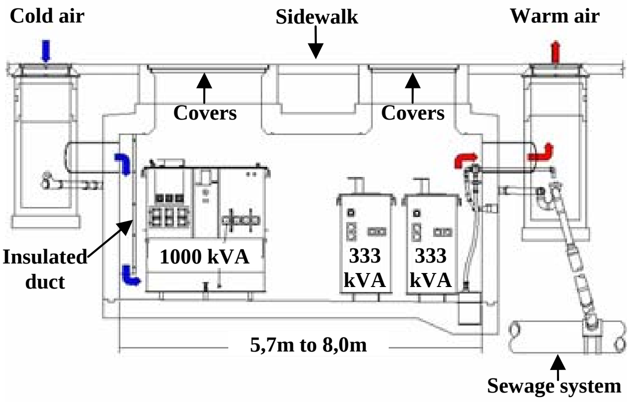

Figure - 1: New generation vault - Flow of the incoming air

4. PERFORMANCE OF THE NEW DESIGN

A prototype vault of 7,3 m length, 2,6 m wide and 2,6 m height was built and instrumented. This vault had a total capacity of lodging 1,5 MVA transformers (1 x 500 KVA + 3 x 333 kVA). The first tests were done with no transformers inside. The losses normally generated by the transformers were replaced by an equivalent 6 kW heating elements. Several tests were done by varying the size of the openings from 2 x 0,535 m^2 down to zero with intermediate openings of 2 x 0,15 m^2 which is the size that would equip the final design (see figure 2). The zero opening means that all the heat generated inside is dissipated by conduction through the walls to the ambient. Figure 3 shows the evolution of air temperature inside the prototype vault.

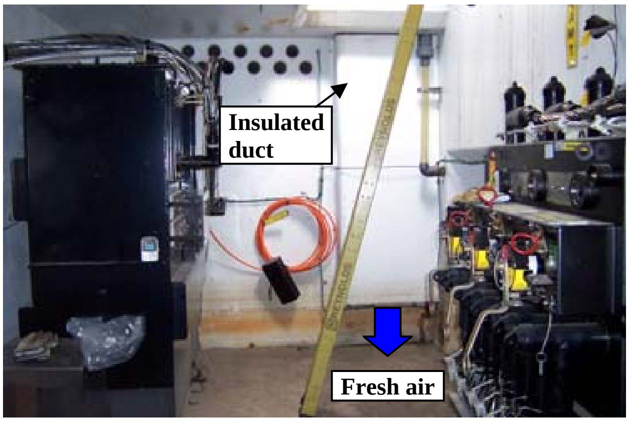

Figure - 2: Final design with the chimney at the air intake side

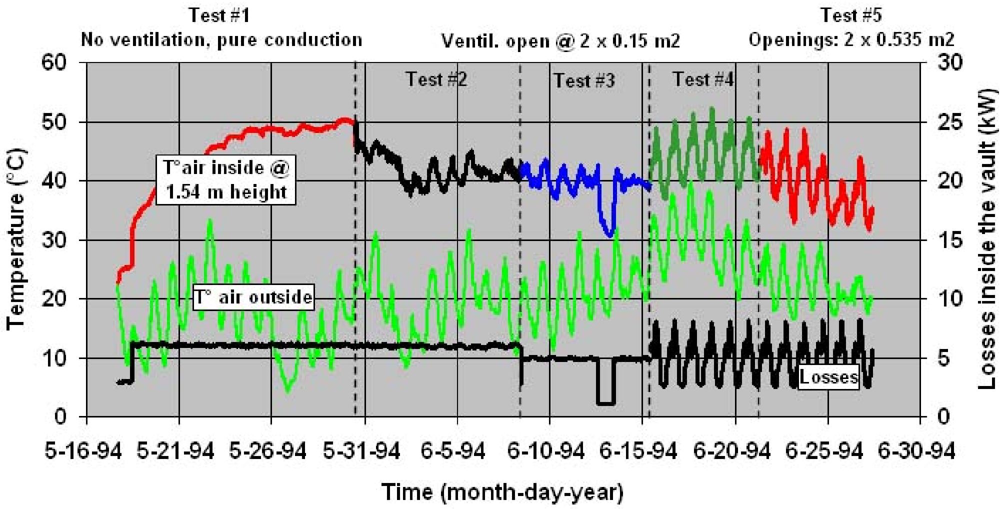

Figure - 3: Prototype vault temperature variation during summer of 1994

The conclusions of this study show that despite the great reduction in ventilation openings by a factor of 7,5 (from 2,24 m^2 of the comparable old design to 0,3 m^2), the thermal behaviour of the equipment and the air inside remains acceptable, although little bit higher than the old design. We estimate the temperature increase in summer time for the new design to be 3°C for every kW of losses inside the vault compared with 2,3°C for the old design. The slight reduction in performance is largely compensated by the lower humidity conditions ensured by the sump pump. Another conclusion of the testing is that the heat evacuated by conduction through the wall and the soil around is a non negligible portion of the total heat loss and should be evaluated carefully. The immediate conclusion is to have a good backfill or soil around. To generalize the findings for other vault sizes, we have developed a computer program based on 3-D finite element methods to calculate the heat conduction and based on conventional theory of fluid mechanics to evaluate the induced air flow and the amount of heat removed by ventilation.

5. UPGRADING EXISTING VAULTS

The majority of large existing underground vaults in Hydro-Québec distribution network were built to accommodate several transformers for a maximum load capacity of 1,5 MVA, most of them dubbed PT-1500. Nearly 1400 of them are located in downtown Montréal. The ventilation openings of these vaults, located at street level, were sized according to the 1977 Canadian Electrical Code and ANSI which recommend 2 m^2/MVA. The free area of the two ventilation openings of the PT-1500 is 2,24 m^2. Temperature measurement done for several years inside these structures including the "top oil" of the transformers showed that the thermal conditions are well below their limits.

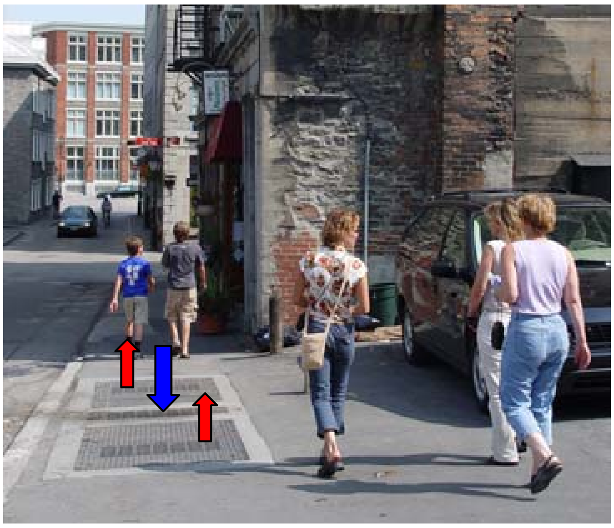

Figure - 4: Upgraded existing vault with directional air flow

This is despite the fact that both openings are at the same height thus reducing the chimney effect to null. It was concluded that by improving the chimney effect, we could shave a big chunk of these openings and consequently reducing the spillage and rain water infiltration. A big campaign was initiated in 2001 to modify these vaults and the upgrading program will last until 2011. The main modifications consist of removing completely the roof of the vault and replacing it with new prefabricated one that allows for 3 openings. A small one in the centre for air intake and two other at the extremities of the access chimneys for air exit. The total vent area of the openings is much smaller than the original design. The second action consisted on blocking the gap between the cables and the conduits, thus preventing any water leakage. Finally, a sump pump was installed that ensures dry floor inside the vault at any time. In order to improve the ventilation, we first installed a 550 mm by 375 mm, thermally insulated duct directly below the middle opening. With this addition, we succeeded in increasing substantially the chimney height from almost zero in the old design to approximately 2 m. Figure 4 show the three openings from outside and figure 5 shows the added duct in the middle of the vault.

Figure - 5: Upgraded existing vault: central chimney for incoming cold air

To validate the new concept, a large campaign was initiated in 2004 to measure the vault and transformers' temperature in one of the modified vault in downtown Montréal. The preliminary results, baked by simulation using the computer programs developed previously for the new vault design, show that the majority of PT-1500, lightly to medium loaded, are to perform satisfactorily with the new modifications. However, for highly loaded vaults, it was concluded that forced air circulation is needed.

The forced ventilation was obtained by shortening the insulated duct and installing a blower at its extremity as shown in figure 6. The impact of this addition is shown in figure 7 where one can see the drop in inside air temperature before and after the operation of the blower. Air flow measurement showed an increase in ventilating air from 225 cfm (cubic feet per minute) with chimney effect alone to 1500 cfm with the addition of the blower. The impact on transformer temperature is also obvious as shown in figure 8. The gap in temperature between inside and external air remained very small in summer time, around 3 °C. Based on the important gain in performance with forced ventilation and in prevision for increased load in the future, Hydro-Quebec has decided to choose the forced ventilation for the entire remaining existing vault included in the upgrading projects. The main advantage is that the blower significantly reduces the top oil temperature of the transformers (mainly during the night) and delays the effect of the increased heat loss during the day. Therefore, the employees can work in the vicinity of transformers without feeling the discomfort of the heat particularly if the structure is fully equipped. The other reason to retain the forced ventilation was that this equipment, once in place, doesn't need any planning to replace the insulated long duct by a box and a blower when the vault becomes fully loaded.

Figure - 6: The blower box at the center of the vault pushing in the incoming fresh air

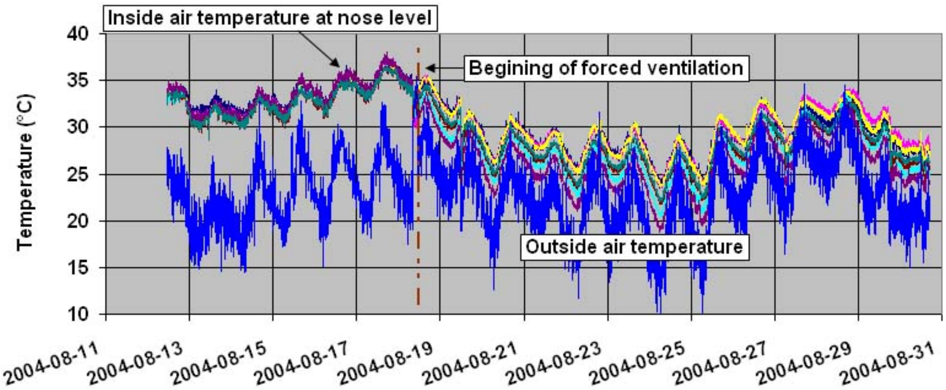

Figure – 7: Inside and outside air temperature before and after the forced ventilation

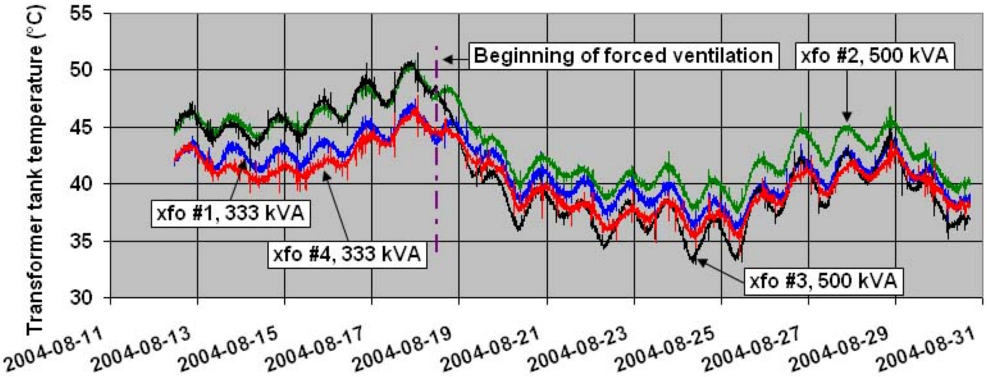

Figure – 8: Transformer tank temperature before and after the forced ventilation