DYNAMIC VENTILATION OF SECONDARY SUBSTATION: INCREASE OR DECREASE THE OPENNINGS?

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ABSTRACT

Based on an empirical principle, there is a widespread believe that in MV/LV secondary substations, more ventilation means better performance. In order to demystify that idea an investigation was done so that a correlation between ventilation and temperature and humidity variations, occurring inside secondary substations, could be established. The influence of those environmental conditions on the medium voltage equipment with air circuit breaker insulation was also studied.

The heat released by the power transformer when used to increase and maintain the value of the temperature stable inside the cabin, give their contribution to the reduction of relative humidity level.

Based on ventilation behavior analyses at secondary substations during winter and summer periods, conclusions were achieved that allow implement working enhancements at secondary substations, through the application of practical actions, integrated into preventive maintenance, in order to provide a ventilation area to the transformer load by obstructing the openings.

INTRODUCTION

The secondary substation cabin include in its design ventilation openings with different height level in a way to provide air circulation between the interior and exterior. The orientation and characteristics of cabin environmental conditions give a contribution for thermal capacity level and ventilation performance, that when combined with the wind effect can provide the ventilation increase or decrease.

The electrical equipment MV/LV (case study 30kV/0.4kV) installed inside the cabin includes the power transformer, the air circuit breaker equipment and the low voltage distribution board.

Among those equipment components, the power transformer is the one that produces more heat in the cabin interior. The heat is transferred through the cooling surface to the surrounding air and then transferred to the exterior through the natural ventilation that is an air flow, generated by the inlet and outlet holes.

This natural ventilation depends on the power transformer load, on the temperature difference between the interior and the exterior and on the size, type and position of ventilation holes.

This study was carried out in two low cabin MV/LV secondary substations, with conventional masonry construction. Within this work, we analyzed the interior substation cabin ventilation and its influence on the temperature and humidity.

Measuring equipment

The electronic equipment shown on figure 1 was designed and assembled for continuous acquisition and storage of temperature and humidity measures.

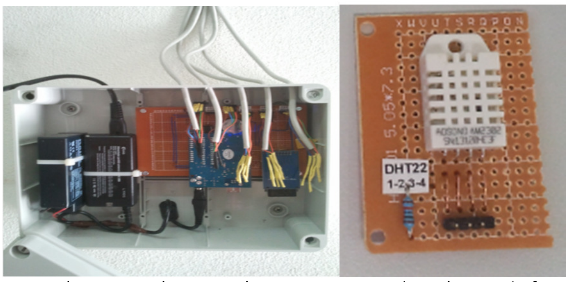

Figure 1. Measuring equipment, central unit on left and sensor on right

This equipment was assembled into two secondary substations selected from the electrical energy distribution network, hereinafter designated CB1 and CB2. Temperature and humidity sensors were placed strategically inside and outside the cabin, as shown in Figure 2.

Within CB1, the inlet and outlet holes were obstructed in 80% of the nominal value through the application of acrylic plates, adjusted for average load regime in winter period. This secondary substation has the MV equipment in good condition of conservation.

The CB2 had the openings within nominal value and exhibited damage on the MV equipment that implicated its immediate replacement.

Figure 2. Sensor location inside and outside of secondary substation

From the collected temperature and humidity data it was possible to verify that, through ventilation openings adjustment, it is possible to reach a stable temperature value inside the cabin independently of the observed exterior conditions.
The heat produced by the power transformer, when used to increase and maintain the temperature stability inside the cabin, gives his contribution for the reduction of relative humidity values. Within a constant unit air volume with, the relative humidity value decreases with the temperature increase.

Influence of humidity on MV equipment

The MV equipment insulation in the secondary substations is currently built on epoxy resin insulators. In normal service conditions the insulator material has a good behavior.

However, if submitted to long periods of time at high humidity levels a life time reduction is observed. This is, due to their mechanical and electrical properties degradation and leads to emergence of the partial discharges and corona effects over the insulators [1], as shown in Figure 3.
The humidity amount can be influenced by the cabin surrounding vegetation, rain and water infiltrations through cabin cover or through the underground channels for the inlet and outlet cables.
In cabin interior, low temperature values give origin to high humidity values, especially during the winter period. In these conditions the temperature variations can lead to formation of dew point. This effect can be eliminated by using additional heating through radiators, aiming to stabilize the temperature over extreme situations, or by increasing the cabin thermal isolation level, that in secondary substation already built would be difficult and expensive.

Ideally, it is desirable to reach a balance between the temperature and humidity inside of the cabin, minimizing the influence of outdoor climate factors.

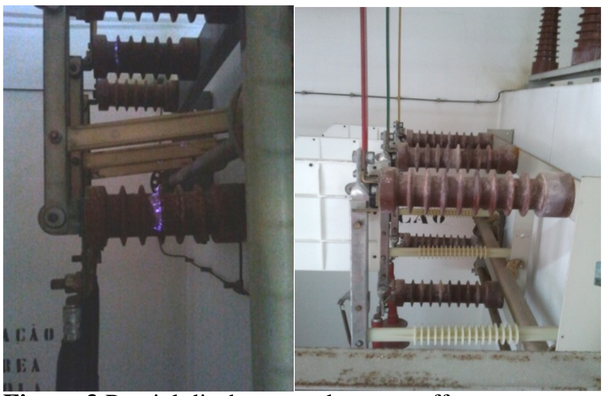

Figure 3. Parcial discharge and corona effect

Openings Regulation

The ventilation holes are typically designed for the transformer heat dissipation considering the maximum power of 630kVA [2] and the transformer nominal load regime during the summer period. In these conditions, it is expected that the cabin interior temperature would become lower than the predicted in its initial design, therefore influencing the relative humidity values, that would became higher.
Keeping this situation for long periods of time, lead to undesirable secondary effects that occurs on the equipment, such as, partial discharges and corona effect at the insulators surface, of insulators that in at long term cause degradation of MV equipment, as reported in previous publication [3].

Air Flow Determination

The correct value for the openings regulation at secondary substations, through a practical and low cost implementation, was theoretically calculated, by the equations below.

The necessary air flow to dissipate the heat produced by the transformer, Q_{Diss} $[m^3/s]$, is calculated [4] through equation 1. Q_{Diss}, depends on the power loss at no-load P_0 [w] and power loss by Joule effect P_{cu} [w], considering the transformer load regime C [%] and a temperature difference between cabin interior and exterior ΔT [°C]:

$$Q_{Diss} = \frac{P_0 + C^2 P_{cu}}{1.16\Delta T} \quad \text{Equation1}$$

The cabin air renewal is done due to the pressure difference between the cabin´s interior and the exterior sides. This results on a fair density difference that has its origin in the temperature difference.
These factors create a natural ventilation, that produced air flow Q_B $[m^3/s]$ can be calculated through equation 2 function of openings discharge coefficient C_d (for this openings was considered 0,6), of inlet and outlet openings area A $[m^2]$, of gravity acceleration g [m/ s^2], of height difference between the openings H [m] and of cabin interior temperature Ti and exterior temperature To, given by [5]:

$$Q_B = C_d A \sqrt{2gH \frac{T_i - T_0}{T_i}} \quad \text{Equation2}$$

The desired air flow regulation is fulfilled by the inlet and outlet holes area regulation and should be designed for the transformer average load regime. With equation 1 and 2 it's possible to achieve the necessary openings area.

Winter and summer time analyses

This study was done throughout summer and winter periods. During winter time, there is a need to regulate or obstruct the ventilation openings of secondary substation in a way to provide a higher thermal capacity to the cabin and a reduction of humidity levels in its interior. Through the summer period, it is then important to verify that the implemented regulation will not degrade the adequate power transformer refrigeration.

MONITORING RESULTS

Within figures 4 to 7, the cabin exterior temperature, T_{ext}, the cabin interior temperature, T_{int},the cabin exterior humidity, H_{ext}, the cabin interior humidity,H_{int}, and the power transformer load regime, $Load_{PT}$are represented for the CB1 and CB2.

CB1Winter Period

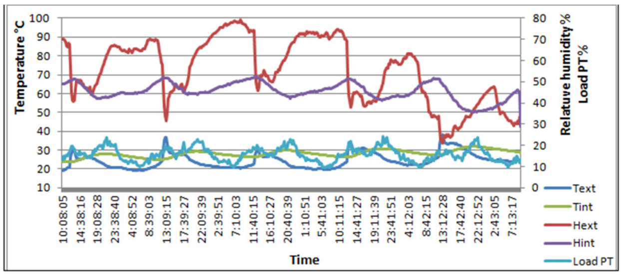

Figure 4. Data fromCB1 with openings regulated to 80 %of the nominal value, winter.

From CB1, with obstructed openings, analysis it can be seen, see figure 4, that the interior temperature varies between 16ºC and 18ºC showing greater stability through time. This directly influence the relative humidity stability that ranges from 56 to a maximum of 75%.
This value is achieved when the outside relative humidity reached a higher percentage of humidity. The power transformer load regime has an average value of 20% and the peak load matches with the higher temperature points, making their contribution to the temperature stability, verified in the cabin´s.

CB2WinterPeriod

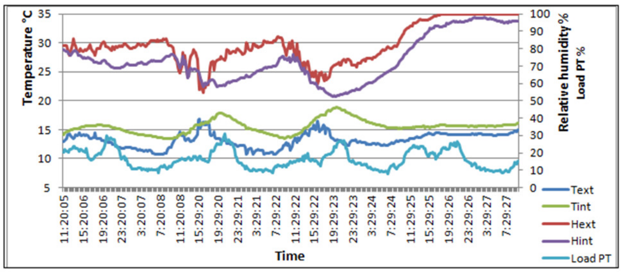

Figure 5. Data from CB2with openings in nominal value, winter.

For the CB2 with openings in nominal value, the temperature variation inside of cabin has greater oscillation and varies between 13ºC and 18ºC. The major influence on this comes from the outside temperature variation. The transformer load regime has an average value of 16% and the peak loads raise the interior temperature to values identical to the previous case. The relative humidity also shows a greater oscillation with values between 53 and 98% and the average value is higher. It can be seen that the interior relative humidity reaches higher values when the exterior humidity also reaches its maximum value.

In both graphics it is shown that the increase of temperature inside the cabin, clearly cause a decrease of the relative humidity level.

CB1SummerPeriod

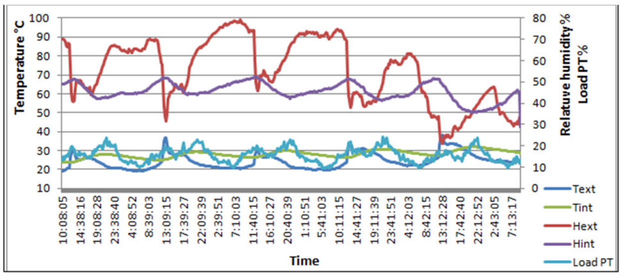

Figure 6. Data from CB1 with openings regulated in 80 %, summer.

From the analysis of CB1 with obstructed openings at 80%, it is shown that the interior temperature varies between 25ºC and 32ºC. It shows a good stability throughout the time, influencing the relative humidity that assumes values between 32 to a maximum of 56%. The humidity minimum value recorded in the cabin´s interior is also due to the contribution of the lower outside air relative humidity. The transformer load regime has an average value of 16% and the peak load matches with the points of higher recorded temperature. During the summer, the humidity average values are normally low and the generated ventilation with openings obstructed in 80%, is sufficient to provide full transformer refrigeration.

CB2 SummerPeriod

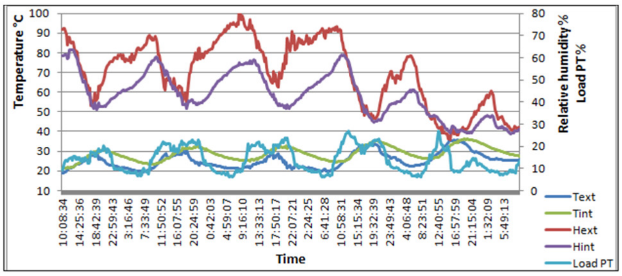

Figure 7. Data from CB2 with openings in nominal value, summer.

For CB2 with openings at nominal value, the interior temperature variation shows a higher oscillation and the values range between22 and 36ºC.
The recorded interior temperature peak values are influenced by the outside temperature together with the transformer load regime, which represents an average value of 14%. The interior relative humidity also presents a higher oscillation with values between 26 and 63%. In the summer, due to the openings being at its nominal value, the cabin interior relative humidity and temperature has greater oscillation and the interior temperatures achieved are higher than the recorded for the CB1.

Synthesis

The study and simulations performed with several transformers load regimes and different nominal power values lead to the establishment of a table, with standard values.

Transformer Power Rating [kVA]	**<= 160**	**250**		**>250 to <=630**		
Load [%]	Any	<=40	>40	<=20	>20 to <=60	>60
Recommended value for closing the openings (winter and summer)[%]	80	80	50	80	50	0
Peak area of the openings [m2]	*0,10*	*0,10*	*0,23*	*0,10*	*0,23*	0,45

Table 1. Openings obstruction in function of power transformer load regime and nominal power.

Table 1 points out to which ventilation openings regulation can be applied into secondary substations.

The knowledge of the installed power and of the average load regime of any installation, can have a practical and direct application from this table, integrated in preventive maintenance actions.

CONCLUSIONS

With this work, we studied and analyzed the ventilation within two secondary substations of 30kV, both during winter and summer periods, through recorded data from cabin site.

Considering the existing physics relations between humidity and temperature at constant pressure, a humidity decrease is achieved with a temperature increase and this effect is the one that is desired inside the cabin.

Knowing that the main heat source inside the cabin comes from the transformer loss and that the natural ventilation has the function of remove the generated heat from the cabin´s interior, then the air flow control is achieved through the ventilation openings regulation. This is the more practical method to maintain a particular temperature level inside the cabin, with the objective of decrease the relative humidity levels.

This study was split in two periods, considered as winter and summer period and allowed to establish that during winter period, when the MV equipment is under higher humidity levels, the degradation velocity increases.

During the summer period the relative humidity levels are normally lower. Therefore, it was necessary to verify if the calculated openings regulation for the winter period could degrade the power transformer refrigeration.

The study shows that the openings regulation can be used during both periods. In winter time it has the function to decrease the temperature oscillations and supplying greater thermal capacity to cabin allowing the reduction of humidity levels.

In summer, the average temperature, at cabin’s interior and exterior, increases. Nevertheless, the differential between temperatures is bigger, that implicates a higher ventilation capacity that removes a higher heat quantity.

When the openings regulation doesn’t exist, the cabin interior conditions from thermal point of view, are worst and the interior temperature value achieved is lower, meaning higher humidity levels. The cabin interior conditions are submitted to a higher influence of the exterior temperature and humidity variations.

The simulations conducted for several transformers load regimes and with different nominal power had as a goal the elaboration of table 1, where it was standardized the percentage of ventilation openings obstruction as a function of the power transformer load regime.

Contents on table 1, are based on research in CB1 and CB2 cabins. This table can be applied to any type of cabins, yet the value of obstruction should be increased in higher cabins, or pre-fabricated low cabins due to the value of thermal losses verified in those structures.

The cabin ventilation regulation must be designed considering the transformer average load regime and calculated for the winter period.

Through identification of secondary substations with low values of power transformer load regime the direct application of this table has great practical advantage and its implementation in secondary substations can be integrated in preventive maintenance actions. The bulky investments in the secondary substations are done with a lower frequency.

REFERENCES

[1]C. Kilindjian, F. Ercole., M. Perrone, D. Serve, 2007, “*Environmental installation and operating conditions of MV products*”, Conference publication.

[2] EDP Distribuição, 2004, “*Postos de Transformação MT/BT de Distribuição Pública*”, DMA-C13-910/N.

[3] J. Geria, P. Cristino, C. Santos, T. Santiago, 2013, “*MV/LV Substations-Solutions to improve the technical quality of service*”,CIRED-Stockholm,

[4] E. R. Oliva, 1991, “*Transformadores de potência, medida e proteção*”, Marcombo, Barcelona

[5] D. Etheridge, M. Sandberg, 1996, “*Building Ventilation-Theory and Measurement*”, Wiley & Sons.