DISTRIBUTION TRANSFORMER COOLING USING THE GEOTHERMAL ENERGY FROM THE UNDERGROUND ELECTRIC PIPELINES

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ABSTRACT
In a world where every year humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste, efficiency is one the keys to fight against it. But beyond that, if we mix, in an intelligent and a simple way, efficiency with sustainability, we can obtain an optimal result than can be a humble contribution to make our distribution network business more profitable and at the same time more respectful of the natural environment.

INTRODUCTION
The indoor transformers centres (ITC) are an important elements in an urban distribution network in Europe and many other countries around the world. But also in other electric networks: like large photovoltaic farms, wind farms, and so on. Over time, it is more usual that the peak load happens when the ambient temperature is the highest, especially during the summer in hot climates. This coincidence creates the worst operating conditions for the transformer and the rest of elements inside, producing an acceleration of its loss of life and increases the risk of suffering an accident due to the high temperatures reached inside. To prevent this, it is essential to dissipate the heat to the outside in the best possible way without consuming additional energy.

HEAT INSIDE ITC (INDOOR TRANSFORMER CENTRE)
ITC used in urban areas, are generally small in size and poor ventilation.
The most important element of an ITC is the transformer, responsible for the 97% of the losses as heat generated inside.

In hot climates, especially in summer, the peak of the transformer load in an ITC, and therefore the maximum losses inside, happens when the ambient air temperature is also maximum. This is most likely due to widespread use of air conditioning.

This coincidence complicates very significantly the heat dissipation from inside to outside, subjecting to all ITC electric equipment, in working conditions at very high temperature. The consequences are manifested in accelerating loss of life of the transformer and an increased risk of electric accident inside the ITC.

Transformer loss of life occurs by degradation of windings isolation and can be calculate by the case of oil-immersed transformers based on two rules:

- IEEE [C57.91-2011]: estimates 20,55 years as the lifetime of a transformer, considering that the winding hottest-spot temperature is equal to 110 °C and the ambient temperature 30 °C
- IEC [IEC 60076-7]: estimates 30 years as the lifetime of a transformer, considering that the winding hottest-spot temperature is equal to 98 °C and the ambient temperature 20 °C

In the next figure (3) it can be seen the lifetime variation (PUL = per unit life) of the transformer depending of the winding hottest-spot temperature (θHS). For example, 20 °C of temperature variation of that, involve an alteration up to 10 times in the transformer lifetime.
Figure 3: Transformer life variation with temperature of the hottest point (IEEE)

Methods traditionally used to cool the transformer inside an ITC are the following ones:

1) Natural cooling: based on the chimney effect.
2) Forced cooling: by using fans, when the previous method is not enough.
3) Air conditioning: by heat exchangers, used exceptionally in extreme situations.

The cooling system proposed in this document is intended as an alternative to options 2 and 3 above, particularly suitable in warm climates or spaces where ventilation conditions are not satisfactory to achieve adequate operating conditions of the transformer.

UNDERGROUND ELECTRIC PIPELINES FOR COOLING PURPOSES

The use of geothermal energy for cooling buildings has been a reality for decades. Therefore, the existence of buried electrical pipelines for cables entering and leaving the ITC could be used for the same purpose.

This proposed cooling system, called “geothermal ventilation through electric underground pipelines” has the following basic conceptual scheme:

This system can be made both for new facilities using specifically ventilation tubes placed at the bottom of the new pipes or tubes free in existing pipes that are not occupied by electrical conductors.

The cooling efficiency of the system will depend on several variables, the most important is the ground temperature at the depth where the ventilation tube is placed.

In a general mode, there are three temperature zones in the ground depending on the depth:

- Surface zone (from 0 to 1 m), where the temperature is variable, very sensitive similar to the external environment.
- Intermediate zone (between 1 to 8 m in dry soils and 1 to 20 m in wet soils), where temperature is constant, similar to the average temperature of the external environment.
- Deep zone (at lower depth, but without reaching the area of the terrestrial mantle), where the temperature is constant during all time.

In the next figure it is shown the annual temperature evolution registered in an electric trench at 1.4 m depth, located in a street in the city of Gijón (Northern Spain), compared with the temperature of the external environment.

Figure 5: Annual ground Temperature in a buried electric pipeline in the city of Gijón (Spain) – ITC Quevedo

There are other factors that influence the ground temperature to a lesser extent, like the kind of ground cover (grass, asphalt), insolation level, and physical properties.

PUMPED AIR BEHAVIOUR THROUGH A PIPELINE BURIED

To design a system as shown in Figure 4 it is necessary to simulate the behaviour of the air forced through the underground pipe and identify the variables that affect it.

With this objective a software algorithm that calculates this behaviour was developed, as a specific project. It was tested and adjusted for several years in three pilot installations listed in the following section.
The stated algorithm uses as input variables the following:

- Environment variables (not modifiable for the designer)
  1. Ambient air temperature
  2. Relative air humidity
  3. Air pressure
  4. Ground thermal conductivity

- Design variables (modifiable for the designer)
  5. Ground temperature (depends on the depth)
  6. Air flow rate (pumped)
  7. Tube material
  8. Tube length
  9. Tube diameter
  10. Dirt resistance (tube internal surface)

**OUTPUT/RESULTS:**

1. Air temperature at the outlet (and also at any point in the tube)
2. Condensed water (flow/volume and point in the pipeline where it starts)
3. Cooling capacity obtained

![Graph of Longitudinal Temperature Evolution](image)

Figure 6: Results of the behaviour analysis software of forced air through pipes buried

The main conclusions from experience of using this software in actual installations used as a pilot for several years were as follows:

1. Regarding the tube length and diameter: Greater length means more cooling capacity, but in general terms for use in cooling ITC the recommended lengths are between 50 and 100 m. Larger diameter means more cooling capacity, so the recommended diameters ranging from 150-200 mm Ø.
2. Regarding the type of tube material: Higher thermal conductivity implies greater cooling capacity (Al increases 34.6% compared to PVC).
3. Regarding the amount of relative humidity in the air: Higher relative humidity means less cooling capacity (variation from 30 to 60% in relative air humidity reduces the cooling capacity the 11.79% and at the same time the outlet air temperature in 6.11%).
4. Regarding the ground thermal conductivity (λ): Higher conductivity implies greater cooling capacity (sandstone soil has a λ=3 while clay has λ=1.5, the first increases cooling capacity in 15.94%).

**PILOT FACILITIES AND TESTING PERFORMED**

Three ITC were adapted to this cooling system using forced air through the underground electric pipelines, taking advantage of geothermal energy, and put in real operation during several years till nowadays.

**LLAMAQUIKE ITC**
- Located in Oviedo-Northern Spain, urban area
- Underground of 15 square meters
- Nominal rate 1000 kVA
- Cooling tube: free existing tube of 160 mm Ø- PE
- Tube length: 80 m
- Tube depth: 0.5 m
- Air inlet: lateral wall of a garage entrance
- Date of commissioning: March 2008

**RONDA-3 ITC**
- Located in Parla-Madrid – Central Spain, residential area
- Underground of 15 square meters
- Nominal rate 630 kVA
- Cooling tube: two specific tubes (Al + PVC): 150 mm Ø each
- Tube length: 130 m
- Tube depth: 1.3 m
- Air inlet: in another ITC called “Fuente Arenosa”
- Date of commissioning: July 2008

**QUEVEDO ITC**
- Located in Gijón - Northern Spain, urban area
- Residential building (at street level), 16 m²
- Nominal rate 630 kVA
- Cooling tube: two specific tubes (Al + PVC): 150 mm Ø each
- Tube length: 110 m
- Tube depth: 1.4 m
- Air inlet: in another ITC called “Quevedo 45”
- Date of commissioning: November 2008
In this case (figure 9), due the ITC is located at the level street in a residential building, it was installed an air silencer to reduce the possible fan noise to the minimum.

During these years many tests and trials were conducted at designated facilities. They focused on the study of the behaviour of the air through the buried pipeline and its cooling effect on the transformer of each ITC, in terms of how it affects the transformer lifetime.

One of the most outstanding experiments was performed in the ITC Quevedo. It was called “stress testing”, considering as such a situation in which coincides the maximum load, maximum ambient temperature and maximum inlet air temperature.

Maximum load: obtained from switching in the low voltage network of the area, deriving the greatest possible load from adjacent ITCs.
Maximum ambient temperature: a hot summer day
Maximum inlet air temperature: artificially overheating (by electric heaters) the point where is located the air inlet.

In this situation of stress, tests were performed under two scenarios: with the geothermal cooling system ON and OFF, and in different days with the same values of load and ambient temperature. Below are graphs with the evolution of the most relevant variables of each.
As it can be seen from both graphs, the value of temperature (top oil) achieved in the transformer (immersed oil type) in the scenario with geothermal cooling to ON does not exceed 50 °C, while in cooling OFF scenario the temperature reaches 56 °C. In terms of transformer lifetime, according to the IEEE standard, the use of geothermal ventilation system is an improvement of 53.34% for the day compared with natural cooling.

Another significant finding is the behaviour of the temperature in the outlet pipe which is kept constant throughout the day, even though the temperature at the air inlet reaches 40 °C. Really this outlet air temperature rises very slightly throughout the day, but this is due only to increased internal temperature of the ITC that affects the measurement of the first. This statement is proved by real time measurements of the air temperature along the pipeline, as shown in the graph below:

![Graph showing temperature evolution in the cooling pipeline of ITC Quevedo during stress testing with geothermal cooling fan = ON](image)

**Figure 12: Air temperature evolution in the cooling pipeline of ITC Quevedo during stress testing with geothermal cooling fan = ON (25/August/2014)**

**VERSIONS OF BASIC CONCEPTUAL SCHEME**

From basic conceptual scheme defined in Figure 1, it is possible to define variants that enhance the functionality and performance of the cooling system.

![Diagram showing 2 ITC setting in combined operation](image)

**Figure 13: 2 ITC SETTING IN COMBINED OPERATION**

This configuration above allows operation with a single fan and refrigerate 2 ITC both, one as forced natural air cooling, and the second with geothermal cooling. This is the one used in the tests performed in Quevedo ITC.

![Diagram showing 2 ITC setting in chained operation](image)

**Figure 14: 2 ITC SETTING IN CHAINED OPERATION**

This other setting, as defined above, optimizes the performance compared with a single ITC, since the air flow in each ITC has an impulsion fan and another extraction fan. It significantly improves the cooling effect. It can be extended without limit of ITC, and it is quite realistic to be used in real distribution networks with underground electric pipelines.

**CONCLUSIONS**

1. The use of cooling systems based on forced air through the underground electric pipelines in order to cool ITC are feasible, effective, cheap and environmentally sustainable.
2. This approach is particularly recommended for hot climates or special situations of heat accumulation.
3. It can be used for it new specific pipelines in new network deployments, as free underground pipelines in the existing networks.
4. The operation and maintenance costs of this system are very low, equivalent to a basic ventilation system.
5. The design and estimation of the behaviour of air pumped through buried pipe is possible and accurate using the software made.
6. The location of the equipment inside the ITC influences in a very relevant way in the dynamic heat flow and consequently in the cooling performance of the solution.
7. There are different settings that can improve very significantly its performance without additional costs.

**REFERENCES**

[1] IEC 60076-7 ed1.0 Power transformers - Part 7: Loading guide for oil-immersed power Transformers Ed.15/12/2005