THE SPANISH EXPERIENCE IN THE USE OF HV/LV INTEGRATED TRANSFORMER SUBSTATIONS, ENVIRONMENTALLY FRIENDLY

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ABSTRACT

The increasing concern related to the consequences of the human interference in the environment as the main result of the population growth has changed the policies of all the governments and gradually the conscience of the general public all around the world. This time is the time of the environmental concern, and each day our decisions play more and more an important role in the future of the next generations.

Manufacturers of electrical equipment and utilities are totally involved in the protection of the environment as ones of the most important contributors to industrial waste, CO2 emissions that could reach 33% of the total emissions in Europe, energy efficiency, SF6 or mineral oil leakages, etc.

This new conscience challenges the utilities everyday to analyze the main sectors of their business in which the environmental pollution has a huge specific weight and could be decreased in a considerable amount opening their view to the latest’s available technologies.

At the end of the 90’s, before the events happened, INCOESA, an Spanish manufacturer of power transformers, with one of the biggest utilities in Spain as a partner, IBERDROLA, started an R&D project in the field of the HV/LV Transformer substations trying to find a new environmentally friendly solution for the Substations in use at these moments in Spain. Those days people show some caution against one kind of unknown product and its service results, although a similar concept was been used in the US for years. Since then, an important advance has been made and after more than 10 year service experience, the result is an alternative eco-designed substation almost 100% biodegradable with a tested reliability.

INTRODUCTION

The most typical HV/LV Substation in Spain were those based in the use of SF6 cubicles for the operation of the MV and protection of the transformer and the use of mineral oil as the dielectric medium of the transformer. This parts are manufactured and tested individually and then assembled and connected together either in factory or in site by means of cables and type tested interconnections.

This assembly is introduced in a concrete enclosure for outdoor installation or bolted to a frame for indoor installations.

At the end of the 90’s several initiatives from the Spanish utilities tried to introduce in the Spanish market a totally new concept of HV/LV substation adapting equipment already in use in the US to the specifications of the Spanish network.

One of these initiatives resulted in one of the most ambitious Spanish R&D project in the field of HV/LV substations which led to a compact substation called CTIN.

The successful results of the project were recognized with several European prizes as one of the most innovation and environmentally friendly products.

Picture 1. Environmental and innovation European prizes

CTIN is a HV/LV prefabricated transformer substation (up to 1000kVA 24 kV) in which the main functions (HV switchgear, transformer) are installed in a metallic enclosure and share the dielectric medium (K liquid 100% biodegradable), to this assembly is attached directly the LV panel and finally a metallic enclosure that covers all the assembly preventing public to approach the equipment.

For outdoor installation only a concrete pad is needed, all accessible parts are protected against live parts or high temperatures. For indoor installation a frame with wheels is provided.
ENVIRONMETAL BET

Besides the reliability of an equipment fully tested by the manufacturer totally assembled in factory and its reduced size, this especial design called CTIN has been offering lot of advantages during these last 10 years of service, compare to a common substation, those related to the protection of the environment are listed below:

- Use of a seed based fluid for insulation and cooling;
- Lower losses;
- Lower noise level;
- Lower Electromagnetic fields (EMF).

Alternative dielectric medium

Mineral oil has been used as the dielectric medium for transformers since the end of the XIX century. In the “short” history of the mineral oil, only the concern related to the fire protection has been responsible of the development of some alternatives with a poor success (PCBs).

One century after the first distribution transformer, the first less flammable fluids without PCBs as silicone oil were developed and a new classification for these kinds of fluids was created for those with a fire point above 300ºC.

Nowadays in Spain mineral oil is still been used as the principal insulating liquid for distribution transformers. The Spanish regulations require expensive methods to retain the oil in case of leakage preventing the soil to be polluted; furthermore due to the low fire point of the mineral oil also equipment for fire protection must be part of the installation.

In the other hand, SF6 is used in the electrical industry as a gaseous dielectric medium for high-voltage switchgear and controlgear for the last 30 years. It has a high dielectric strength that made possible to reduce considerably the size of the cubicles, making them suitable for certain purposes such as indoor placement. At this moment it is the most used fluid in Europe for these applications.

Against the great properties of the SF6 there is the environmental concern. SF6 is the most potent greenhouse gas that it has been evaluated, with a global warming potential of 22,200 times that of CO2 when compared over a 100 year period. This force the manufacturers and the utilities to adopt some precautions when handling and at the end of life of the product.

Fortunately few years ago investigations on food quality vegetal oils showed that there is a chance to avoid the use of dielectric fluids mineral oil based, as the dielectric properties of these fluids are very close to the mineral oil. Furthermore it was demonstrated that these fluids has a very good behaviour as a substitute of the SF6 in MV applications.

At the beginning of the XXI century the mixture of a quality substation design and a seed based fluid become real in Spain. The collaboration of Cooper Power Industries, responsible of creating the fluid known as FR3 and INCOESA resulted in the first Spanish HV/LV Transformer Substation without neither mineral oil nor SF6.

Nowadays, after more than 10 years service experience, hundreds of units are working along all the Spanish geography with more than an acceptable reliability.

Lower losses

An approximate number of a 630 kVA HV/LV transformer substation installed per year for a typical utility in Spain as a reference could reach 1.000 units approximately. The table for the rated losses of a typical 630 kVA distribution transformer (DT) following the national standard UNE 21428-1 compare to a 630 kVA CTIN is showed in Table 1.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Load losses</th>
<th>No load losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>630 kVA DT</td>
<td>6500 W</td>
<td>1300 W</td>
</tr>
<tr>
<td>630 kVA CTIN</td>
<td>4170 W</td>
<td>1030 W</td>
</tr>
</tbody>
</table>

Table 1. Rated losses of DT vs. CTIN

No load losses occur in a permanent way throughout the equipment's life, which means that the transformer is permanently connected for 8760 hours per year. To obtain the total load losses it is estimated an average working conditions of 50% the rated power during a total of 4500 hours per year. The total losses and saving is showed in Table 2.
Table 2. Total losses of DT vs. CTIN. Saving

Considering the different existing ways of electric energy production an average rate of 600 CO2 Kg/MW is applied and in this conditions during a little bit more than 10 years of service the decision of installing CTIN with a low rate of losses has saved the atmosphere 4500 Tn of CO2 which is without any doubt a great investment for the future.

The second advantage due to the losses reduction is the decrease in the working temperature of the whole substation that at a rated power could be 40% less compare to a typical distribution substation. An assistance to evaluate this parameter is the national standard UNE 21110 “Oil immersed power transformer on load guidance”. According to this standard all the parameters that affect the hot spot temperature has a direct influence in the life expectancy. The normal life expectancy of a transformer is a typical reference based in the consideration of a continuous rated service conditions, at an ambient temperature of 20ºC and a maximum temperature of 98ºC of the hot spot. If this last value is exceeded the consequence is the decrease of the life expectancy. In that conditions the life expectancy of a transformer according to that standard is 20 years and in order to calculate the life expectancy factor of any transformer the following formula is applied:

\[ V = 2^{(x-98)/6} \]

According to this formula it is possible to calculate the life expectancy of the transformer vs. the temperature of the hot spot:

<table>
<thead>
<tr>
<th>Hot-spot temperature</th>
<th>Life expectancy factor</th>
<th>Life expectancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td>1/2</td>
<td>40</td>
</tr>
<tr>
<td>96</td>
<td>0.79</td>
<td>25.3</td>
</tr>
<tr>
<td>98</td>
<td>1</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 3. Hot spot temperature vs. life expectancy

In case of a CTIN the temperature of the hot spot is much less than 92ºC so the life expectancy related to thermal restrictions reach easily more than 40 years and consequently the damage to the environment reduces in a considerable way

Lower noise level

The limits for the noise level of a typical HV/LV substation are often determined by the transformer, since the test for the whole substation is not normative. Taking that into account, the limits for the noise level of a HV/LV substation following the national standard UNE 21428-1 for a typical 630 kVA transformer compare to a CTIN is showed in the Table 4.

<table>
<thead>
<tr>
<th>Rated power</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>630 kVA typical substation</td>
<td>67 dB</td>
</tr>
<tr>
<td>630 kVA CTIN</td>
<td>54 dB</td>
</tr>
</tbody>
</table>

Table 4. Rated power vs. Noise level

The low rate of no load losses as the principal cause of the noise level and the more quantity of dielectric liquid of the CTIN that works as a sound insulator, compare to a typical distribution transformer, make possible to reach very low rates of sound levels as showed in the previous table. Sometimes distribution substations are installed very close or even inside residential buildings, and they are often over loaded, experience says that 1dB reduction of the sound level costs 400€ approximately by means of shock absorbers or complex sound insulator systems, due to that reason a substation with a low rate of sound level itself could suppose besides the contribution to reduce the environmental pollution, an interesting way of saving money and complaints.

Lower Electromagnetic fields

Another important point considered as an environmental pollution is the electromagnetic fields. This phenomenon concerns more and more each day to the general public and this means a problem for the utilities which install lot of equipment without taking into account that the maximum permissible levels could be reached.

Recently IEC 62271-208 Ed.1, a new document related to methods to quantify the steady state, power-frequency electromagnetic fields generated by HV switchgear assemblies and HV/LV prefabricated substations has been circulated for parallel vote to the national committees of CENELEC and finally accepted for circulate as an FDIS. This means that probably in the near future a low rate of electromagnetic emissions will be included as a rating of the HV/LV substations.

One main characteristic of the CTIN maintains the EMF fields too far from the limits: the LV panel is connected directly to the transformer LV bushings, so that the principal EMF emission is confined inside the metallic tank of the transformer directly connected to earth and consequently decreasing the EMF to a very low levels.
The first unit of this kind of equipment manufactured by INCOESA was installed in Spain in 1998, following the particular standards of the Spanish utilities. In Spain this kind of installation must also comply with some regulations and due to the matter that this kind of equipment was neither cover nor uncover by the approved regulations at these moment they had to be modified. Finally a new definition for the new concept of substation covering CTIN was officially published in April 10th 2000.

At the same time, some Spanish manufacturers trying to offer an equipment with similar characteristics improved their common substations in the terms of reducing size and increasing reliability deviating in some aspect from existing product standard. The result of this improvement was two different products, CTIN and compact substations, not totally covered by the current international standards that deal with this kind of equipment (IEC 62271-200, IEC 62271-201 or IEC 62271-202).

Two years ago the Spanish utilities, main users of this equipment, claimed for an European support in the shape of an international standard covering both assemblies. Consequently the work was started at the level of CENELEC, a European WG was created and the project was called PrEN 17118 “Compact Equipment Assembly for Distribution Substations (CEADS).

This work is nowadays at the level of CD2 and probably become a standard during 2009.