HiDry^{72}: The Oil-Free and Safe Power Transformer for Sub-transmission Level

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Abstract HiDry^{72} is the safe and environmentally friendly solution in transformer technology for distribution and sub-transmission lines capable of reaching up to 63 MVA and 72.5 kV insulation level. The HiDry^{72} uses dry-type (non-oil) insulation materials to achieve these ratings. For the customer, this means superior safety and environmental friendliness for people and property. These advantages make the HiDry^{72} a product very suitable for applications in urban substations, power generation plants, substations located near or in public buildings or sensitive ecosystems, in cavern/underground locations and in crowded public places. This technology also provides the ability to install higher voltage systems directly to the main load centers; providing higher power and reducing distribution losses by reducing the amount of low voltage cable runs. The development of a dry-type power transformer for the 72.5 kV voltage class was already presented in 2011 [1]. Since then, a great interest has been shown in the market for many utilities as well as industries because all benefits inherent to the dry technology. In this abstract we report about the technology and some current projects in operation.

Keywords Dry-type power transformer · Subtransmission · Indoor substation · GIS · Fire-safety

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1 Introduction

In the past, the use of dry-type transformers was only possible in the distribution grid since there were no products available for voltages >36 kV. Dry-type power transformers for the 52 kV voltage class were introduced about a decade ago. They are meanwhile used in a number of utility and industrial installations and have proven their high reliability. The next level in voltage has recently been achieved when ABB introduced the HiDry^{72} transformers. These are dry-type power transformers for the 72,5 kV subtransmission voltage level. CIGRE already published in 2013 the brochure "Guide for transformer fire-safety practices" applying to power transformers rated >10 MVA and 66 kV [2]. A survey on transformer failures concluded that, assuming 50 years lifetime, one out of 20 transformers catches fire during its life.

HiDry^{72}, the dry-type power transformer for the 72.5 kV subtransmission voltage level, offers all general features of dry-type transformers. The major benefit being the lack of flammable liquids, as used in oil-filled power transformers. The dry-type transformer is non-explosive and self-extinguishing. In case of an external fire, its combustible mass is much smaller and much less smoke is created. Their installation and application is simple and fast. They have high strength against short-circuit or other mechanical loads and require less maintenance.

With the above advantages, the HiDry^{72} is therefore ideally suited for inner-city and underground installations. It can be installed in any building. When combined with GIT switchgear equipment, it will allow for future, simpler and compact substation designs [3].

The availability of an oil-free (dry-type) on-load tap changer has supported the introduction of the HiDry^{72} transformer product in the market. The first installations of HiDry^{72} transformer were presented at CIRED 2013 [4].

One important aspect to consider is the EcoDesign required by the European Union that has finally concluded in the EN50629 "Energy performance of large power transformers", $U_m > 36$ kV or $S_r > 40$ MVA. It is the first time there is an international requirement about efficiency in dry-type power transformers, and the HiDry^{72} transformers fulfill the requirements indeed.

2 HiDry^{72} Dry-Type Power Transformer Technology

The base for the development of the 72.5 kV dry power transformers were the well-established ABB medium voltage transformers in VCC technology; however, the higher voltage level, a higher rated power, and an increased range for voltage regulation lead to several technical challenges. An excellent understanding of the underlying physics and intensive use of FEM based simulations in combination with experimental testing were required for materializing a reliable new product [5].

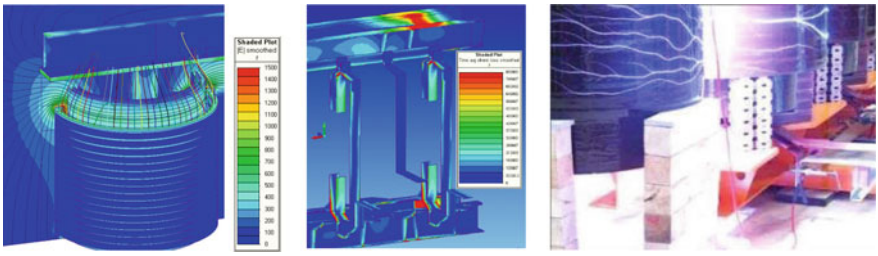

Fig. 1 Development of 72.5 kV dry-type power transformer: electric field simulation with electric stream lines, stray losses in structural components and busbars, and testing beyond the limits

The dielectric stress within a dry-type transformer is withstood by solid and air insulation. Due to the higher permittivity of the solid insulation, the electric field in the solid material is reduced and air becomes the main insulator. The dielectric strength of air is therefore the limiting factor and defines maximum electric fields and minimum insulation distances.

Magnetic stray fields can cause eddy currents in the windings which can become very significant with increased power rating and growing cross section of the conductors. The larger stray fields also create additional eddy losses and hot spots at unexpected locations. These eddy losses strongly depend on the winding design. When the OLTC is connected at its minimum position and part of the winding turns are "deactivated", the magnetic stray fields and eddy currents are especially strong and local hot spots can easily be generated (Fig. 1).

Although there is no IEC/ANSI standards for this product, HiDry^{72} fulfils the same partial discharge level as the standard requires for transformers up to 36 kV, (maximum 10 pC at 1.3 U_n). This guarantees that no degradation of the insulation due to PD is taking place and that the transformer will have a long lifetime.

3 HiDry^{72} Technical Features

The HiDry^{72} transformers offer identical functionality as 72.5 kV liquid-immersed power transformers [6]. The key characteristics are shown in Table 1.

3.1 Ageing and Overloading of Dry-Type Power Transformers

Both oil filled and dry-type transformer technologies have industry standard loading guides to help estimate overloading capabilities. Oil power transformers follow the loading guide IEC 60076-7 and the HiDry^{72} follows the one for dry-type transformers (IEC 60076-12, or IEE C57.96™). All of these standards show how the

Table 1 Characteristics of 72.5 kV dry-type power transformer HiDry[72]

Rated power	Up to 63 MVA	Partial discharge	<10 pC
Primary voltage	Up to 72.5 kV	Insulation class	F (155 °C) or H (180 °C)
Lightning impulse voltage	325 kV for IEC 350 kV for ANSI/IEEE	Environmental class	E2
Short duration AC withstand voltage	140 kV for IEC 140 kV for ANSI/IEEE	Climatic class	C2
Secondary voltage	Up to 36 kV	Fire class	F1
Connection group	Y or D	Cooling	AN, ANAF, AFAF, AFWF
Tapings	17 positions, $\pm 8 \times 1.25\%$	Enclosure	IP00 (none), IP21 (indoor) to IPX4D (outdoor)

operational conditions (loading profile, ambient temperature, etc.) and design characteristics (average temperature rise in windings…) can affect the overloads admitted and the lifetime of the transformer. They also indicate how measuring the insulation material ageing ratio as well as the calculation of loss of life, and therefore life expectancy, can be estimated in both technologies. What these standards detail is that each transformer has individualized overload capability curves that will depend on its own design (mass of conductors and mass of solid insulation). This method of ageing and overloading prediction is more advanced than the former loading guide that established curves solely depending on ambient temperature.

For lifetime ageing considerations, both transformer technologies (oil or dry-type) must be designed to operate continuously fora minimum of 180,000 h (20 years) working in nominal conditions (at full ratings). Therefore, from performance point of view, both technologies have the same life expectancy working in the same conditions.

The real lifetime for power transformers (oil and dry) can be much longer, however, in cases where the normal operation conditions are less than the full nameplate rated values, in time and loading. For example, the standards show that for dry-type transformers, an increase of 6 K in thermal rise doubles the ageing rate while a reduction of 6 K halves ageing rate. Furthermore, there is an additional margin coming from the gap between the measured values and the guaranteed limits regarding average temperature rise of the windings and core.

3.2 HiDry[72] Dry-Type Power Transformers Installations

A number of HiDry transformer indoor and outdoor substation installations have been carried out and are currently in operation. In the following section we present a few of these case examples:

1. Indoor 66 kV Substation in Industrial Plant

The ABB factory in Córdoba (Spain) has a long tradition of manufacturing transformers being since 1999 the ABB center of Excellence for shell-type transformers.

For both technical and safety reasons, it was decided in 2011 to upgrade the entire electrical installation of the factory (HV, MV and LV), in a turnkey project. The project included a complete substation with GIS, transformers, cells, lines, etc. And the two HiDry^{72} transformers manufactured by ABB in Zaragoza were installed (Fig. 2). Each one 12 MVA, 66/20 kV power rated, provided with an on-load dry tap changer (OLTC), with 17 positions and 1.25% tapping step, which will work as back-up on each.

2. Indoor 69 kV Substation in Soccer Stadium

This project in Salvador de Bahía (Brazil), where the new Fonte Nova Stadium hosted matches of the FIFA World Cup^{TM} in 2014. This new building includes a new substation where two vacuum cast coil dry-type distribution transformers have been located: 2 × 25 MVA power rated, 69 kV at primary voltage, suitable for two levels of secondary voltage: 11.95 and 13.8 kV, and also provided with an on-load tap changer regulation OLTC (+4/−12) × 1.25%. Its main function is the power supply of the stadium as well as inner-city substation.

In fact, these two HiDry^{72} transformers have been installed under the access-stairs to the stadium (Fig. 3). The end user, which belongs to Coelba—Neoenergía Group, part of Iberdrola, showed special interest in ABB solutions for high power and large voltage transformers Fig. 3 shows that the transformer is installed without an enclosure. Instead a simple fence is used to prevent unintentional contact of service personal or other people with the energized transformer.

3. Outdoor 52 kV Substation in Forest

HiDry transformers are also used in outdoor installations in Sweden. The utility Ulricehamns Energi has installed a 16 MVA, 45/11 kV HiDry transformer in an outdoor substation (Fig. 4). The substation is located in an environmentally

Fig. 2 Installation of HiDry^{72} (12 MVA) in the bay (*left*). GIS installation (*right*)

Fig. 3 Fontenova stadium overall view (*left*). HiDry^{72} (25 MVA) and OLTC installation (*right*)

Fig. 4 Enclosure for outdoors (*left*). Unloading of HiDry^{72}(16 MVA) with the enclosure (*right*)

sensitive area and it is equipped with an OLTC (also oil-free) with voltage steps of $\pm 7 \times 1.67\%$. The transformer was delivered and installed in the enclosure (IPX4D) and with the OLTC mounted on the transformer (Fig. 4).

4. Outdoor 69 kV Substation for Gas combined cycle PP

Another oil-free power transformer is in the **US** where Wildcat Point will be one of the cleanest natural gas facilities of its size in Maryland (belonging to Old Dominium) and will generate approximately 1000 MW. The customer needed two

Fig. 5 Overallview of the power plant (*left*). HiDry^{72} (2 MVA) for outdoors during FAT (*right*)

HiDry^{72} transformers (2 × 2000 kVA, 67/6.9 kV NLTC for outdoors installation (enclosure NEMA 3R)) to feed a new pump station for cooling the power plant, in an environmentally sensitive area, since the substation is by the river (Fig. 5).

4 Indoor 66 KV Urban Substation

The latest installation is located in **Spain**, where Enel-Endesa has chosen the HiDry^{72} transformers for safety reasons. They chose the Hi Dry72 technology because the 4 transformers are in urban substations in the downtown of Sevillecity, close to livings and hospital (Fig. 6).

Figure 7 shows one of the four units 34 MVA 66/22 kV, including also OLTC (± 8 × 125%), YNyn0, installed in the substations and subject of dimensional restrictions of the substation. One of these transformers was short-circuited tested in CESI (2014) passing the test at first, showing an excellent reliability of the product (Fig. 7).

Fig. 6 Pictures nearby Arjona substation, in the downtown of Seville (Spain)

Fig. 7 HiDry^{72} (34 MVA) installed in the substation (*left*). One of the units 34 MVA was withstand short-circuit tested in CESI (Milan, 2014)

By choosing HiDry^{72} ABB provides a solution with a **superior safety for people and environment**, almost maintenance-free and with a very easy installation

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