Safe and powerful

Dry transformers for subtransmission

MARTIN CARLEN, MARIANO BERROGAIN – ABB's recent innovative power transformer, the HiDry^{72}, is now in operation in a number of substations around the globe. With HiDry^{72}, ABB has paved the way for dry-type transformer use to move from distribution applications into the subtransmission voltage range. The very capable and very safe oil-free technology behind this power transformer now allows substations to be easily integrated into any building, with full peace of mind. HiDry^{72} is particularly beneficial for substations located in cities and busy public venues with hefty power requirements.

Title picture
Salvador da Bahia in Brazil, with the Arena Fonte Nova stadium, which contains a 69 kV substation, equipped with 69 kV / 25 MVA dry-type transformers. Photo credit: World Cup Portal.

A number of new stadiums were erected for the 2014 FIFA World Cup in Brazil. One of the stadiums is the Arena Fonte Nova in Salvador da Bahia, a city of 2.7 million, located on the Atlantic coast in central Brazil. The stadium has 55,000 seats and is located in the center of the city → **title picture.**

Electric power is supplied to this part of the city by a 69 kV subtransmission cable line. With the demolition of the old stadium and construction of the new one, a nearby outdoor substation had to be replaced. The substation site was on a planned recreational space, so the local energy provider came up with the idea of integrating the new substation into the stadium under construction. Fortuitously, this was at the same time that ABB announced the launch of a dry-type power transformer for the 72.5 kV voltage class – HiDry^{72} [1]. HiDry stands for "high-voltage dry"; the superscript "72" indicates the 72.5 kV voltage class.

Those responsible for the project were intrigued by the idea that fire- and explosion-proof dry transformer technology could now be used not only for medium-voltage (MV) applications, but also for high-voltage (HV). It also became clear that dry transformers allowed the most straightforward design and layout, provided the most cost-efficient solution and that their use would remove any safety concerns about integrating the substation into the stadium. Safety is a primary aspect in a venue attended by tens of thousands of spectators.

Dry transformer technology

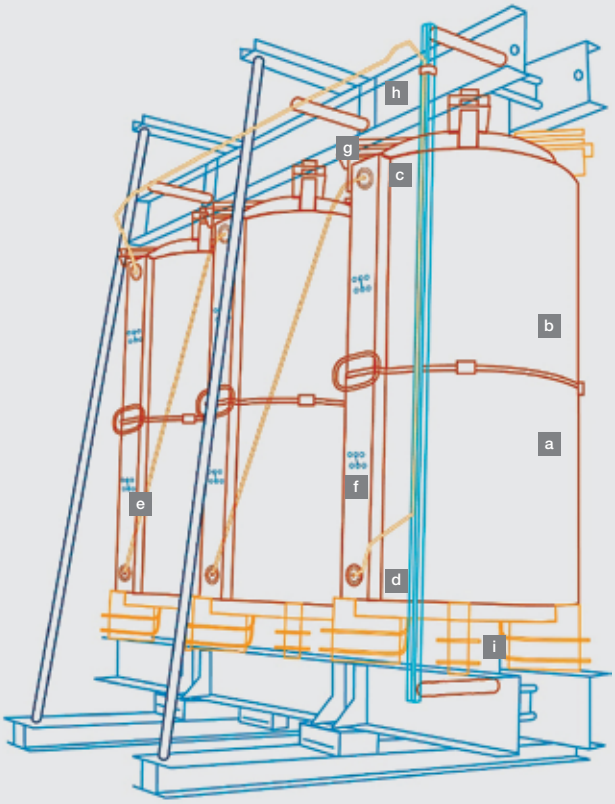
In contrast to oil-insulated transformers, dry transformers are air-insulated. This has pros and cons: The dielectric strength of oil is about eight times that of air, so the dimensions of an oil-immersed transformer core and coils are smaller than the air-insulated equivalent. On the other hand, dry transformers need no bushings and oil spills cannot occur. Their major advantage, though, is the lack of inflammable oil and other combustible materials. While a typical power transformer contains several thousand liters of inflammable oil, the insulation materials used in fire class F1 dry transformers are self-extinguishing. Dry transformers also provide an alternative to gas-insulated transformers and are safer to handle.

There are a number of different technologies used for dry transformers – like vacuum cast coil (VCC), RESIBLOC® and Open Wound – with each offering different special features. → **1** shows the main components of a VCC transformer.

Dry transformers need no bushings and oil spills cannot occur. Their major advantage, though, is the lack of inflammable oil and other combustible materials.

Between the primary and secondary coil of a VCC transformer is an air duct. Since the dielectric constant of the solid insulation material around the winding is higher than that of air, the electric field is mainly taken

1 Dry transformer



a – Primary coil (HV)
b – Secondary coil (LV, inside)
c – HV coil terminal (top)
d – HV coil terminal (bottom)
e – Delta connecting bars
f – Taps
g – Transformer core
h – Core clamps
i – Entry of cold cooling air

2 HiDry^{72} characteristics

Primary voltage	Up to 72.5 kV
Rated power	Up to 63 MVA
Lightning impulse voltage	325 kV for IEC 350 kV for ANSI/IEEE
Short-duration AC withstand voltage	140 kV for IEC 140 kV for ANSI/IEEE
Secondary voltage	Up to 36 kV
Connection group	Y or D
Partial discharge	<10pC
Insulation class	F (155°C) or H (180°C)
Environmental class	E2
Climatic class	C2
Fire class	F1
Cooling	AN, ANAF, AFAF, AFWF A: air W: water N: natural convection F: forced convection
Tapping and OLTC	17 positions (± 8 x 1.25%)
Enclosure	No enclosure, or IP and NEMA (National Electrical Manufacturers Association) indoor or outdoor enclosure according to requirements

up by the air in the duct. The size of the air duct needs to be large enough to withstand lightning impulse testing. Each transformer is tested for partial discharge (a partial discharge level below 10 pC is required). This guarantees that the solid insulation is of high enough quality and is free from voids.

The same air duct also provides a flow of cooling air, which enters at the bottom and creates a self-sustaining flow thanks to the chimney effect. This provides an automatic regeneration of the insulating air. Additional air ducts are located between the low-voltage (LV) coils and core legs. The HV coils are also cooled on their outer surface. For transformers with high power ratings, additional air ducts can be introduced into the LV and HV coils.

The windings can be made from an aluminum or copper conductor, depending on customer preference. Incoming cables or open busbars are directly connected to the HV coils.

Globally, there is a significant trend toward using more dry transformers. The market potential is large: While for LV applications dry transformer technology already strongly dominates, in MV applications oil-immersed units are still the most prominent. For HV applications, besides a few units using SF_6 gas insulation, oil-immersed types predominate as well. HiDry^{72} transformers are the first series air-insulated transformers for the 72.5 kV voltage class.

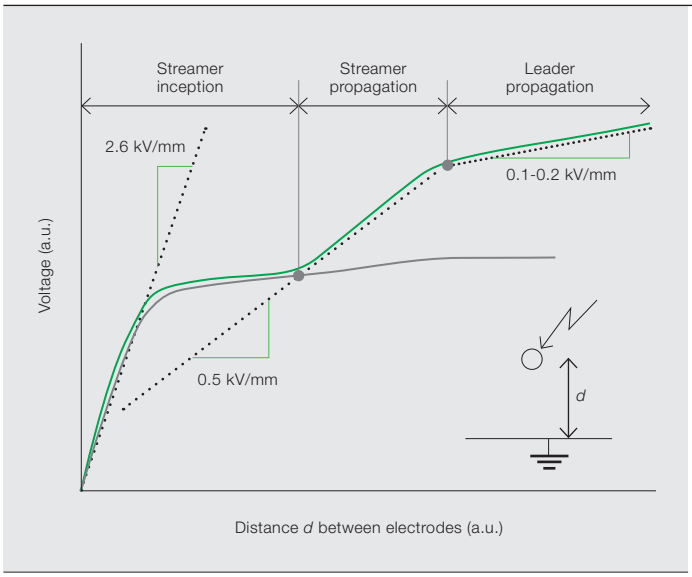
HiDry characteristics and technology

HiDry^{72} is available for power ratings up to 63 MVA in either three-phase or single-phase solutions. It offers the same functionality as an oil-immersed power transformer [2, 3] – including on-load voltage regulation using a dry-type on-load tap changer (OLTC). The OLTC offers a regulation range of ±10 percent ➔ 2.

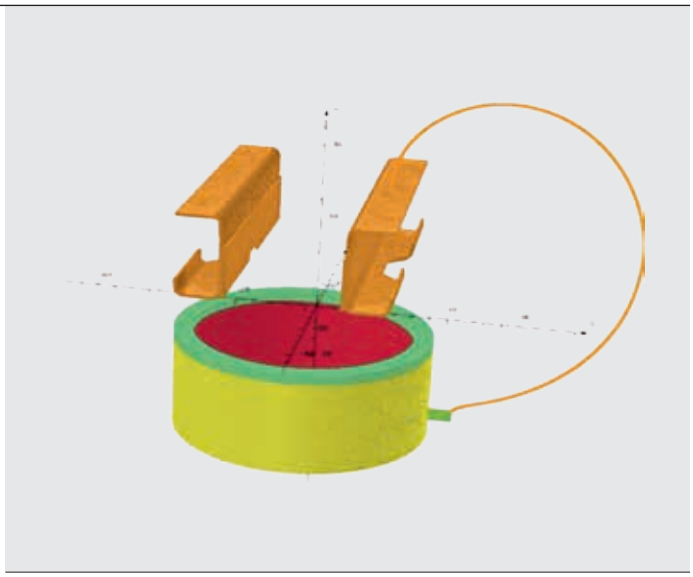
HiDry^{72} transformers use the same base technology as is used for MV applications and is available in ABB's VCC and RESIBLOC dry transformer implementations. But the demands placed on transformers for subtransmission voltage levels are much higher than those placed on distribution transformers: The higher voltage, higher rated power and increased range for voltage regulation

While a typical power transformer contains several thousand liters of inflammable oil, fire class F1 dry transformers are self-extinguishing.

3 The dielectric behavior of air is a critical factor in the transformer design.

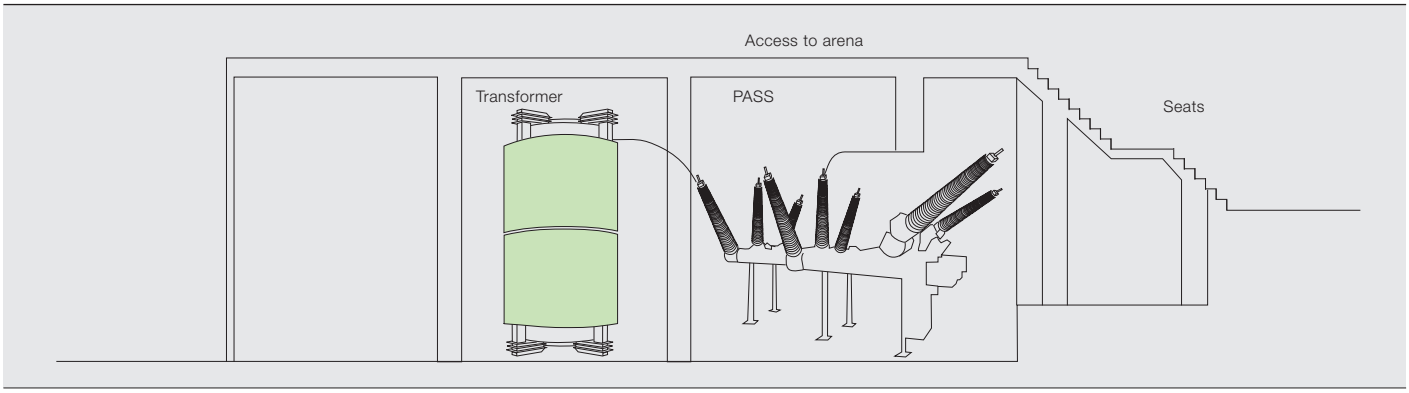


3a The green curve represents the withstand voltage for a sphere-plane arrangement [1].



3b Evaluation of prospective discharge path by dielectric simulations

4 HiDry^{72} 69 kV substation in Arena Fonte Nova, Salvador da Bahia, Brazil, with transformer and GIS installation



Globally, there is a significant trend toward using more dry transformers and the potential market is large.

require complex dielectric, thermal and mechanical problems to be solved.

In particular, when going beyond the 36 kV voltage class a thorough understanding of gas breakdown physics is required in order to minimize dielectric distances in air ➔ 3. Distances are minimized by introducing shielding rings in the windings, shielding core parts, and applying multiple-barrier concepts and barrier arrangements. These techniques influence the local electric field distribution and determine discharge paths.

Fire safety – decisive for indoor and underground substations

HV substations in city centers are mostly located in special buildings, mainly because of transformer fire and explosion risk. However, growing use of HV in inner-city settings and decreasing space availability makes the integration of HV substations into public or private buildings very desirable – a market situation for which HiDry^{72} is ideally suited due to its excellent fire-safety properties.

HiDry^{72} transformers use an epoxy resin for the casting of the coils. Epoxy resin is a thermosetting polymer that – in contrast to thermoplastic polymers – does not melt at elevated temperatures. The resin is filled with a large amount of non-combustible silica – either small sand particles or glass fiber – which, in case of fire, takes up heat and reduces the combustion temperature. When subjected to high temperatures, the epoxy does not spontaneously ignite but, rather, degrades and starts to degas and oxidize. Once the external input of heat stops or an external fire extinguishes, this process ceases. Thus, the HiDry^{72} transformer never poses a flammability risk.

Flammability testing

Transformers of fire class F1 (which is based on the IEC 60076-11:2004 standard) have restricted flammability and the

5 HiDry^{72} 69 kV/25 MVA transformer at the Arena Fonte Nova

5a With dry OLTC (on the left)

5b PASS M00 72.5 kV SF_6/air hybrid switchgear

HiDry^{72} transformers offer the same functionality as oil-immersed power transformers – including on-load voltage regulation using a dry-type OLTC.

emission of toxic substances and opaque smokes is minimized. The F1 fire behavior test is performed with one complete phase of a transformer – comprising HV and LV coils, the core leg and insulation components. A container filled with ethyl alcohol is placed below the coil and the alcohol is ignited. An electrical heating panel, representing an additional external heat source, is placed along one side of the HV coil, irradiating it with 24 kW. The test is performed in a standardized test chamber and the temperature and optical transmission properties of the exhaust gas are measured.

It is very important that the exhaust gases are not of poisonous or of a highly corrosive nature since they can flow into other parts of the building or be distributed via the ventilation system and may affect a large number of people. High transparency of the smoke allows people to orient themselves and find emergency exits.

ABB's experience of dry transformers with internal failures is that they do not explode or eject parts. Normally the coils crack, local arcing and carbonization occurs, and some smoke is generated. Depending on the fault, the system protection will then disconnect the transformer or the temperature sensor will detect a tripping temperature [4].

Arena Fonte Nova substation, Brazil

The 69 kV substation installation in the Arena Fonte Nova stadium has a redundant configuration of two transformers and two sets of HV switchgear ➔ 4. The transformers are placed below the access area of the stadium, very close to the grandstand. Open busbars fixed to the ceiling of the electric room connect switchgear and transformers. The substation was put into operation in spring 2013, well in time for hosting 2013 FIFA Confederations Cup games.

The 25 MVA transformers connect on the secondary side to the MV switchgear ➔ 5. They have a secondary voltage that is switchable between 11.95 kV and 13.8 kV. The transformer coils are made with VCC technology, which provides robust windings (E2 environmental class) and good protection from environmental

6 HiDry^{72} 31.5 MVA / 66 kV dry power transformer at CESI test lab for short-circuit testing

7 16 MVA / 45 kV dry transformer with OLTC and enclosure for installation in an outdoor substation in Sweden

pollution and humidity. The transformer is cooled by natural convection. It is tested for a lightning impulse voltage of 350 kV.

The dry-type OLTC is installed in front of the transformer, with each phase having its own unit. The OLTC uses vacuum interrupters for switching. It is configured to provide a regulation range of +4/-12 percent in 1.25 percent steps. Both transformer and OLTC are fenced off in order to avoid unintentional personnel contact, but no enclosure is required.

Seville inner-city substation, Spain

There are now many HiDry^{72} transformers installed around the world. In Seville, Spain, for example, Endesa, the largest electrical utility in the country, decided to replace the existing oil-filled power transformers in two substations with HiDry^{72} transformers in order to eliminate any related risk for the neighborhood. Each substation has two transformers. One of the 31.5 MVA, 66/22 kV, OLTC (±8 x 1.25 percent) transformers was successfully short-circuit tested at the CESI independent testing facility in Italy, against the relevant requirements of IEC 60076-5 ➔ 6. The OLTC was mounted on the transformer. This was the largest power rating of a dry transformer ever tested at CESI.

Similarly, the utility in Ulricehamn, Sweden needed to replace an outdoor oil-immersed transformer in a forest. The utility decided to install a 45/11 kV, 16 MVA HiDry transformer and OLTC, thus reducing the environmental risk to zero ➔ 7. The RESIBLOC coils are qualified for temperatures down to -60°C.

Future substations

Combining gas-insulated switchgear with HiDry^{72} transformers allows very compact substations to be constructed and easily integrated into any building. HiDry^{72} transformers can deliver higher voltages and more power to urban areas without the need to build additional substations. The very positive experience achieved so far with the 72.5 kV dry power transformer suggests that the portfolio of dry transformers should be extended to the next-higher voltage class.

Martin Carlen
ABB Power Products, Transformers
Zurich, Switzerland
martin.carlen@ch.abb.com

Mariano Berrogain
ABB Power Products, Transformers
Zaragoza, Spain
mariano.berrogain@es.abb.com

References

[1] M. Carlen *et al.*, "Transformer innovation: Dry-type transformers for the 72.5 kV voltage class – safe and ecological," Advanced Research Workshop on Transformers, Santiago de Compostela, Spain, 2010, pp. 8–13.

[2] M. Carlen and M. Berrogain, "Dry-type transformers for the subtransmission voltage level," presented at the EEA 2014 Conference, Auckland, New Zealand, 2014.

[3] A. Pedersen *et al.*, "Streamer inception and propagation models for designing air insulated power devices," IEEE Conference on Electrical Insulation and Dielectric Phenomena, Virginia Beach, VA, 2009.

[4] M. Carlen *et al.*, "Dry-type subtransmission transformer: Compact and safe indoor substations," paper A2-304, presented at the 2014 CIGRE Session, Paris, 2014.