POLEMOUNT DRY-TYPE TRANSFORMER – TESTING AND EXPERIENCE

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ABSTRACT

The development of a dry-type transformer for pole mounted application and its major features allowing to use it as an outdoor transformer without need for an enclosure was presented at CIRED 2011 [1]. Meanwhile extensive testing of the outdoor performance of the transformer has continued and field installation of pilot units has taken place. Tests have been performed at both, the demanding KIPTS outdoor test station in South Africa and under controlled harsh conditions of a salt-fog chamber. The applied test conditions are used for proposing typical test procedures for such kind of transformers. Testing with respect to fire behavior was additionally performed.

INTRODUCTION

A dry-type outdoor 3-phase 100 kVA, 15.0/0.4 kV, Dyn11, distribution transformer has been developed for pole mounted application. This transformer is of IP00 protection degree, i.e. without enclosure. It is therefore fully exposed to ambient and environmental conditions, i.e. rain, snow, and sun, and to deposits from air contamination or living organisms.
Dry-type transformers are usually not able to operate under such demanding conditions and either a ventilated, or in case of polluted ambient, a non-ventilated enclosure with a heat exchanger is needed. Using an enclosure-less approach allows to maintain dimensions and weight comparable to those of existing polemount installations. Oil-immersed polemounts can therefore in most cases be replaced by dry-type ones and retrofit is possible.

Although there is a general trend to go to more underground and cable-based systems and having the distribution transformers installed at secondary substations, overhead distribution is very common in many countries and in rural areas. It is an easy, fast and cost efficient way to set up an electricity distribution grid and provide power.
Polemount transformers are quite easy to access and since often installed in remote areas, they are exposed to vandalism and theft. Theft of oil and copper is an unpleasant, but widespread practice in many countries. Increasing oil and copper prices make theft even more attractive. When theft occurs, it is not only that there will be an outage in power supply and that the transformer has to be replaced, but spilt oil also contaminates the ground. In many countries, environmental legislation requires from the grid owner to clean the ground; often being more expensive than a new transformer.
The same happens if the oil-filled transformer tank ruptures or leaks due to an internal failure or external damage. This is especially bad in ground water protection areas, near rivers and lakes, or in public and national parks.
Another benefit of the dry-type technology is that it is non-flammable, non-explosive and self-extinguishing in case of external fires. It is, therefore, also excellently suited to install in fire risk zones like forests or bush areas, close to buildings, or above parking lots where drops of burning oil can cause extensive damage.

Fig. 1: 100 kVA, 15/0.4 kV dry-type polemount transformer for outdoor installation

TRANSFORMER SPECIAL DESIGN

The development of the dry-type polemount transformer requires some special considerations. There are four major features. First, in order to eliminate the risk of contamination or ingress of animals between coils, the air gap between primary and secondary windings, typical of dry-type transformers, is eliminated and replaced with solid insulation. This is important for ensuring long-term reliability in an outdoor transformer.
Epoxy resin which is usually used for dry-type transformers is not suitable for outdoor application and would quickly degrade under solar UV radiation and wet conditions. A hydrophobic cycloaliphatic epoxy (HCEP) is therefore used

to encapsulate the windings making the second feature. This type of epoxy provides superior outdoor performance in other applications like insulators, current transformers, or reclosures. It is outstanding in terms of resisting fire, UV rays, erosion and external tracking.

The third special feature is that the primary and secondary bushing terminals and the voltage adjustment taps, which are cast together with the windings, are fully integrated to prevent the risk of water penetration along interfaces. Simulations and experimental testing were done to control the external electric fields, optimize the design, and avoid any tracking on the coil surface. A last feature is the core`s special protection against corrosion.

The transformer is traded under the name “PoleDry”. It’s no-load loss is below the Ao loss class value according to EN50541-1. Aluminum is used for the windings, which is much less attractive for theft than copper and more difficult to remove from the casted coils.

STANDARDS FOR DRY-TYPE POLEMOUNT

The IEC60076-11 standard applies for dry-type power transformers. The standard defines environmental classes, which specify environmental conditions in terms of humidity, condensation, pollution and ambient temperature. Class E2 is the most demanding and allows “frequent condensation and heavy pollution”; however, this always applies to indoor installations or installations with enclosures.

Recently a standard for power transformers for wind turbine applications (IEC60076-16) has been established and an additional environmental class E3 for operation of dry-type transformers under more severe conditions was introduced. The E3 testing requires a humidity above 95%, with conductivity of water being in the range 3.6-4 S/m. The temperature is chosen so that condensation takes place and the transformer is kept for 6 hours under these conditions without being energized. Within 5 minutes the transformer shall be submitted to a 15 min. induced voltage test at 1.1 times the rated voltage. The test is passed if no flash over occurs and visual inspection does not show serious tracking. For IP00 outdoor installations, we consider neither E2 nor E3 as being a sufficient test for showing the performance of a dry-type transformer under such conditions.

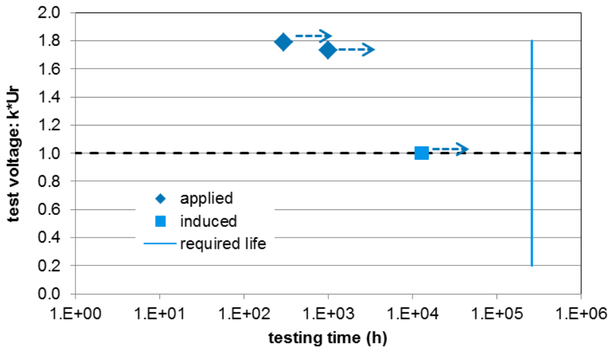

Fig. 2: Lifetime testing of solid insulation between primary and secondary coil. All tests passed without damage.

IEC60076-11 was prepared for dry-type transformers of usual design with an air duct between primary and secondary coils. The Paschen criterion was applied for designing the solid insulation of the polemount transformer coils; with the voltage over any potential void in the solid insulation being below the Paschen voltage (at rated voltage). Instrument transformers use a similar design and it appears to be more appropriate to apply the test conditions for partial discharge as defined for instrument transformers in IEC61869-1.

TESTING

Solid insulation

Testing of a new product with a required lifetime of 30 years under nominal conditions is not possible and accelerated testing has to be done. Increased voltage stress was therefore applied. Fig. 2 shows the test conditions which have been passed without failures.

Two coils were tested with increased applied voltage for a longer duration, one at 1.79*Ur (300 h) and the other at 1.73*Ur (1100 h). In both cases the current was monitored, but no indication of an increase of leakage current and a deterioration of the insulation was observed. These results give high confidence that the required life of 30 years will easily be achieved. The longest test period has a transformer installed at KIPTS. At the time of preparation of this paper it was energized for about 15’000 hours.

Note that in case of applied voltage testing the entire area between the primary and secondary winding is tested with the respective voltage; whereas in the case of induced voltage testing there will be a voltage gradient along the coil and only the insulation at the end of the coils is tested with full voltage.

Climatic class C2 and mechanical strength

A C2 thermal shock test was performed and passed. The transformers are therefore suitable for operation, transport and storage at ambient temperatures down to -25°C. In the C2 test the coil is first cooled down to -25°C and afterwards very quickly, by using twice the rated current, heated up. Large thermal gradients between conductors and surrounding insulation materials will arise; creating high mechanical stress in the coil. Since the construction of the polemount transformer with its solid insulation and the integrated bushings differs considerably from standard transformers, the C2 test is very relevant in showing the mechanical rigidity of the coils.

Outdoor performance

Testing has been done both, in a demanding natural environment as well as in an artificial one which allowed for control and intensity of ambient conditions.

Outdoor testing at KIPTS

The harsh outdoor environment of ESKOM’s Koeberg Insulator Pollution Test Station (KIPTS) near Cape Town, South Africa is located about 30 meters from the sea. The location provides an environment that includes plenty of exposure to UV, about 15 rainy days per month, strong wind, sand erosion, industrial pollution, salt-laden moisture, and wildlife. It is well-known in the industry for testing and qualification of MV outdoor components, e.g. insulators or instrument transformers. The 15kV transformer shown in Fig. 3 is energized from the secondary side and operated under no-load conditions. The test duration has passed 1.5 years.

Fig. 3: Polemount dry-type transformer installed at KIPTS test station in South Africa. The Atlantic Ocean is seen in the background.

The transformer was observed with a UV video camera in order to detect corona discharges. No significant corona was detected. The unit was carefully inspected after ½ year in operation and having passed the more severe winter season. It did not show any substantial damage (only along some mold lines there were signs of a small amount of tracking activity and salt deposits and some corrosion occurred on steel parts). Also after 1.5 years and having passed two winter and one summer seasons the transformer is still in perfect condition.

Testing in a salt-fog chamber

Coils and model cores were tested in a salt-fog chamber

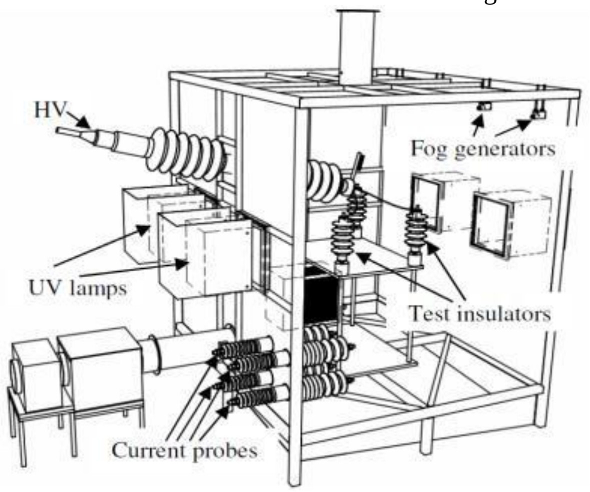

Fig. 4: Drawing of climatic salt-fog chamber used for testing of dry-type polemount transformer coils [2]

(Fig. 4) [2], which allows controlled and accelerated cycling between periods with salt fog, clean fog and UV radiation (Fig. 5). We consider consecutive periods with altering conditions to represent a more realistic picture of the natural environment than a test with constant conditions, e.g. a 1000 hours salt-fog test. In nature there are also periods with strong or weak wind, day and night, and condensation of fog may occur mainly in early morning hours. The test coils have gone through almost 100 test cycles.

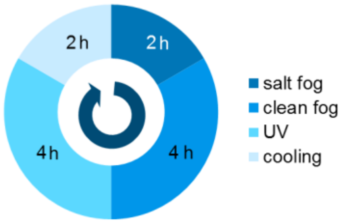

Fig. 5: 12 hours cycle for accelerated aging in salt-fog chamber

Since the chamber is not able to carry sufficient weight, itwas not possible to test a full transformer. The coils were tested by grounding the secondary winding and applying an AC voltage to the shorted primary winding. The main test was performed with a voltage of 15 kV phase-to-ground. With this set-up the field distribution on the surface of the coils is not fully identical with the case of a delta connected transformer with 15kV phase-to-phase voltage since there is no voltage gradient between HV bushings along the coil. However, the voltage between HV and LV terminals and between taps and LV terminals is higher than the intended 3-phase application. Additionally, the region at the end of the coils is heavily stressed. Testing of earlier coil designs has shown tracking after a few cycles already and pointed out the weak points.

Polymeric materials are sensitive to UV radiation, which can break molecular bonds and quickly degrade the polymer. The artificial UV source in the chamber allows to have up to 50 times higher intensity compared to natural UV radiation. The exact amount of UV radiation depends on the positioning and exposure of the test object with respect to the UV lamps. Its side parts are less exposed than the front sides, making it easier to identify differences due to degradation by UV. The four UV lamps are supplied with a power of 1200 W each, causing a temperature rise in the chamber of 40-50°K. Note that the temperature of the directly irradiated surfaces of the test objects increases significantly more. The combination of periods with strong UV radiation and with salt fog while applying a high voltage makes it a very demanding test procedure.

The conductivity of sea water is around 50’000 µS/cm, while for drinking water it is 100 times less. There are a number of IEC standards for outdoor insulating components which also request testing with fog created from water of increased electrical conductivity. Depending on the standard, the values vary from 1’300 to 20’000 µS/cm. If too high of conductivity is used, flashover quickly occurs instead of dry band discharge activity with the related aging of the components. Based on experience, we have therefore selected a conductivity of 5’000 µS/cm as being most appropriate for the salt fog period and 1’000 µS/cm for the clean fog period. The nozzles vaporize 3-5 gram of water per second.

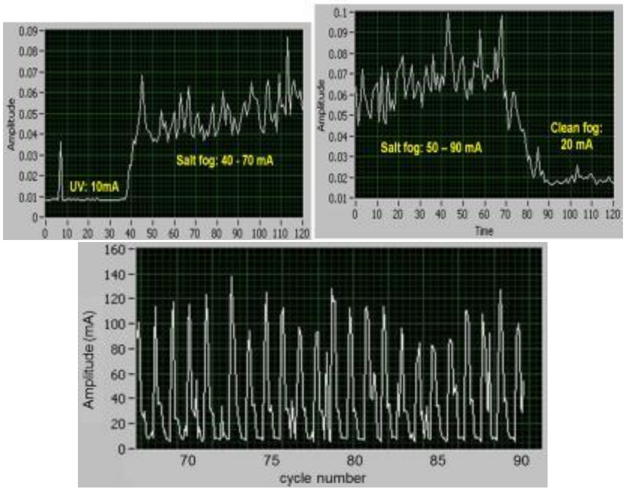

Fig. 6: Current during dry, salt-fog and clean fog periods (top) and current during 20 last cycles (bottom)

The current is measured during the whole test cycle. Besides its capacitive component, it consists of the coil internal leakage current and the surface currents. Salt-fog, clean fog and dry periods can easily be recognized from the current intensity (Fig. 6). Especially during the salt fog period, quite large variations in amplitude can be seen. In order to pass the test, the current should show between cycles a more or less stable value and no trend to increase.

Fire resistance

A fire resistance test for class F1 according to IEC 60076-11 was performed and passed. A coil with core leg is placed above a container filled with 30 mm of ethyl alcohol. The alcohol is lit and burns the coil for about 20 minutes. The coil is additionally heated by an electric heater at 750°C.

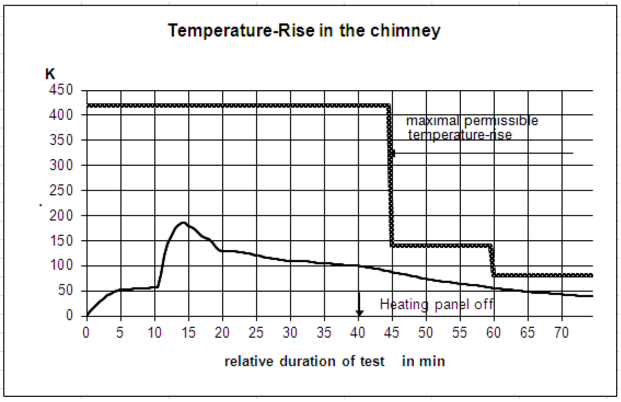

Fig. 7: Temperature rise during F1 test. It remains well below the maximum permissible temperature rise.

The test is passed if the temperature of the air outlet of the test chamber remains below a given value (Fig. 7).

FIELD INSTALLATIONS

The first 20 commercial units, three-phase transformers with a 100 kVA power rating and with 15 or 20 kV primary voltage, are destined for the Italian utility, ENEL. Fig. 8 shows a dry-type polemount transformer installed in the grid of ENEL Distribuzione. In this case the transformer mainly supplies a farm with livestock. The farm has a 60 kW photovoltaic plant on its roof. By June 2013 the transformer will be 9 months in operation.

Fig. 8: Dry-type polemount transformer installed in the region of Brescia, Italy

DISCUSSION AND CONCLUSION

The introduction of dry-type outdoor transformers for polemount application is a major step in providing equipment with increased safety for people, property and the environment. Since it is not attractive for theft of oil or copper, it also increases security of supply and reduces service and replacement needs.
Being directly exposed to all kind of weather conditions and pollution, the transformer design has special requirements and significantly distinguishes from standard dry-type transformers. The development therefore involves a number of innovations like the use of solid insulation between primary and secondary windings or the use of cycloaliphatic epoxy.

Dry-type transformers without enclosure protection for outdoor application are new on the market. There are also no appropriate testing procedures existing at this time. We have presented in this paper our testing and qualification methods and believe that they could make the base for a future standard for such products. We consider a combination of a one or 1.5 year outdoor testing in a suitable test station like KIPTS and testing in a chamber with salt-fog and UV irradiation (100 cycles of 12 hours duration) to give a representative picture of the performance of the transformer.

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