Fire behaviour of transformers

Challenges for reliable step up transformers and substations for multi-megawatt turbines

Transformer Technologies

Wind turbines require a grid connection where generation voltage is increased to medium voltage by a step-up distribution transformer. This transformer can be installed outside the turbine in a substation or as a pad-mounted solution. For inside tower or nacelle installation, the wind turbine industry has the choice between dry type transformers and high temperature liquid-filled transformers.

Dry type transformers have been installed in wind turbines because of their fire behaviour and compact dimensions. Recently high temperature liquid-filled transformers, such as SLIM® with fire retardant liquid have been developed for the multi-megawatt turbines because of their compactness, performance and high reliability. The insulation system consists of a silicone liquid and a high temperature solid insulation NOMEX®.

Functional specifications

The electrical functional specifications for both technologies are the same, and both technologies can meet the requirements such as low voltage, high voltage, power, impedance, load losses, no-load losses that a multi-megawatt turbine needs. The high temperature design has more advantages:

> On average the no-load losses for liquid-filled transformers are 50% lower leading to significant savings.
> When high temperature insulation materials are used, the new transformers can be designed much more compact and with improved thermal reliability.
> Example: 4MVA SLIM® step-up transformer with 2 low voltages 3300V and 690V, high voltage 33kV has dimensions of length 2800mm, width 1400mm and height 2100mm. Load losses can be as low as 23000W and no-load losses 6000W.

Operating conditions

The electrical environment of the step-up transformer is also different in a wind turbine:

> more switching surges with fast transient overvoltages in windings and system voltage drops;
> higher harmonic content;
> overfluxing due to voltage and frequency fluctuations.
> For transformers with open insulation systems such as dry type transformers, filtering and drying of the cooling air and maintenance is suggested especially for transformers in a humid and salty environment.
> For nacelle installations, vibrations with frequency range 5Hz up to 250Hz.

Taking all this into account, the transformer industry perceives liquid-filled transformers in general to be more reliable.

Risk assessment and Standards

The likelihood of a transformer failure is extremely low. This statement is justified by our own experience (more than 10000 transformers in wind turbines), general feedback and appreciation of users worldwide. The Mean Time Between Failures for liquid-filled transformers is > 500 years.

International Standard IEC 60695-1-40 “Fire hazard testing: guidance for assessing the fire hazard of electro technical products - insulating liquids” illustrates and confirms the good fire safety record of liquid-filled transformers and that such incidents are very rare. Conventional transformers have a mineral oil class O1 liquid (liquid with fire point < 300°C and a net calorific value > 42 MJ/kg). The SLIM® transformers use a silicone liquid and are classified as class K3 (liquid with fire point > 300°C and a net calorific value < 32 MJ/kg). The IEC-guide states that fires...
resulting from class K liquid-filled transformers (such as silicone) are zero, while some 150000 of these transformers are in service since the late '70s.

In case of a dry type transformer, the fire behaviour is classified as F0 or F1 according to Cenelec Standard EN 60076-11 where a test is done on a set of a low and high voltage winding.

**Full-scale fire test on step-up transformers**

Two transformers were tested at Ineris, France, namely a cast resin transformer 1MVA 20kV 400 V with F1 fire properties and a 1.1MVA 10kV 400V SLIM® transformer.

The transformers were put in a thermal-aggressive environment characterized by a fire from alcohol below the transformers for 20 minutes and radiation for 2 panels along the side walls for 40 minutes with a heat input of 30kW/m². It should be noted that this test uses the same conditions as the standard but the standard limits itself to one winding from a dry type transformer. The temperature profile and self-extinguishing feature result in its fire safety classification.

**Discussion on the dry type transformer**

After initiating the fire and radiation panels, the transformer leads to a combustion and smoke after 6 minutes. The temperature of the external fire was 400°C whereas the temperature on the central winding was between 800°C and 870°C after 8 minutes. This temperature dropped slowly to 700°C after radiation and dropped further to 400°C leaving the transformer burning on its own for more than an hour, producing dense black smoke.

**Discussion on SLIM® and Bio-SLIM® transformers**

The high temperature liquid-filled transformer has been put in identical conditions of fire and heat flux. The heat generated resulted in external temperatures of 500 - 600°C and internal temperatures of 260°C. Due to the thermal expansion of the liquid, the pressure rise to 1.6 bar. However, this pressure rise was not enough to open the tank. The outside of the transformer suffered no significant damage. The transformer did not participate in the external fire. In order to open the transformer and to note the effects, a more severe fire situation is needed. However, it is expected that small leaks will occur and no rupture of the tank.

**Conclusions**

- Different transformer technologies are available for multi-megawatt turbines.
- Dimensions, losses, reliability (MTBF), protection, electrical environment are important because the operating conditions in a turbine are severe!
- Fire behaviour of dry type and high temperature liquid-filled transformers are comparable.
- Good protection and prevention is always needed, independent of transformer technology.
- Other materials in turbines also have a fire load (nacelle, blades, cables, generator insulation, oil of gear box).

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