A Fiber Optical Overheating and Fire Protection System for Dry Type Transformers

B. Fruth, P. Werle*, V. Wasserberg*, H. Borsi*, E. Gockenbach *

PD Tech Power Engineering AG, Switzerland

*Institute of Electric Power Systems, Division of High Voltage Engineering, Schering-Institute, University of Hannover, Germany

Abstract: A new protection and monitoring system for dry type transformers is introduced, which is based on innovative sensor technologies. It protects the device against local overheating by using a fiber optical sensor. A reliable alarm is signaled whenever a local overheating appears. Thus, the transformer can be switched off before catastrophic damage occurs.

The developed monitoring system operates online, is efficient and cost-effective and can be easily installed at almost all categories of dry type transformers. The system is partially installed in conjunction with capacitive partial discharge couplers for periodic inspection of the insulation.

INTRODUCTION

Efficient power transmission and distribution require high voltage equipment to operate at maximum load without sustaining any malfunctions.

Especially transformers, used at the junctions of energy supply systems, are of major importance. A transformer failure usually results in a variety of negative consequences.

Since the use of PCB contaminated transformers was restricted and the production of PCB was forbidden, so called dry type transformers (usually insulated by epoxy resin) were introduced for power levels up to 24 MVA and rated voltages up to 36 kV. These dry type distribution transformers are extremely sensitive to Partial Discharges (PD) as a result of local field strength extensions in non-homogenous areas of the insulation.

In contrast to paper-oil insulated transformers, partial discharges in dry type transformers may eventually lead to the destruction of the solid insulation. Due to the absence of self healing effects, as they exist in liquid or gaseous insulating systems, partial discharges in dry-type transformers lead to irreversible damage and disintegration of the inter-turn insulation.

Ultimately, partial discharge activity will cause inter-turn short circuits, which subsequently lead to a local overheating by induced currents. This will increase the partial discharge activity due to the rising local temperature and related material deterioration.

Once this chain reaction is initiated, the breakdown of the complete system is unavoidable.

This breakdown may be accompanied by fire hazards (see Figures 1 and 2), which can entail dreadful damages, often more expensive than the purchase costs of the transformer itself.

Figure 1: Burnt coil of a dry-type, epoxy insulated transformer due to inter-turn short circuit.

In order to prevent failure it is mandatory to monitor transformers during operation by an appropriate monitoring system.

Although many dry-type transformer failures were encountered there was no commercial protection system available until to date.

The main reason is that partial discharge monitoring systems are generally too costly, because their price
can exceed the price of the transformer to be monitored. Therefore a new modular system has been developed, which protects transformers on-line against overheating.

In case of an overheating alarm, e.g. an off-line analysis of the transfer function will verify the winding shorts [3]. A specific replacement of the faulty coil or the improvement of the defective insulation is then possible.

**OVERHEATING PROTECTION**

Local overheating caused by inter-turn short circuits is a pre-stage of breakdown. The result is fire and fume development (Figure 2).

A shut-down of a transformer in time avoids consequential damages. Therefore some dry type transformers are equipped with a PTC (Positive Temperature Coefficient) temperature fuse which is embedded in the low voltage coils. In this area high temperatures are encountered more frequently as a result of a high current.

In some cases overheating of the high voltage coils can take place. In this case, the PTC protection is useless.

PTC protection usually causes high frequency disturbances which causes on-line partial discharge measurements to get more difficult.

The new overheating protection system overcomes these disadvantages. Both the high and the low voltage coil as well as the core can be guarded against overheating. The principle of operation is based on a temperature dependant shift of the optical transmission properties of an fiber optical cable [1]. An optical sensor does not cause any electromagnetic interference or influences the operation of the transformer in any other way. If a light signal is injected into one side of the fiber optic sensor it can be detected at the opposite end with an optical receiver as shown in Figure 3.

If the surface temperature of the optical fiber rises the light transmission is attenuated by the deteriorated reflectivity characteristics. At still higher temperatures the light transmission is interrupted, and, no signal can be received any more. This state is used for providing an overheat alarm.

![Figure 2: Burnt transformer bearing secondary damage due to inter-turn short circuit](image)

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A temperature increase caused by winding shorts will spread out annular. This leads to the typical ring-shaped changes of the resin color. Therefore it is not necessary to place a sensor directly on a hot spot but on any position on the overheated winding package.

A special mounting technique (as shown in Figure 4) is used: The fiber optical sensor is aligned on 4 different positions on the inner and outer surface of the coil. In essence, 8 areas per coil are monitored.

![Figure 3: Principle of operation of the fiber optical sensor](image)

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Such a fiber optic sensor is mounted on the surface of all coils and the core of the transformer which allows overheat protection of the whole device.

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The optical fibers are attached to the coils’ surfaces by a special 2-component epoxy resin putty. The optical fibers are connected in series. Therefore only one single optical fiber sensor and only one control unit is required for the protection of a transformer in operation as it is shown in Figure 5. The temperature threshold for an alarm release can be adjusted over a wide range, from about 80°C up to 170°C or more if necessary. This is generally not practicable for monitoring dry type transformers, because their operation temperature typically varies between 60°C and 100°C. The alarm threshold temperature is varied by selecting the appropriate optical fiber material for the sensor. Furthermore a fine tuning is possible by modifying the characteristics of the transmitter and the receiver.

Figure 5: Overheating protection system in operation

The most important advantages of the new developed overheating protection system can be summarized as follows:
- Overheating of both insulation and core can be detected online.
- In case of a local temperature extension an alarm reduces the risk of fume, fire or damage of the insulation.
- No electromagnetic interference, surface discharges or any other impairment of the environmental conditions.
- Safe overheating detection in a range of 80°C up to 170°C which is well tried in practical operation.
- Cost efficient and easy to install.
- Processing unit enables due to an intelligent design self control and supports several interfaces as well as remote access.

OVERHEATING ALARM ANALYSIS

In case of an alarm of the overheating protection system it is necessary to check whether this overheating was caused by a winding short or by another reason. As the alarm may occur already in an early stage of the overheating, the transformer surfaces will look completely unaffected. Therefore all coils must be thoroughly inspected for inter-turn shorts. This can be done off-line by a detailed analysis of the optical sensor and by the evaluation of the transfer function of each phase [2, 3]. There are different possibilities for the determination of a transfer function, but beside a manual frequency response measurement a so called delta impulse response measurement is efficient and easy to perform.

CONCLUSIONS

The patented fiber optical overheating protection system is now commercially available on the market [1]. The monitoring systems were tested for more than two years and have proven to be reliable. More than 50 transformers were equipped this year with this novel cost effective protection system. To a part of these installations coupling capacitors for periodic on-line PD inspections were added in order to study the pre-stages of the dielectric failure.

REFERENCES

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1 Original in German language, title translated