White Paper

Early Fire Detection

for Power Transformers

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January 2017

Note: Transformers are the critical links between the generation, distribution and transmission networks within the electrical grid. A major transformer failure can wreak havoc, causing power shortages or outages affecting millions of homes and businesses and costing many millions of Euros. This paper presents a discussion of technology issues considered for enhancing fire protection of power transformers. The contents of this Paper are presented to create discussion in the fire detection industry on this topic and not to be considered an adopted standard of any kind.

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1. Abstract

Electrical transmission and distribution systems are the heart of every economy. Demand for electricity rapidly increases as a country becomes more developed and industrialized.

Transformers are an essential part of the power grid that supplies electricity to homes, offices and factories. However you may look at them as “potential weak links” in the grid. If one fails the entire network is rendered vulnerable. If a power surge occurs across the network, knocking out a number of transformers, the electrical grid could be crippled for months, even years.

As an example a transformer fire in June 2007 at Krümmel nuclear power station in Germany caused it and another nuclear plant at Brunsbüttel to be shut down. The resulting repairs put Krümmel – the largest reactor of its kind in the world – out of action for two years. Days after the plant was restarted in June 2009 further transformer problems forced it to be shut down again, creating power shortages across Hamburg. Following that, Vattenfall, the plant’s owner, decided to replace two of Krümmel’s important transformers, causing another lengthy shutdown [6].

The problem is that these transformer units are big, expensive to build and largely custom made, meaning that if a transformer fails it can take three years before a replacement is delivered.

To prevent faults and to minimize the damage in case of a fault, transformers are equipped with both protective relays and monitors. However, 50% of the fire incidents are related to the bushings and therefore not covered by any protective devices. Bushings are made of porcelain filled with Oil Impregnated Paper (OIP). There’s simply no way to attach equipment on such a porcelain body without destroying its insulation properties.

Picture 1: Fire as a result of a bushing fault: Oil / flames spread all over the tank [3].

Bushings may get cracks, lose the oil and catch fire due to arching. The bushings also may lose their insulation properties due to aging, build up gas and explode as a result of arching. The result is a burning oil film all over the transformer tank. In such a case disconnecting the transformer and extinguishing the fire needs to take place instantly, within fractions of a second. This can only be achieved by ultra fast responding heat or flame detectors. These detectors are substantially reducing the damage of a fire incident. They are the aim of this article to show why and how such devices are used to avoid a disaster in case of a bushing fault.

2. Introduction

Power transformers contain large quantities of mineral oil. While the probability of an explosive failure is low, it is not insignificant. In the event of an explosive fire occurring in a bushing, in a cable box or within the oil-filled transformer, there's a high probability it will develop into a serious disaster, causing loss of the transformer , loss of supply and, in the worst case, loss of life. Therefore, a fire is a serious risk all operators of power transformers are aware of.

Risk

The probability of a transformer failure varies considerably among types of transformers, but it is typically in the range of 1% per transformer service year. In practice, it means 3% of all transformers will cause a fire during a 40-year service life.

Cause

Transformer fires are predominantly mineral oil fires and it is often assumed tank rupture is the dominant cause. However, this is an erroneous assumption, especially for voltage levels *below 300kV* where failure of oil-impregnated paper (OIP) *bushings* and air- or oil-insulated *cable boxes* account for *70% to 80%* of transformer fires, and on-load tap changers account for 10% to 15% of transformer fires. Even the remaining 15% is attributed to a range of causes other than tank rupture. In fact, tank ruptures are rare for voltages less than 245kV, as the arcing fault energy is often below the critical level of energy required to cause tank rupture [2].

In short: *Failure of Oil Impregnated Paper (OIP) bushings* is the single leading cause of transformer fires counting for about *50%* of serious transformer fires. The other *50%* are related to *failures within the tank and the tap changers* [3].

Damage

When a transformer does fail, the result is often catastrophic. A power substation by its nature contains all of the ingredients to generate the perfect fire storm: A typical transformer bank is comprised of three or more transformer tanks, each containing thousands of liters of extremely flammable mineral oil. The ignition of the oil can come from a variety of sources including solid particles of insulation and conductor that are produced by incipient arcing fault or short circuit electrical arcing inside the tank, any of which can generate heat and pressure sufficient to cause the tank to rupture [8].

Once a rupture has occurred, air rushes into the tank and the tank explodes resulting in a blast of intense radiation scattering oil, steel shrapnel, gaseous decomposition products and molten conductor material onto the surrounding area. The duration of a transformer fire can range from 4 to 28 hours, the time it takes the fire to burn itself out [8].

Transformer fires can quickly result in the partial or total loss of the entire electrical substation. However, the higher cost by far is the replacement energy, which must be purchased from the spot market at premium prices. During peak hours the rates could spike up to EUR 200'000 per hour.

Specific transformer fires are difficult to anticipate and prevent, however, additional damage is preventable with the proper maintenance and fire controls in place.

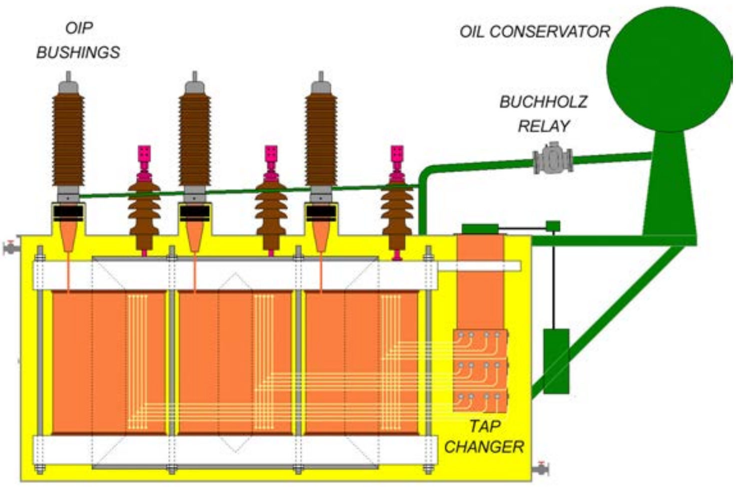
3. Risk Mitigation

During transformer life, structural strength and insulation properties of materials used for electrical insulation deteriorate. Aging reduces both mechanical and dielectric strength. For this reason, fire damage is largely preventable with the proper ***maintenance*** in place.

For example, *replacing aged bushings* will significantly reduce the fire risk since these components are classified as the single leading cause of transformer fires[3]. Similarly, doing regular checks of the transformer integrity by performing ***frequency response analysis*** will uncover winding and tap changer problems at an incipient stage [1].

Picture 2: Leaking bushing turret

4. Consequence Mitigation



Picture 3: Elements of a transformer

Transformer tank and tap changer failures

Electrical faults within the transformer tank and the tap changer are detected by a gas relay (Buchholz Relay). It detects electrical faults in oil-immersed transformers. Usually there are two Buchholz detectors installed: One between the transformer main tank and the oil conservator and the other above the tap changer [4].

The **Buchholz** protection is a fast and sensitive **Early Warning** fault detector as it accumulates gases produced by ***minor faults*** rising from the fault location to the top of the transformer. The relays (mercury switches) are finally activated by a gas bubble built up within the relay housing [4].

The **Buchholz** relay has a second triggering device consisting of a **Pivot Vane**. This vane triggers the shutdown of the transformer in case of a steep build-up of pressure as it is typical for ***major faults***, either to earth or between phases or windings. Such faults rapidly produce large volumes of gas and oil vapour which cannot escape. This sets up a rapid flow of oil from the transformer towards the conservator. The Buchholz vane responds to the high oil flow by closing a mercury switch [4].

Both Buchholz switches, the Early Warning minor fault and the Vane major fault switch, may be used to release extinguishing [4].

OIP bushing failures

Almost 50% of all serious transformer fires are initiated by **failure of OIP bushings**. The main root causes are:

- 80% leakage (defective seals)
- 13% deterioration of insulation
- 7% mechanical damage (cracks in the porcelain body)

Leaking bushings may spread oil over the transformer main body. This oil will partially evaporate and get ignited by the arc created by a switching process. The resulting fire may have a limited impact in case extinguishing is released instantly. However, this is most likely not the case for standard heat bulb activated sprinkler heads, because these components are part of the extinguisher tubes which are placed a few meters away around the transformer. Especially in an outdoor application, where rain and wind may disable these triggers. Detecting the fire near the zone of ignition for triggering the extinguishing is therefore imperative. This can be done with industrial grade flame or heat detectors.

5. Heat Detection

Requirements

A water spray system usually involves heat-actuated detectors operating an automatic mechanical flooding valve that supplies water to spray nozzles.

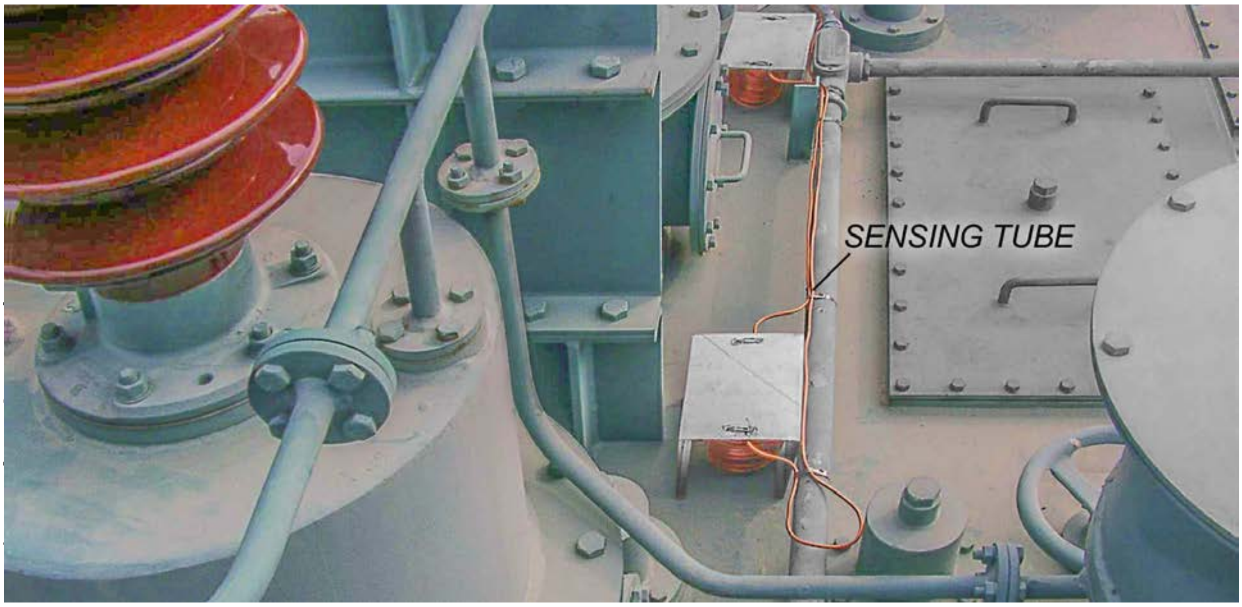
Besides a comparably slow response, standard point type heat detectors are not made for harsh outdoor conditions typical for transformer sites. Challenges are:

- Operating Temperature Range (day, night, winter, summer)
- Humidity Changes
- Lighting strikes
- Snow, Fog or heavy rain
- Dust / Dirt

Transformer fire detectors must be able to cope with these challenges and in plus, respond extremely fast to an incident. Because a detector should be mounted close to the potential flame zone, the sensing element should be able to withstand high temperature.

Ultra-fast responding heat detectors

The fastest responding heat detector in this category is Securiton's ADW 535, a sensor offering rate-of-rise heat detection within a few milliseconds for releasing extinguishing valves instantly. It is based on a sealed metal tube whose inherent pressure is evaluated at a rate of 2'000 samples per second at 0.2°C precision. This sensing tube is placed in the ultimate proximity of the transformer tank.



Picture 4: The sensing tube is placed right on top of the transformer where leaked bushing oil will collect

The tube material can be of copper or stainless steel. Special care is therefore not required when cleaning the transformer with pressurized air or cleaning chemicals.

Lightening protection is simple: A connection tube to earth will do.

Picture 5: The ADW 535 Detector.

It offers all the flexibility needed for industrial application:

- Free programmable detection properties
- EN 54 compliant setting
- UL compliant setting

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