TRANSFORMER EXPLOSION: WHY IT HAPPENS AND ITS PREVENTION

Transformers are considered as very efficient electrical machines and plays as essential device between a generator and its primary distribution circuits. However, like any devices, power transformer also have they own risk. It has been reported a cases where transformer in-service failed and explode. Although their likelihood is relatively low, these explosion often lead to property damage, injuries, and deaths. Therefore, it is necessary to avoid them as much as possible.

INTRODUCTION

Transformer fire explosion

An increasing number of power transformer failure has lead to greatest interest in building a transformer with more safety design as failure of certain components such as tap changers and bushing led to fire and explosion. Subsequently, it causes major loss of power supply to the consumer and danger to other expensive power equipment in substations and to human lives. The transformer condition monitoring and fire risk management is now are major concerns to power utilities.

WHAT CAUSES OF TRANSFORMER EXPLOSION?

Transformer fires and explosions can occur for a variety of reasons. External factor such as lightning strike may causes a quick discharge of electricity between two charged clouds or between a charged cloud and the ground. If a lightning strike happens between the charges cloud and the transmission line, it induces a very high voltage on the conductors of the overhead transmission line. The transmission line has a guard wire to protect the line from such incident high voltage. However, in some cases when lightning intensity is very high, it can induce voltage on the transformer. A too high current through the transformer leads, terminals and windings can cause localised or even wide spread overheating within the transformer. If excessive over-current is not interrupted and sufficient heating occurs, then it can cause overflowing and possibly boiling of oil, which may cause spilling from the conservator, pressure relief valves or damaged gaskets. However, to start the fire there still must be a source to ignite the oil.

Other causes are considered internal factors and contribute to the major incident of transformer fires and explosions, resulting from a pressure build up from arcing causing rupture of bushing porcelain, a cable box, a tap changer or the transformer tank.

How do Fire Start in Transformers?

Inter-turn insulation failure due to an internal short circuit may cause temperature reaches 1200 degree Celsius, vaporizes oil inside transformer tank and creates explosive gases. Within milliseconds, it creates a dynamic pressure peak traveling at the speed of 1,200 meters per second. Being in a closed area, the pressure wave will reflect off the transformer wall, coils and other obstacles leading to complex waves. These complex waves create a static pressure which the transformer tank generally cannot withstand. With the pressure being being constant in all the transformer, the tank will rupture. The explosive gases generated during the short circuit will be in contact with oxygen and oil contained in the transformer, which leads to an explosion and associated fire.

The sequence of events that may lead to a fire from an internal fault can be summarised in 5 phases.

Phase 1: When electrical stress in insulation material (oil or solid) exceeds its dielectric strength it will break down and high energy electrical arcing can occur.

Phase 2: The very quick energy transfer between the arc and the liquid oil induces a very fast increase of temperature in the vicinity of the arc. The arc energy is then used to heat and vaporise the surrounding oil, crack this vapour into smaller molecules and flammables gases and decompose the gases into plasma.

Phase 3: The pressure within the gas bubble surrounding the arc increases very rapidly due to the very localized phase change (saturated vapour pressure at high temperature)

Phase 4: The pressure difference between the gas and the surrounding liquid generates pressure waves that propagate at finite speed (close to speed of sound in oil) from the arc location throughout the transformer tank. The local pressure rises because of the front of the pressure wave passing. It is important to note that the tank walls can withstand these high local overpressures for only a very short time period (a few milliseconds) and that the tank will rupture if subjected to an overpressure exceeding its static pressure withstand limits for more than some millisecond.

Phase 5: If a transformer tank, a cable box or and OIP bushing ruptures in the presence of an electrical power arc, then there is a high probability that an oil fire will follow. This is because the large quantity of oil present in a transformer tanks and the conservator my also become exposed to heat and oxygen when spilling through ruptures or flange openings or when oxygen enters the tank through such openings, which can lead to auto ignition. Additional measures may therefore be required to reduce the risk transformer fires and consequential damage for high energy arcing faults.

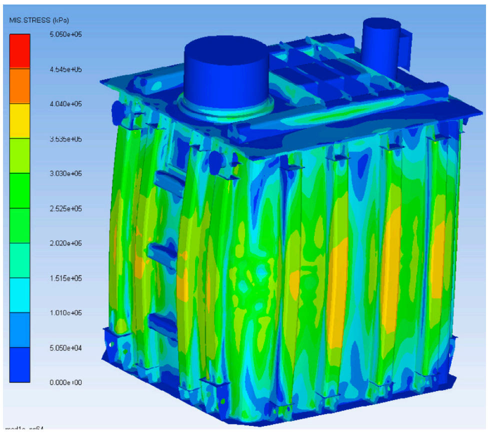
For a fire to exist and propagate, it requires the three key elements of Heat, Fuel and Oxygen in well defined ratios. If anyone of these three elements is absent then the fire will not start, or if removed after a fire has started then the fire will extinguish.

Fire Triangle

FIRE RISK MITIGATION OPTIONS FOR TRANSFORMERS

Considering the big impact of transformer fire and explosion, minimising the risk of transformer fire is crucial to the power utility or asset owner. Mitigating the risk of transformer fire is a multi stage approach with the first stage is directed towards minimising the probability of a transformer failure to develop in a fire. The next step is to minimise the probability of transformer failure by specification and selection of components of good quality with low fire risk. Improved tank designs and various forms of pressure venting is also a strategy that can reduce the risk of tank rupture. Some of the approach to minimise the risk of transformer fire and explosion is discussed as follows.

Tank with Higher Pressure Safety Margin



Design transformer tank with higher safety margin

The requirement of transformer with regards to tank strength expressed either in terms arc energy containment capability or pressure withstand capability has been described in IEC 60076, IEEE C57 or equivalent national standard. By putting specifications typically have more stringent test requirements and include additional tests to those required for compliance with the above standard appears as a proactive steps in reducing transformer failure rate. Utilities who have more demanding specifications and choose to buy transformers from well reputed manufacturers with proven ability to supply high quality transformer have lower failure rates than transformer users who have less demanding specifications and is less discerning in their choices of suppliers.

Improve Protection Schemes


Fault current limiter

Fast reliable, duplicate protection together with a fast acting circuit breaker minimises the risk of a through fault causing the failure of the transformer, and in the event of a transformer failure limits energy injected into an icing fault within the transformer tank and thus reduces the risk of tank rupture. The most common elements of the typical transformer electrical protection schemes are overcurrent protection, earth fault protection and differential protection. Other commonly protective device include bucholz relay, sudden pressure relay, pressure relief device, over-fluxing relay and over temperature protection.

The use of voltage and current limiting devices also help reducing or limiting the current through the winding during external faults and also reduce the arcing current for internal fault and thus provide a significant reduction in arcing energy, the risk of tank rupture and consequently the risk of transformer oil fire.

Less Flammable Insulating Media

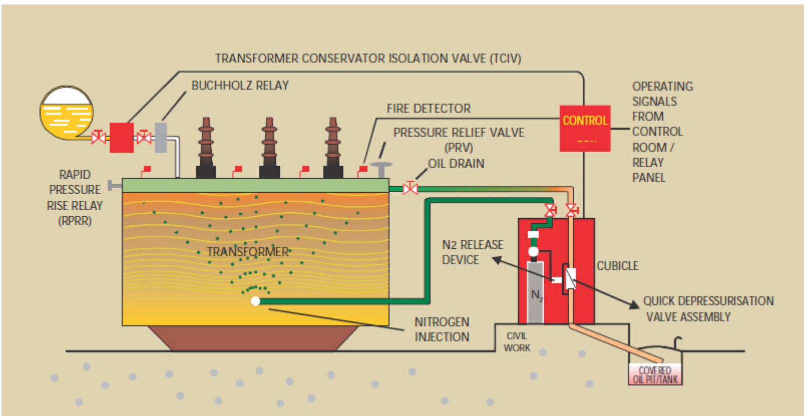
The use of less flammable insulating media is another options to reduce the significantly risk of transformer fire and explosion. Gas Insulated Transformer (GIT) using the inert gas sulphur hexafluoride (SF6) as a cooling and insulating medium has excellent non-flammable and non-explosive characteristics. However, SF6 is a very potent green house gas and the potential leakage to atmosphere is of concern.

Low pressure GIT

The alternative insulating fluid with a fire point greater than 300oC, also known as less flammable K-class fluids have been developed to reduce the risk of pool fires since the fluid must be raised to a much higher temperature before it sustain a fire. Typical fire scenario is similar to the scenario for mineral oil filled transformer, however the low flammability transformers are superior in combustion performance and have good ignition time characteristic. The common less flammable fluid currently available are silicone oil, natural ester, synthetic ester and high molecular weight hydrocarbon.

Pressure Venting and Depressurisation

A variety of pressure reduction technique have been developed to provide pressure reduction against excessive pressure being developed by arcing fault in transformer tank, tap changer tanks and oil filled cable box. The existing solutions are in general insufficient to provide sufficient pressure relief for other than low arcing energy faults. Recent design provide faster and higher relief capacity such as tank protection system based on rupture disc and nitrogen injection. The system utilises a single or multiple rupture discs for pressure relief on main tank and separate rupture discs on the tap changer and each cable box. In addition, a conservator shut-off valve, pipe work and a holding/separation tank for collection and separation of the vented oil and explosive gases, and nitrogen injection equipment for injection of nitrogen into the base of the main tank for evacuation of the explosive gas was also included. The purpose of nitrogen injection is to stir the oil and extinguish a fire, in the event the tank has ruptured and a fire has been initiated.



Pro-active pressure venting and depressurisation of transformer fire protection system

Other transformer fire protection offer a system which proactively open a large oil drain valve and initiates nitrogen injection in response to an internal fault detected by the transformer differential or the master trip relay, in addition to trip signal from a Rapid Presure Rise Relay, Pressure Relief Valve or a Bucholz relay.

Transformer Passive Protection

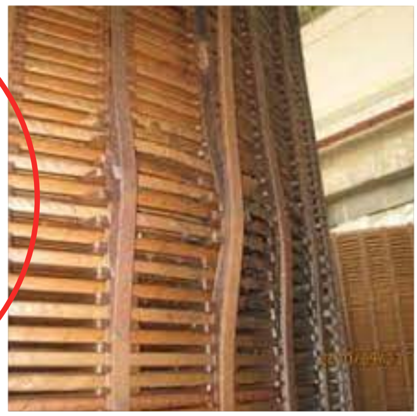

Transformer fire wall

The aim of transformer passive protection are to control the impact of a transformer fire on humans, economic assets and the environment. Humans include utility staff that may be exposed to the risk of injury due to proximity to a transformer fire in course of their normal duty and publics which could be in the vicinity of a substation when a transformer catches fire. Economic asset are primarily nearby substation or power station plant, equipments, buildings or structures within close proximity of the transformers; whereas the major risks to the environment is primarily from spill of oil or other forms of insulating fluid, water contaminated by oil as well as risk of air pollution from accidental released gases and smoke from a fire.

Three construction features considered as passive transformer protection include oil catchment areas, heat radiation barriers and oil drainage system. The oil catchment area and oil drainage system is constructed to allow any oil discharged is confined within the catchment area and reduced the potential of burning oil from endangering the main transformer respectively. Meanwhile, heat radiation barriers between transformers reduce the risk of damaging adjacent transformer against a fire of explosion involving a single transformer.

Next Issue : Jan-Mac 2024

SFRA Measurement for Mechanical Assessment of Power Transformers



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