Safety by Design
Flexible tank design advances transformer safety

Transformer safety

Today's power transformers are designed to prevent internal arcing, but despite such precautions there remains a minor risk of an arcing event, which carries a subsequent risk of tank rupture and fire. The chances of such an event are exceedingly small, but the consequences can be severe.

When a power transformer tank does rupture, there is a significant risk of explosion and fire. A statistical survey[1] on 735kV transformers revealed that about 32 percent of explosions were caused by bushing failures and of those, 44 percent led to a fire. For all other arcing faults, a fire was caused in 25% of cases after the tank rupture. (It is assumed that the fire risk for system voltages larger than 135 kV is slightly but not significant lower.)

From a financial standpoint alone, the cost of an unplanned replacement of a large power transformer can be five to six times the initial purchase price, but a catastrophic failure often involves more than the failed unit itself. According to a 2011 report[2], transformer explosions have been documented to ignite neighboring transformers more than 60 feet from the initial fire and send projectiles more than 250 feet away. The resulting fire burns hot—between 1760°F and 2190°F—and can take several hours to consume the oil in the tank. Even if surrounding equipment is not damaged, it often must be de-energized while emergency personnel deal with the failed unit.

The report also notes that while there are no standards currently in place for firewalls placed around transformers, the authors recommend following UL 752 for impact loading, which calls for the firewall to withstand the equivalent of a .44 caliber bullet.

Clearly, the risk of a transformer failure, however small it may be, carries grave implications for not only the surrounding equipment but for human safety as well. Transformer manufacturers have developed techniques aimed at minimizing the danger associated with transformer failures. Use of rupture disks is one approach, often used where large transformers are located indoors or in close proximity to people.

However, rupture disks must be combined with a containment system to handle the expulsion of oil, gases and other material during a rupture event. This adds considerably to both the footprint of the unit and the expense, not to mention maintenance costs. An alternative approach developed by ABB in recent years obviates the need for a containment system altogether by absorbing the energy of an explosion through deformation of the tank itself.

Flexible tank concept

ABB has studied the mitigation of transformer tank ruptures for more than 20 years. The company began work on the flexible tank concept in 2007 and entered into a cooperative R&D effort with Hydro Quebec to refine the concept. The basic idea behind the flexible tank concept is simple: design a transformer tank such that it would deform during an internal flashover according to a predetermined scheme.

The project began with a review of the theoretical arc energy absorbed before rupture for a number of transformers using the finite element analysis method. This review also included the detailed analysis of several field events resulting in tank deformation or tank rupture, which provided valuable insights for design improvements. Finally, a sophisticated three-dimensional FEM simulation and evaluation routine was developed to correctly evaluate various tank designs, and several key features were identified.

Figure 1: Transformer with pressure relief system (left) and flexible tank design (right)

The type of steel used in the tank walls, the design of tank wall stiffeners, the shape of tank edges and the overall size of the unit all play a role in how the flexible tank concept works.

Also, because tank deformation can only absorb a certain level of arcing energy, the tank is designed to rupture above that energy limit at a defined location. To ensure the safety of employees, the public and the environment, the point of rupture is placed at the cover to minimize the danger of projections and major oil spills.

ABB's flexible tank design does not use any rupture discs. The built-up tank overpressure is relieved via classic pressure relief devices after the highly dynamic arcing event. This is because, in order to reduce the peak pressure during an internal arcing fault sufficiently, a venting area much larger than that of just one typical 12" rupture disc is required. Even if an operating rupture disc could decrease the localized peak pressure slightly, this would not be sufficient to mitigate the tank rupture risk.

Flexible tank units in the field

In 2008, an autotransformer (750MVA, 500kV) was delivered to Hydro One with a special pressure relief system (see figure 1). In order to have sufficient venting area, 40 rupture discs were installed on the tank together with a piping system to capture the oil in case of an operating rupture disc. Flexible tank design features were also applied at the utility's request. This autotransformer was also designed with an insulation class one level higher than necessary in order to reduce the risk of an internal arcing.

In 2010, ABB delivered a 460MVA, 161kV GSU transformer to TVA with a fully realized flexible tank design that incorporates the key features noted earlier. It has higher graded steel than normally used, specially shaped tank corners and walls, and flat rather than bent stiffeners. The estimated tank withstand energy level for this unit was calculated to be 18 megajoules (MJ).

ABB is currently building six single-phase GSU transformers (212MVA, 550kV) with flexible tank design and an arcing energy withstand capability of more than 35MJ for BC Hydro. These units will be delivered by end of 2012.

To date, ABB has not observed any internal arcing fault events on transformers with a flexible tank. A live test of an arcing event is scheduled to be conducted on a flexible tank transformer in 2013.

Additional safety measures

The energy consumed during internal arcing failure is in linear dependency of the arcing time. In other words, reducing the duration of a fault will correspondingly reduce the energy released. Fast detecting protective devices coupled with fast clearing circuit breakers can play a key role in minimizing event duration, which serves to further mitigate risk of tank rupture. Failure current clearing after three or maximum 4 cycles is a recommended target.

References

[1] Marc Foata, J.B Dastous, "Power transformer tank rupture prevention", A2_102_2010, Cigré

[2] Jackson Bishop, Alonso Rodriguez, "Electrical Transformer Fire and Explosion Protection," Engineering News-Record, March 28, 2011.

A more elegant solution

The risk of a transformer failure is low and the risk of a catastrophic tank rupture is even lower. However, transformers do occasionally fail and the results can be both costly and dangerous. Solutions are available to minimize the risk of a rupture and mitigate the impact should one occur. Rupture disks—in conjunction with containment systems—offer one approach, but the associated cost and footprint requirements make it less than optimal.

By contrast, the flexible tank concept presents an alternative that addresses the impact of tank rupture by preventing it from happening in the first place. The design also allows for a controlled failure using an engineered rupture point at the cover weld should arcing event energy exceed the tank's withstanding capability.

The flexible tank transformer offers a safe alternative to the rupture disk + containment system that is simpler, more efficient and virtually maintenance free.

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