A flexible friend

ABB's flexible tank concept for transformers mitigates rupture risk

SAMUEL S. BRODEUR, YASSER S. SALMI, ANDREW COLLIER – Explosions in oil-insulated transformers are primarily related to arcing between parts inside the transformer tank that are at different electric potentials. Such a failure event causes a rapid formation of gas and, as the volume of gas builds up, the pressure inside the tank increases significantly. As the metal tank starts to expand, it will deform and may even rupture. The consequences of such an explosion can include oil spills and even extensive fire damage to both the transformer and surrounding equipment. Traditional mitigation methods use, for example, circuit breakers, and mechanical relief and expansion chamber approaches – all of which have drawbacks – such as effectiveness, footprint or cost. ABB's flexible tank concept is a simple and cost-effective way to mitigate tank rupture risk that has none of the disadvantages of the traditional methodologies.

1 735 kV Transformer (15 MJ of arc energy) [3]

Despite design precautions to prevent internal arcing in oil-immersed transformers and reactors, there is always a residual risk of such an event, with the possibility of a subsequent tank rupture leading on to a fire and, possibly, an explosion. This risk is a major concern for the safety of employees, the general public and the environment. A statistical survey of 735 kV transformers revealed that approximately 32 percent of explosions were caused by bushing failures and almost half of those ended up in a fire [1]. This fire risk can be reduced significantly by using resin-impregnated paper (RIP) or resin-impregnated synthetics (RIS) bushings.

It is also reported that 54 percent of fires are caused by rupture of the tank or bushing turrets. Another large survey [2], covering 47,000 transformers, concluded that transformers with on-load tap changers (OLTCs), transformers in voltage classes above 300 kV, auto transformers and generator step-up transformers all tend to have higher failure rates than other types of transformers. Furthermore, the average probability of an explosive failure over a transformer's lifetime of 40 years is 40 percent, where 4 percent of these events lead to a catastrophic oil fire and 22 percent to a major oil spill. A catastrophic failure of a transformer is, therefore, by no means a negligible risk ➔ 1.

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Traditional risk mitigation techniques

The potential energy released by a low-impedance fault in a large transmission transformer can be as high as 147 MJ. However, several electrical and mechanical protection techniques can, individually or collectively, avert most of the major damage caused by arcing events.

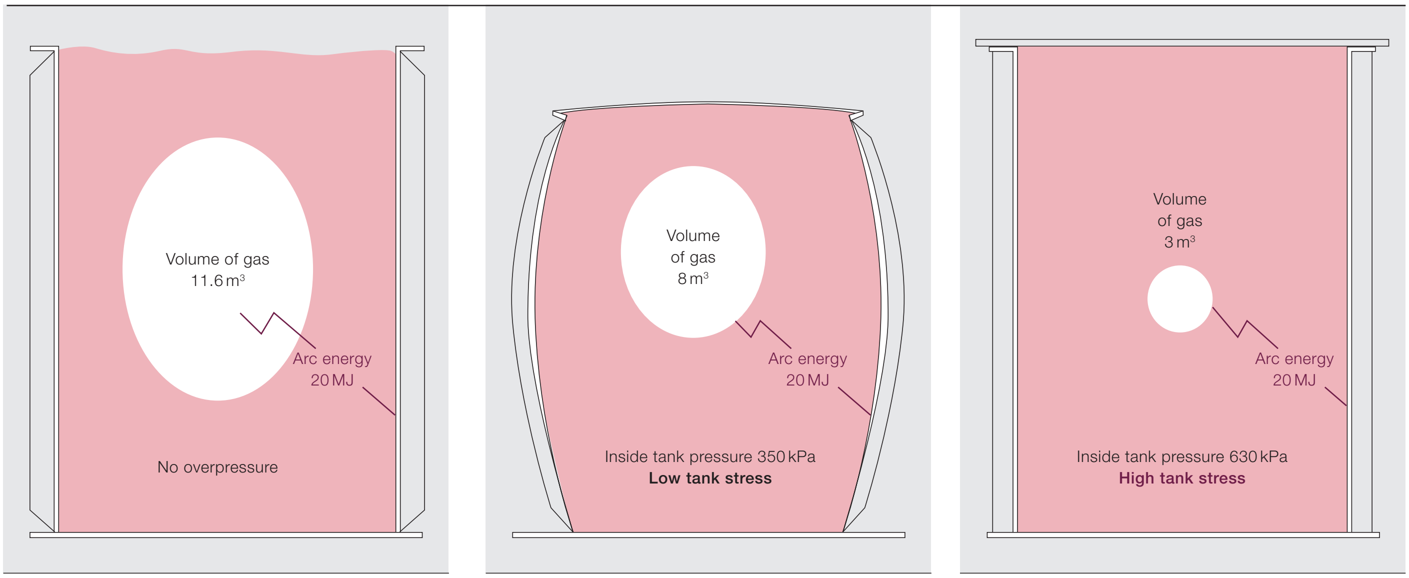
Electrical protection methods include:
- Fast-acting circuit breakers. These are the most important type of electrical protection as they minimize the fault duration, which is linearly proportional to the arc energy generated.
- Buchholz relays, which sense the buildup of gas within the oil. However, these are situated some distance from the potential source of a high-energy fault and may only start to trip after the pressure wave has already propagated.
- Circuit protection techniques such as differential protection or earth fault detection. These techniques must be robust enough to deal with the daily demands of inrush currents, phase imbalances and load fluctuations while having sufficient tolerance to ensure that nuisance tripping does not occur.

Even with modern commissioning tools, a human element will remain in the final choice of settings for many of these devices.

There are several mechanical approaches, such as the simple pressure relief valve. With a shorter opening time and lower resistance along the venting path is another mechanical approach – the rupture disc, which requires a containment system, complicating installation. An alternative is the large-volume expansion chamber. Here, a large connecting duct connects the tank to an expansion tank or enlarged conservator (the reservoir for the transformer oil). These absorb any sudden expansion.

Title picture
No matter how good the design and construction are, there is always a residual risk of a transformer catching fire or exploding. Traditional methods to mitigate the effects of such an event have their drawbacks. How does ABB's flexible tank concept get around these?

2 A 20 MJ arc energy event: The risk of rupture is mitigated by much lower tank stresses compared with a rigid tank.



2a Open tank

2b Flexible tank

2c Rigid tank

Gas-insulated transformers (GITs) avoid the oil issue altogether by using inert SF_6 gas for cooling and as an insulating medium. However, SF_6 is an extremely potent greenhouse gas, which means that potential leakage to the atmosphere is a concern.

Flexible tank concept

ABB has explored fire risk mitigation in large power transformers since the 1990s. Following an extensive evaluation in 2007 of the different technological approaches, the decision was made to focus on what is now known as the flexible tank concept.

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The idea behind this concept is to absorb a certain arc energy in a deformation of the tank ➔ 2. The tank is designed to rupture above this defined energy level. For safety reasons, the point of rupture is typically arranged to be at the edge of the cover, making dangerous ejections and major oil spills less likely.

The flexible tank solution is better than a pressure venting approach – eg, rupture disc or large-volume expansion chamber as it became clear from studies that even a large venting area of 1.0 to 1.5 m^2 would reduce the peak pressure by only 10 to 30 percent during an internal arcing fault – insufficient to mitigate the tank rupture risk under normal circumstances [4].

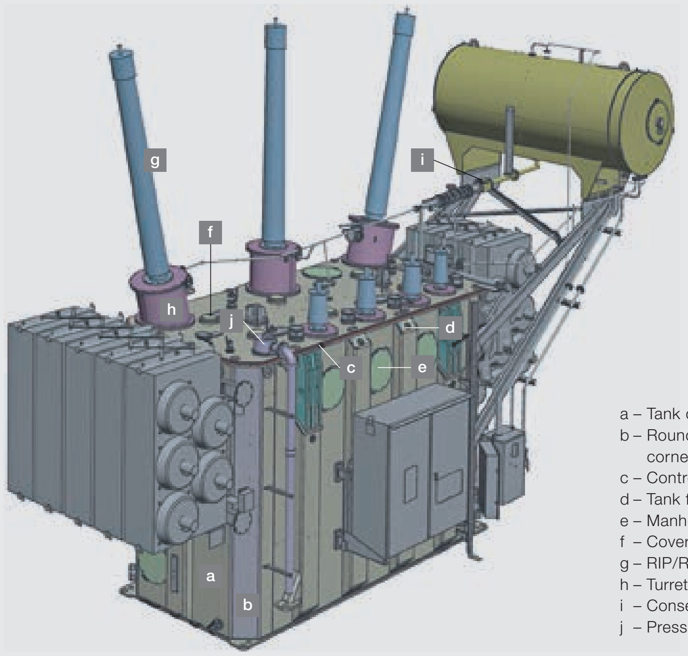
Tank withstand capability

The flexible tank concept includes many safety features that mitigate the risk of an oil fire or major spill during an internal fault ➔ 3.

Tank design and controlled rupture point (➔ 3, a and c)

A 3-D numerical simulation and evaluation were performed to verify a given theoretical tank capability. This finite element analysis (FEA) included nonlinear material properties, the large deflection effect, a careful meshing refinement and an analysis of the results by an experienced engineer. It applies the quasi-steady-state model, which is based on the conservative assumption of an isothermal expansion of the gas bubble and uniform pressure distribution amplified by a dynamic factor. The tank capa-

3 Tank withstand capability



a – Tank design
b – Rounded tank corners and bottom
c – Controlled rupture point
d – Tank flange reinforcements
e – Manholes
f – Cover support devices
g – RIP/RIS bushings
h – Turrets
i – Conservator shutter valve
j – Pressure relief valve

4 Tank flange reinforcements failure

5 Manhole experimental test

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bility is a function of the controlled rupture point prediction predefined at the tank cover weld. The evaluation results are detailed in a technical report that is provided at the transformer order stage.

Shaped tank corners and bottom (➔ 3, b)
The weld joints at the tank wall corners and those between the tank wall and base plate are likely points of failure during internal arcing. For this reason, the flexible tank concept includes shaped tank corners to move the weld joint from this high-stress location. Furthermore, a flexible connection between the tank wall and the bottom plate reduces the risk of rupture. For additional safety, all the weld joints of the tank wall are full-penetration welds certified by ultrasound testing during the manufacturing process.

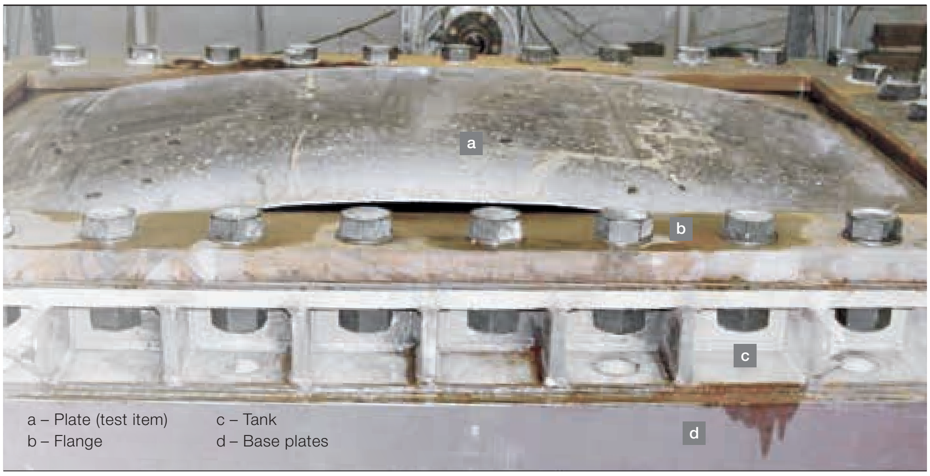
Tank flange reinforcements and cover support devices (➔ 3, d and f)
The tank flange reinforcements and the cover support devices are highly loaded and will fail first during internal arcing ➔ 4. This behavior was observed during transformer failure investigations and is implemented in the FEA evaluation routine to improve result accuracy.

Manholes and turrets (➔ 3, e and h)
The tank manhole withstand capacity under overpressure has been successfully qualified by an experimental test at the IREQ (Institut de recherche d’Hydro-Québec) laboratory [5] ➔ 5. Furthermore, this same qualified bolting system with o-rings is applied to the turrets, valves and bushing connections.

RIP and RIS bushings (➔ 3, g)
RIP and RIS bushings mitigate the risk of major oil spills, fires and porcelain

6 The conservator shutter valve

7 Partial tearing failure occurs according to FEA predictions



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shattering during an internal arcing. They contain, at most, a very small amount of oil.

Conservator shutter valve and pressure relief valve (➔ 3, i and j)

The conservator shutter valve is installed on the oil pipe connecting the conservator to the tank ➔ 6. The shutter valve allows oil flow in both directions, but in order to mitigate the risk of oil spilling from the conservator and feeding the fire, it will close and initiate an alarm if the flow rate exceeds a certain limit.

ABB expertise

As mentioned, ABB has been investigating risk mitigation of tank rupture since the early 1990s and so has gained a wealth of knowledge and understanding in this area. In 2007, the ABB plant in Varennes, Canada, began designing tanks according the flexible tank concept. Over the last five years, more than 20 flexible tank concepts have been designed, analyzed and delivered – including autotransformers, generator step-up transformers, shunt reactors, and single-phase and three-phase transformers – and from this work, further valuable lessons have been learned. The ongoing ABB development work in this area has resulted in a good correlation between FEA failure predictions and experimental tests, and has shown that the simplest and most efficient tank rupture risk mitigation approach is the flexible tank concept ➔ 7.

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