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Transforming future trends into innovations:

Siemens tank rupture-safe power transformers

Safety first

In principle, power transforms are safe, long-lasting, high-voltage converters. But even our 120 years of expertise in manufacturing the highest quality transformers cannot prevent transformer failures in operation. As a reliable partner of power suppliers and distributors, minimizing the consequences of these failures is essential, for example, in the most unlikely event of an internal arc. The latter can cause multiple effects, even tank rupture, which are researched, identified, and managed by our experienced engineers. This significantly reduces the probability of a tank rupture, minimizes damage to the environment and losses for our customers, and enhances grid reliability.

Tank rupture prevention reduces failure and damage

Environmental protection:

- Transformers filled with specific insulation fluids should not leak into the environment

Fire risk protection:

- In combination with heat and oxygen, the expulsion of insulation fluid could cause fire

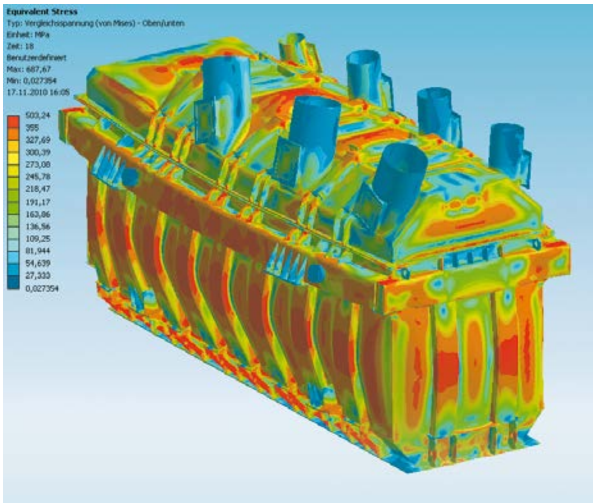
Cost and explosion protection:

- Reduces property damage
- Minimizes business interruption costs

Siemens Power Transformers tank rupture prevention through high-safety tank design

From internal arc to tank rupture

If an internal arc occurs which sometimes cannot be avoided, the released energy decomposes the ambient insulation fluid, for example, mineral oil. The duration of the arc can neither be predicted nor calculated. In any case, the internal pressure will increase due to the formation of a gas bubble. As a consequence, the rising pressure may deform the transformer tank. If pressure continues to increase, eventually the tank breaks (tank rupture). The leaking hot insulation fluid in combination with atmospheric oxygen ignites and starts a fire.

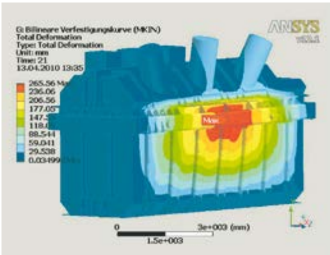


Internal arc characteristics

- Pressure is distributed spatially and non-uniformly
- Pressure rises in a range from 25 bar/s to 5,000 bar/s
- Very high local overpressure for less than 60 milliseconds (>14 bar)
- Local mechanical stresses

Answers for energy.

Tank rupture prevention across the board



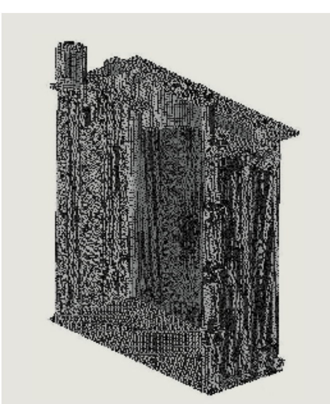
Voltage class [kV]	Arc energy [kJ]
72.5	2,000
145	4,000
170	4,000
245	8,000
330	20,000
765	20,000

Table source: Hydro Quebec

$$P_S = F \cdot \left(100 \cdot \sqrt{\frac{1}{4} + \frac{k \cdot E}{100 \cdot C}} - 50\right)$$

P_S Pressure
F Dynamic amplification factor
k Emerging gas volume caused by arc energy
E Arc energy to be contained
C Volumetric flexibility of tank

Equation source: Hydro Quebec



Under pressure

A transformer tank is not a pressure vessel. It is designed to withstand full vacuum and a pressure 25 percent above the normal operating pressure. Most rectangular tanks will sustain 1.4 to 2.10 bar before distortion or rupture. A transformer tank must be able to resist the following types of loads: acceleration forces of the active part during transportation and lifting, hydrostatic pressure, vacuum pressure and, in the event of a fault, the arc pressure.

Like TNT and dynamite

The table above shows the energy a power transformer must contend with in the event of an internal arc. From a voltage class of 330 kV and above, energies greater than 20,000 kJ can occur.
This is the energy in 10 sticks or 2.6 kg of dynamite or 5.3 kg of TNT.

Calculating arc pressure

Hydro Quebec simplified the dynamic behavior to a static formula so that the complex tank structure can be modelled with FEM to locate weak points and increase the pressure resistance. Note that the flexibility of the tank is a significant element.

Types of faults

The energy noted above is unleashed by internal arcs that could be caused by inter-turn failures, inter-section failures, inter-winding failures or inter-phase failures for example. Studies show that fire probability in the event of tank rupture increases with higher voltage. About 50 percent of all transformer fires are caused by tank ruptures, a hint as to how important their prevention is to ensure substation safety.

How to ensure prevention of tank rupture

Transformers have been saved from rupture by common protection devices like real-time gas monitors, gas detector relays, rapid pressure rise relays, and pressure relief devices. But tank rupture prevention is the most effective way to reduce damage costs.

The following steps describe the calculation procedure:

- In the calculation, the internal pressure is increased in steps and the volumetric flexibility of the tank ("C" in the formula) is obtained by static FEM
- The 3D CAD model of the transformer tank was imported to ANSYS Spaceclaim to create a mid-surface model (from shell-model, less nodes to solid model, which means faster computation), as shown on the left: a half model with 106,000 nodes
- In addition, the arc pressure is calculated for each step in this formula
- This proceeds until the arc pressure is equal to the applied pressure
- Finally, the stresses inside the tank are calculated. The model is modified until the calculated stresses are lower than the mechanical strength of the steel used
- This tank design also places the weakest parts near the top to minimize amount of insulation fluid loss in the event of a leakage

Design adjustments

- Aligned tank and cover stiffeners, which are extremely beneficial
- Tank symmetry effectively homogenizes stress distribution
- The choice of material is significant in a controlled deformation of the tank

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