ZURICH
Resilience Solutions

Risk Insight

Loss Prevention for Large Industrial Transformers

Transformers are often single points of failures, they are critical assets for the transmission or distribution grid, and they are essential to maintain production at your process, facility, or power asset.

It is reasonable to suggest they are largely reliable and do what they are designed to do. Due to their static nature and constant energisation, they can almost become invisible, often quietly transforming voltage as per design and without showing signs of ill health. It is for that very reason a transformer's condition can be overlooked leading to catastrophic failure, financial loss and potentially resulting in a high potential safety event.

Global failures, for greater than 100 MVA transformers, stands in the region of 0.75% of the installed units. Whilst their failure may come as a surprise to some asset owners, it should not. There are industry standard testing programmes that provide critical health condition statements for the different components of a transformer.

Principal Failure Mechanisms

Mature asset management plans for transformers will be informed by the known failure mechanism and the accepted preventative maintenance activities. Through the assessment of claims within Zurich Commercial Insurance, Zurich Resilience Solutions can provide the principal failure mechanisms, shown in Figure 1. Whilst not included, it is possible to experience a failure of the core itself, although that is less likely.

Where maintenance programmes do not focus on the recommended predictive and planned maintenance the likelihood of a failure resulting in an unplanned outage can be high, resulting in property damage, business interruption, and potentially liability claims.

Causation	Failure Mode	Outcome
Moisture Ingress Overheating Aging Electrical Stress	Insulation Breakdown	Short Circuit Partial Discharge
Mechanical Stress Overloading Short Circuit Event	Winding Failure	Open or Shorted Windings Performance Loss Failure
Excessive Wear Mechanical Failure Poor Alignment	Tap Changer Failure	Voltage Errors Arcing Transformer Outage
Contamination Insulation Breakdown Mechanical Damage	Bushing Failure	Flashover Insulation Loss Failure
Overload Cooling System Failure Airflow Failure	Overheating	Accelerating Aging Insulation Damage Failure

Figure 1: Typical claim causations seen by Zurich Resilience Solutions

Zurich Resilience Solutions present below our recommended care programme for industrial transformers, itself informed by OEM recommendations and enhanced with loss and causation data.

Zurich Resilience Solutions' Recommended Care Programme

Dissolved Gas Analysis (DGA)

Zurich Resilience Solutions has aligned its requirement for DGA analysis with the IEEE C57.104 standard. Table 1 is an extract from that standard and lists the gasses under test. A minimum of annual testing is required where no ongoing care programme is in place.

In addition, to establish a baseline of gas behaviour, it is good practice to test every 3 months for a new transformer, and for a period of 2 years. End of life and those under monitoring require a bespoke testing regime.

Table 1: IEEE C57.104 DGA condition boundaries

Status	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	TDCG
Condition 1	100	120	1	50	65	350	2,500	720
Condition 2	101-700	121-400	2-9	51-100	66-100	351-570	2,500-4,000	721-1,920
Condition 3	701-1,800	401-1,000	10-35	101-200	101-150	571-1,400	4,001-10,000	1,921-4,630
Condition 4	>1,800	>1,000	>35	>200	>150	>1,400	>10,000	>4,630

Degrees of Polarization (DP) or furan analysis is also recommended by ZRS. As the cellulose insulation breaks down over time furanic compounds are released into the oil, which is used to indicate insulation health via the degree of breakdown. A DP value of 700-800 indicates normal age whereas at 200 the paper has reached end of life. Corrosive sulphur testing should also be carried out when the oil is new or replaced and every 3 to 5 years as a validation exercise.

It is critical that the oil sample is not contaminated nor is there a delay between sampling and testing; both will reduce the effectiveness of the result and may mislead the response of the asset team looking after the transformer. A maximum of 7 days between sample and test is recommended. Online DGA and Partial Discharge (PD) monitors can provide condition measurements as when required due to pre-installed sensors and without taking the transformer offline.

Condition 1 and 2 require increased observation and trending whilst condition 3 and 4 indicate where faults are likely to be present, decomposition is high, and action is required to investigate and prevent failure.

Table 2 sets out the ZRS recommended planned preventative and predictive maintenance activities for monitoring the health of the transformer windings, insulation, tap changer, transformer bushings and protection devices. The purpose and potential outcomes are provided to support the motivation for the testing schedule.

The frequency assumes that there are no known faults with the transformer, and it remains in the operational phase of its lifecycle, outside of the early life and end of life periods.

Table 2: Recommended planned preventative & predictive maintenance activities

Winding Testing

PPM	Purpose	Outcome	Frequency
Resistance test	Identifying high resistance, open circuits, or shorted turns.	Can reveal loose connections or deteriorated contacts	Every 2 years
Turns Ratio	Compares the ratio of primary to secondary windings.	Indicating shorted or open windings	Every 2 years
Short-Circuit Impedance	Measures impedance between windings	Indicates winding faults caused by short-circuit events	Every 5 years

Insulation Testing

PPM	Purpose	Outcome	Frequency
Insulation Resistance	Measures resistance between windings & ground. Ideally utilises 5 kV DC test voltage for injection.	Low resistance- contamination or cellulose breakdown >1000MΩ - excellent health.	Annually
Power Factor (Tan Delta)	Assesses degradation of insulation. Tests phase difference between voltage & current within the insulation.	Higher values indicate aging, geometry changes, moisture & contamination. A good result is < 0.5%	Every 3 years
Polarisation Index (PI)	Compares insulation resistance readings over time (1 min Vs 10 mins)	$\geq$2.0 indicates insulation is in good condition	Annual
Partial Discharge (PD)	Finds electrical discharges within insulation	Avoidance of complete failure	5 years

Tap Changer

PPM	Specific tests/checks	Frequency
Visual	Physical condition Evidence of leakage	Monthly
Operation Checks	Full range movement Noise assessment Indicator movement	Annual
Electrical Tests	Insulation resistance Contact resistance	Annual
Contact Inspection.	For pitting, burning, wear	3 yearly
Functional Tests	Control system led operation	Annually
Lubrication	Deposit removal Linkage lubrication	Annually

Bushings

PPM	Purpose	Frequency
Visual	Physical condition Evidence of leakage	Monthly
Cleaning	To remove deposits and contamination	Annual
Electrical Tests	Insulation resistance Power factor (Tan Delta) To detect deterioration of insulation & crack formation	Every 3 years
Thermal Imaging	To identify hot spots	Annually
Torque Tightness	Maintain integrity	Annually
Oil Checks	DGA, level, condition, dielectric strength.	Annually

Protection Devices		
PPM	**Specific tests/checks**	**Frequency**
Visual	Physical condition Evidence of leakage	Annually
Functional Tests	Test all protection devices & relays operation (e.g. earth fault, overcurrent, differential protection) Ensure all settings are tested, (e.g. current pick-up levels, time delays) Complete simulations for fault, error signals Confirm correct polarity & integrity of connections Check protection cabling - insulation resistance continuity.	Annually
Alarms/Trips	Ensure all alarms operate & trip response is as design	Annually
Buchholz Relay	Presence of gas, float movement, oil level, seals	Annually
Temp' Sensor	Sensor calibration, positioning,	Annually

Typical loss impact

As a single point of failure, a large oil filled transformer will have a significant impact on the export capability of a power plant if lost in an unplanned event. Whilst typical business interruption values differ, project to project, in 2025 Zurich Insurance is seeing values for loss of power generation revenue of USD 2,500,000 per month for the failure of a 450 MVA transformer.

Zurich Resilience Solutions is currently recommending our insured client consider a business interruption period of 24 months for a replacement transformer at above 450 MVA. Should the main grid step up transformer suffer a catastrophic loss event the business interruption impact alone can be at least USD 45,000,000.

Zurich Resilience Solutions Recommendation

Zurich Resilience Solutions' recommend that every transformer has a baseline care plan embedded into the computerised asset management system. The baseline should include, as a minimum, the actions identified above. Should the results indicate a potential health issue additional actions are necessary.

Failure to complete the maintenance programme will increase the likelihood of transformer loss; in turn increasing the operational risk within the organisation. It is better to manage an informed risk position rather than the impact of a loss event.

We recommend the adoption of online monitoring for DGA and PD, and for new facilities, including this requirement within the design specification is the best opportunity to install.

ZRS always recommend that a business continuity plan includes specific mitigation for the loss of a transformer, regardless of the criticality. Identifying critical spares for all transformer types forms a vital component of failure planning. An unplanned catastrophic failure will impact the organisational performance across the financial, safety, and reputational business processes.

References

1. IEEE C57.104 Guide for the interpretation of gases generated in oil-immersed transformers

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