Transformer Reliability Survey: Interim Report

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Introduction

In 1983, Cigré Working Group 12.05 published a report summarizing the results of the analysis of transformers that failed in the period 1968 to 1978 [1]. Thirteen countries from 3 different continents took part in this survey. The authors reported of difficulties to compile and analyse the data of the survey due to incomplete or incompatible responses. Ten years later, Working Group 12.14 attempted to upgrade this survey but it was unsuccessful due to similar reasons. Study Committee A2 also started an Advisory Group on Reliability and their findings were presented at the Cigré 2006 session in [2].

Some countries have published reliability surveys locally with some being published annually. However, this knowledge is not shared amongst the international transformer community, where most benefit can be drawn.

To date, the only international survey on large power transformer failures was published in 1983. The failed units were classified according to voltage level, age and application, and for each class, corresponding failure rates were calculated as well as classification into failure component, presumed cause and failure origin.

The survey concluded that the average failure rate of transformers may be regarded as 2 % across all voltage categories. Since then, this statistic has become an international benchmark in the transformer industry for the failure rate performance of transformers. However, this survey was based on transformer failures occurring in the period 1968 to 1978.

Working group A2.37 Transformer Reliability was formed in 2008 with the following objectives:

- Reviewing all existing survey and study different practices (in terms of data collection, compilation, etc.)
- Conducting a new international survey on transformer failures
- Compiling and analysing the collected data, and interpreting the results (calculation of failure rates, classification into failure location, failure causes and failure modes)
- Preparing a brochure documenting the above-mentioned.

This interim report discusses the progress of the working group to date in terms of data collection, and will present results of the analysis in terms of failure rates and the classification into failure location. Because data collection is still in progress, this report will refrain from giving a detailed interpretation of the results.

Review of Existing Surveys

The working group collected publicly available surveys from Canada, Germany and Japan [3, 4]. The main objective of these surveys is the systematic collection of data on the availability and disturbances of the electrical power supply, with emphasis on the frequency, duration and extent of the interruptions. Detailed statistics about the failure location in the respective equipment, failure cause or mode and repair activities are normally not included. The benefit of these statistics with respect to asset management is therefore limited. Additionally, the failure surveys of utilities, manufacturers and consulting companies are being collected and analysed by the working group. However, different definitions and information content constrain forming a coherent database from these individual sources.

Initial working group discussions concentrated on analysing the readily available statistics, but it was agreed that the scope needed to be broadened to allow comparison with the failure statistic of 1983 survey. A questionnaire was therefore developed to collect utility failure statistics in a standardised way. Besides information about the population under investigation, failure data is being collected for various groups of transformers in terms of the failure locations, failure causes, failure modes, actions, external effects and others parameters.

Data collection and preparation for analysis

Definition of failure

The definition of failure was limited to major failures. Based on the experience of previous working groups on this subject, it was decided to limit the data requested from the sources by concentrating only on major failures of power transformers and shunt reactors of operational voltages higher than 60 kV only.

According to the working group, **a major failure** was defined as any situation which required the transformer to be removed from service for a period longer than 7 days for investigation, remedial work or replacement. Where repairs were required, this should have involved major remedial work, usually requiring the transformer to be removed from its installation site and returned to the factory. A major failure would require at least the opening of the tank, including the tap changer tank, or an exchange of the bushings. A reliable indication that the condition of the transformer prevents safe operation is considered a major failure, if remedial work (longer than 7 days) was required for restoring it to the initial service capability.

Reliability questionnaire

A questionnaire consisting of two major sections were developed to collect data, in accordance with the definition of major failure in section 3.1. [5]

The first section of the questionnaire requested general information about the population of the operating transformers for the indicated failure period. The population information requested included the transformer application, type, number of phases, voltage, rated power, typical loading, and manufacturing period.

The second section captured the transformer failure data, grouped data into 4 categories as follows:

- ***Identification of the unit:*** application, type, construction type, year of manufacture.
- ***Features of the unit:*** rated power, nominal voltage, number of phases, cooling system, type of oil, tap changer, tap changer arrangement, oil preservation system, over voltage protection.
- ***Detail of occurrence:*** year of failure, service years to failure, loading immediately prior to failure.
- ***Consequences of failure:*** external effects, failure location, service years of failed bushings (if location is bushings), failure mode, failure cause, action taken, and detection mode. It is important to note that:
  - Failure location referred to the primary location in the transformer where the failure was initiated.
  - Failure cause referred to cause of failure in the location where the failure was initiated.
  - Failure mode referred to a description of the nature of the failure, in the location where the failure was initiated.

Collected data

Each participating utility was required to complete the questionnaire described in section 3.1, and all the responses were compiled into a database. In order to achieve a data security and anonymity, the failure data from each source was labelled by a code based on the geographical location and a sequence number. Information about the transformer manufacturer was not collected.

To date, the working group has collected 685 failures which occurred in the period 1996 to 2010, with a total population of 156,186 unit-years, contributed by 48 utilities from 16 countries. The year of manufacture of the units span from the 1950's up to 2009. The data analysis was performed for all failures which happened after 2000.

Data collection is still in progress and will continue until May 2012.

Calculation of failure rate

Failure rate was calculated according to the definition in Bossi [1983], which was expressed as: •••

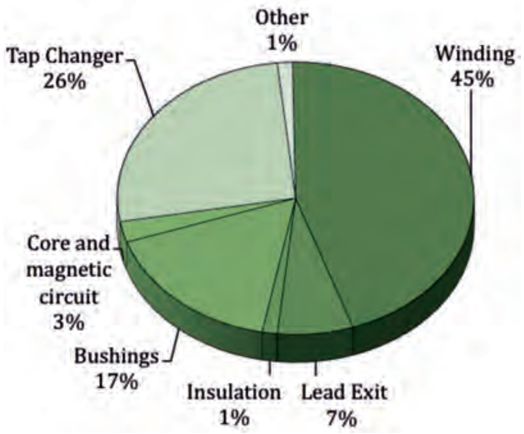

Figure 1: Failure locations of Substation Transformers (>100kV) (based on 364 failures)

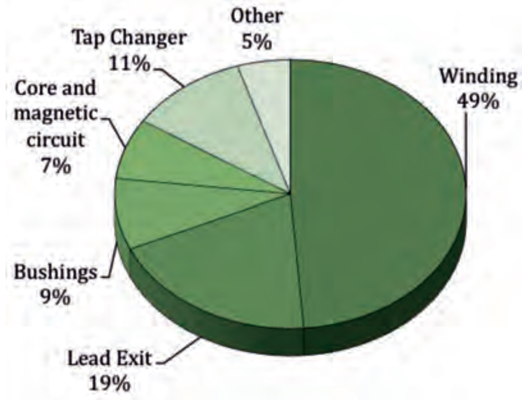

Figure 2: Failure Locations in Generator Step-Up Transformers (>100 kV) (based on 82 failures)

$$\lambda = 100 \cdot \frac{\sum_i n_i}{\sum_i N_i} \% \qquad (1)$$

Where:

n_i = the number of transformers that failed in the i^{th} year

N_i = the number of transformers in service during the i^{th} year

Data analysis

The analysis presented was based on the population and failure data collected to date, as described in section 3.3. The data were grouped into substation, and generator step-up transformers, and further categorised into 5 voltage classes.

Failure rates

The calculated failure rates according to the voltage category for the substation and generator step-up transformers, as well as the combined group of transformers, are given in Table 1 to Table 3. It is important to note that the number of generator step-up unit failures, and units in voltages classes above 500 kV, as well as the

Table 1: Failure Rates of Substation Transformer

FAILURES & POPULATION INFORMATION	HIGHEST SYSTEM VOLTAGE [kV]					
	69 ≤ kV < 100	100 ≤ kV < 200	200 ≤ kV < 300	300 ≤ kV < 500	kV ≥ 700	All
Failures	145	206	136	95	7	589
Transformer - Years	15077	46152	42635	29437	219	135491
FAILURE RATE	**0.96%**	**0.45%**	**0.32%**	**0.32%**	**3.20%**	**0.43%**

Table 2: Failure Rates of Generator Step-Up Transformers

FAILURES & POPULATION INFORMATION	HIGHEST SYSTEM VOLTAGE [kV]					
	69 ≤ kV < 100	100 ≤ kV < 200	200 ≤ kV < 300	300 ≤ kV < 500	kV ≥ 700	All
Failures	0	6	27	59	4	96
Transformer - Years	143	2842	4838	12132	740	20695
FAILURE RATE	**0.00%**	**0.21%**	**0.56%**	**0.49%**	**0.54%**	**0.46%**

Table 3: Failure Rates of Combined Group of Transformers

FAILURES & POPULATION INFORMATION	HIGHEST SYSTEM VOLTAGE [kV]					
	69 ≤ kV < 100	100 ≤ kV < 200	200 ≤ kV < 300	300 ≤ kV < 500	kV ≥ 700	All
Failures	145	212	163	154	11	685
Transformer -Years	15220	48994	47473	41569	959	156186
FAILURE RATE	**0.95%**	**0.43%**	**0.34%**	**0.37%**	**1.15%**	**0.44%**

population of these two categories, has been low to date. The calculated failure rates should thus be considered with caution.

The working group further invites participation from utilities and countries for failure data, in particular the abovementioned two transformer groups, to improve the statistical significance of the results. Data may be supplied by completing and submitting the questionnaire (available via the web link given as [5]) to the convenor or secretary of the working group.

Failure location

The contributions of failure locations in substation transformers and generator step-up transformers for voltages higher than 100 kV are given in Figure 1 to Figure 2.

As seen in previous surveys, major failures can originate from several transformer components. Windings related failures appear to be the main contributor of major failures. The contribution of tap changer related failures decreased significantly in comparison with the statistics from 1983 given in [1]. 95% of the failed substation transformers and 91% of the failed generator step-up units were equipped with a tap changer.

It is important to note that failure locations in some cases have an operating voltage dependency. Regional significance also has an impact [6]. A more detailed analysis and interpretation of the results will be provided in the brochure, which will be published after completion of the working group's expected outcomes.

Conclusion

A questionnaire was developed by the CIGRE working group A2.37 (Transformer Reliability Survey) by which utility failure statistics could be collected in a standardised way [5]. Transformer failure data can therefore be analysed and interpreted for various types of transformers in terms of failure locations, failure causes, failure modes, actions, external effects and failure rates in transformers. In contrast to several public available statistics, the results of this questionnaire deliver valuable information which can be used for asset management of a power transformer fleet.

The preliminary results, based on a transformer population with more than 150.000 unit-years and 685 major failures in 48 utilities, indicate a failure rate of 0.44%.Winding related failures appear to be the largest contributor of major failures, and a significant decrease in tap changer related failures has been observed in comparison with results of the 1983 survey.

In order to improve the validity of the failure statistics, the working group invites participation from utilities to provide failure data, in particular shunt reactors, generator step-up transformers, and transformers with operational voltages above 500 kV. ■

REFERENCES

[1] A. Bossi, et al., "An International Survey on Failures in Large Power Transformers in Service" – Final report of CIGRE Working Group 12.05, Electra, No.88, pp. 22 – 48,1983.

[2] J. Lapworth: Transformer reliability surveys, A2-114, Cigré Biennial Conference, Paris 2006

[3] The Canadian Electricity Association. forced outage performance of transmission equipment , Equipment Reliability Information System. canada : s.n., 2000-2009.

[4] VDN-Störungs- und Verfügbarkeitsstatistik , Verband der Netzbetreiber VDN, Berlin, www.vde.com/fnn, Berichtsjahr 2004.

[5] Questionnaire of CIGRE WG A2.37 "Transformer Reliability Survey", November 2011,url: http://www.uni-stuttgart.de/ieh/wga237.html., last accessed: November, 2011

[6] S. Tenbohlen, et al., "Assessment of Power Transformer Reliability", Int. Symp. on High Voltage Engineering, Hannover, Germany, G-026, August 2011