Trends in Power Transformer Failure Analysis

ABSTRACT

Part three of this series on *Trends in transformer failure analysis* will report on some recent progress on standards body projects that were described in the first issue. It will describe some failures which have evolved recently. It will also identify many things that are not found in the IEEE Guide for Failure Analysis and describe the reasons why they are not included.

KEYWORDS

power transformer, failure analysis, failure reporting, failure investigation

Recent development in failure analysis and reporting

In my first article on the subject of failure analysis [1], I described work underway in the IEEE/PES Transformers Committee to revise the IEEE C57.125 *Guide for failure investigation, analysis, and reporting for power transformers and shunt reactors* [2] and parallel work in CIGRE WG A2.45 *Transformer failure investigation and postmortem analysis*. What I neglected to mention is the IEEE effort included incorporating the process by which any entity can establish a database of a population of similar transformers, determine the differences and statistically come to some conclusion about how the population was behaving. The original work on developing the database was titled IEEE C57.117 *Guide for reporting failure data for power transformers and shunt reactors on electric utility power systems* [3]. We have merged the rules for statistical analysis, the appropriate definitions, and the suggested forms which we hope will become a part of the data describing the transformer so that its identity and pertinent rating information can be entered into a database. An Electrical Power Research Institute (EPRI) project took that effort to the pilot stage but the effort died for lack of funding or lack of interest. Fortunately, another U.S. company has stepped up to host a database for clients who wish to participate and have sufficient interest to proceed. Each participating company's data has been converted into a "standard format" and the queries are developed to calculate various failure rates of interest to the group. The host is currently updating everyone's 2013 data; adding in

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failures that occurred during the year plus adding in newly installed transformers and noting transformers that were retired so that the database maintains accurate population data.

The CIGRE A2.45 Working Group has met six times, the latest meeting being August 2014 in Paris. Their early meeting minutes recognised the C57.125-1991 as state of the art. We share some common interests although we are not actively coordinating the work between the two groups. The A2.45 WG is making progress toward a brochure which, based only on my reading of their minutes, appears it will address many of the same issues that are addressed in the IEEE Guide.

I am happy to report that as of this writing, the effort by the IEEE/PES Working Group has progressed to ballot of a final draft of PC57.125 and if all goes well, that ballot should be concluded by the time this issue of Transformers Magazine reaches you. The final draft contains tables of tests whose interpretation can help with the diagnosis of problems. I mentioned some of the new tests which I included in the "Alphabet test" category in the last article on Trends in transformer failure analysis contained in the second edition of Transformers Magazine [4]. There are other documents to which one can refer to obtain values where industry norms have set limits. It still remains up to the individual to analyse the test results and compare them to previous readings to detect trends or to detect when limits indicate that either a failure has occurred or is imminent.

Failure analysis is an ever evolving process

While we have been revisiting the document, we have been made aware of several failure modes which have revealed themselves. These and perhaps others which manifest themselves in the future will have to become part of the next revision since there is a time limit on completing a revision within the cycle required by the sponsoring body (in this case IEEE-SA)

What is new in the latest revision of the guide for failure analysis?

1. Expanded safety clause

– A significant change to the C57.125 Guide is the inclusion of a comprehensive safety clause for the hazardous conditions which may be encountered when performing field inspection and testing on a suspected failure.

2. Additional test techniques

– Besides the addition of the safety clause, additional test techniques which were not in common practice at the time when the original guide was written have been added where their results point to a cause or narrow the possibilities for causes.

3. Reliance on more comprehensive test interpretation which is contained in IEEE Field Testing Guide

– The interpretation of test results from tests suggested by the C57.125 guide now refer to the more comprehensive IEEE C57.152 *Guide for diagnostic field testing of power apparatus - Part 1: Oil filled power transformers, regulators, and reactors* [5]. This guide, published in 2013 is an expanded and completely overhauled version of IEEE 62 which had the same title. It contains a clause devoted to all commonly used field tests, the interpretation of test results, and in many cases, the appropriate action to determine if a test specimen has passed. It recognises that some tests are PASS/FAIL while others must be evaluated by analysis of TRENDS.

What is not in the revised c57.125 guide?

1. Guaranteed methods that ensure that a cause will be found are not in the Guide. One must remember that the fault current flow available, and the resulting energy of the fault, will likely vaporise (or at minimum, relocate some distance) traces of contamination, chemical compounds, and other possible root causes of the

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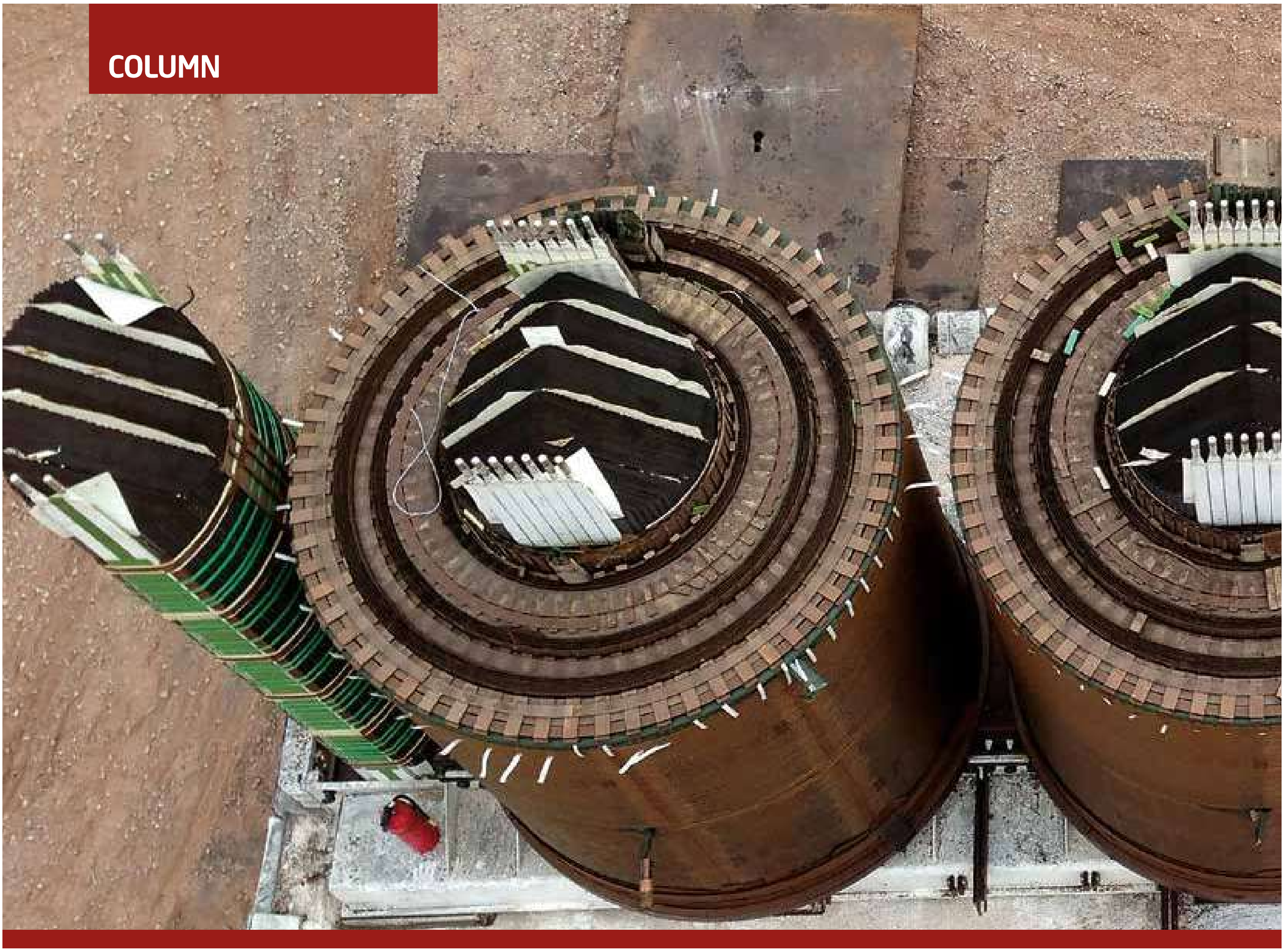

events which follow and ultimately lead to the fault current flow. The precision and thoroughness of data collection is also important to obtain conclusive results.

2. Failure Modes and Effects Analysis (FMEA). Those that feel the need for such analysis should refer to IEEE C57.140 *Guide for evaluation and reconditioning of liquid-immersed power transformers* [6]. This guide contains a number of charts from which FMEA analysis could begin.

3. The Guide cannot supply or guarantee that the investigation will always be performed in a safe manner. Safety should be inherent in the design, comprehensive in worker training, and under constant review for improvement. Equally important is that safety regulation is an evolving process and what may be standard practice today may be viewed as an unsafe practice in the future. Regulations and work practices have certainly come a long way in providing worker safety and property damage reduction but accidents can still happen. Caution is of the utmost importance.

4. While writing the introduction to the latest revision, I made the plea to the industry to use the guide to allow users of the guide to reach the same or nearly the same conclusion when investigating failures and I made a plea to the industry to create and use a database to collect and facilitate analysis of failures to permit early awareness of deficiencies in design or application. These are statistical tools which will help but not guarantee success in determining the root cause. Nevertheless, progress is being made to answer that need. We are not quite there but are getting closer. Data analytics techniques being developed for digesting the data available from all the smart devices on the smart grid may in the future be applied to data collected to arrive at a more conclusive result.

5. I believe that there is an expectation that we will reach a point when industry recalls will take place so that an awareness of potential failures will be created before similar failures occur. The underlying approach to the original Failure Reporting Guide (then known as C57.117) would establish

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such a database and that one company's failure would appear with the same severity as another; that identical causes could be located in the data and steps necessary to correct whatever was causing them to be corrected. There is also hope that an unequivocal conclusion can be reached every time the process described in the guide is followed. This, unfortunately, is not the case. On many occasions, the power of a short-circuit fault will destroy the evidence of the underlying cause.

6. We want to believe that all transformers are alike and that the results of tests will provide enough evidence to solve the mystery. Pick your genre – some want to compare transformer failure analysis to medicine and some want to compare the failure investigations to crime drama that is so popular on television these days. While I enjoy a good crime drama or a medical drama on TV, I also know that no two people are exactly alike, just as for every transformer design there are only an average of 1.3 transformers built. Statistics can reveal only so much and there will always be "outliers" which do not conform to the statistical norm.

– If we stay on the medical treatment analogy, there is always a need to tailor the treatment to the uniqueness of the human patient. We must consider doing the same for the transformer patient as well.

7. The abstract to a paper written in 1985 for the Summary of Changes in IEEE *Guide for protective relay applications to power transformers,* ANSI/IEEE Standard C37.91 [7], described the updates and re-organisation which took place under the auspices of the IEEE/PES Power System Relaying Committee. The revision described was an update which guided the user to the correct application of the various methods and devices used to protect power transformers. The paper highlighted the scope and usefulness of the C37.91 guide and initiated discussion of future enhancements. That guide has since undergone at least two major revisions, however, the fundamental protection principles have not changed.

– The paper was, of course written almost 30 years ago when many transformers were still protected by electro-mechanical relays. Protective devices have since become intelligent electronic devices (IED) with more capabilities than, perhaps, the entire station designed and built 30 years ago.

– Advancements in protection and modern circuit breakers design have helped minimise the damage of an internal fault in a transformer, but I still believe the goal of the devices protecting the transformer are really protecting the system from the transformer. Even minimum damage still requires a substantial effort to repair, and since we are talking about an internal fault, there are few utilities and probably no manufacturer who would jeopardise the transformer, the workers, or the system by returning a transformer to service after an internal fault is well confirmed. Most would return the transformer to a shop where it could be properly and thoroughly cleaned, repaired, dried, reprocessed, and tested to confirm it was in good (like new) condition.

8. The Guide does not provide a comprehensive list of all the components on your transformer that could fail or could have caused a failure. Only your transformer specification will have that and only if the documentation has been updated as accessories have been added or removed.

9. The Guide cannot tell you how to design a transformer which is adequate to perform in the application the owner intends.

10. The Guide cannot tell you how to correctly apply and specify a transformer for your needs.

11. The Guide will not tell the manufacturer what type of design to use (unless you have a design expert to provide you with reasons why certain design features are required for your application / conversely, the Guide does not tell the user who has done diligent system analysis what their design features must be (e.g., turns RATIO, impedance, BIL, etc).

12. The Guide does not define the duration of the bottom of the bathtub curve. Hence the need for detailed failure analysis along with all of the „normal" operating parameters to which a transformer population was exposed.

> **Core gassing in wound core medium voltage transformers have been found because the operators of wind farms monitor DGA. Does the same problem exist on medium voltage distribution systems?**

Recent failure mechanisms on which to keep a watchful eye:

1. Core gassing in wound core medium voltage transformers

– Found because the operators of wind farms monitor DGA while most distribution organisations do not.
– May also be a problem on medium voltage distribution systems, but units are usually not tested (e.g., no DGA, no routine maintenance)
– A Task Force has been established to investigate whether routine testing can detect possibility of a problem. This is something to consider adding to the specifications, if not to the standards.
– It has not been established with a high degree of certainty that the gas is the result of partial discharge (PD) in the core and if so, is it a sign of high dielectric stress between core laminations or at the edges of core lamination.
– What are the consequences of the high dissolved gas? Will the gas come out of solution and present an explosion hazard? Will it simply mask the occurrence of a winding PD problem? Everyone agrees that gas is an undesirable symptom and so is the possibility that PD is causing the gas to develop. More analysis and research will be necessary to determine the best solution. Designs can be formulated to solve the problem once the cause is confirmed.

2. Magnetic shunts shorted to the frame in core form units resulting in increased combustibles discovered by DGA
– No final cause identified.

3. How many transformers shipped from manufacturers (anywhere) have been found damaged by forces during transport?

– Logic behind IEEE C57.150 *Transportation Guide*
– One of the reasons for development of SFRA

4. Not so recently, a transformer failed with the following scenario:

– Short-line fault occurred due to lightning
– Station rod gaps flashed to move the fault from 1 - 2 km from the station to the station entrance
– A circuit breaker on the ring-bus directly adjacent to the transformer connection flashed internally from current carrying part to grounded tank.
– The transformer experienced part-winding resonance and failed internally from the overvoltage produced by the part winding resonance.
– Conclusion was that the frequency response to these specific conditions MIGHT have been prevented by installation of a snubber circuit or part winding thyristor valves (essentially surge arresters) installed within the winding.
– No further action was taken as the low risk of a similar failure plus the cost of the system studies to determine the size and capacity of the internal valves could not be justified.
– No failures have occurred at that station since.
– Does this mean that the problem was incorrectly diagnosed or that the probability of such an event occurring is low enough to take the risk?
– Perhaps the cause was not the short-line fault, but the flashing of the rod gaps or the failure of the circuit breaker.
– System studies, though expensive to perform, are becoming a more important part of the failure analysis.

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5. Studies have indicated that corrosive sulfur is a problem

– The simplest solution was to improve the quality of the mineral oil.
– Other solutions have been offered and considered by manufacturers.

6. Studies have demonstrated that under certain conditions, oil flow results in build-up of static charge on insulating surfaces. The phenomenon of static electrification is fairly well understood and was identified more than 20 years ago but continues to result in failures (as recently as early 2014 as reported in the Transformers Magazine Newsletter).

– One must always keep up-to-date with developments in the industry as solutions present themselves.

7. Transformer and breaker interaction was a phenomenon addressed, first in papers, then in an application guide titled IEEE C57.142 *A guide to describe the occurrence and mitigation of switching transients induced by transformer-breaker interaction* [8].

Conclusion

Failure analysis is an ever evolving process. The fundamental process is still a representation or application of the scientific method, but whether designs are fine tuned or radically improved, there will always be an opportunity for a new failure cause to evolve. Keeping aware of the latest findings, practices, and sharing failure information will improve both the failure analysis process, the likelihood of reaching the root cause, and the overall reliability of the system (which is the ultimate goal, is it not?).

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