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EVALUATING AND MANAGING TRANSFORMER FACTORY ACCEPTANCE TEST STATISTICS AS ASSESSMENT CRITERIA

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SUMMARY
This paper explores the use of factory acceptance testing as criteria during factory assessments. It presents the viewpoint from both a transformer manufacturer and purchasing utility. The paper presents a frequent approach and its effectiveness as well as recommending an alternative interpretation of test statistics as evaluation criteria of transformer factories. The paper will consider and categorise different test failures in terms of the impact as seen from the utility's point of view. Differentiation will be made between units based on the risk (or significance) it holds for the utility, the complexity of the specific unit, the factory's experience with the type of unit manufactured and the amount of test failure rework that is required.

KEYWORDS
Transformer, test, fail, assessment

1. INTRODUCTION

Power transformers are subjected to various type, routine and special tests as part of the design evaluation and quality of production assurance. These tests are defined by the IEC 60076-1 (2000) [1] and will be adapted by the manufacturer to include any other special requirements made by a purchaser up front.

High voltage power transformers are complicated and expensive pieces of equipment. Sub standard quality will lead to an unacceptable risk for utilities due to the enhanced risk of unserved energy. Key elements to procuring a quality transformer is a good specification, design reviews and purchasing from a high-quality factory. Another critical ingredient is a thorough assessment of the power transformer manufacturer prior to listing them as an approved supplier.

The statistical performance of a manufacturer with regards to the percentage of units that fail the factory acceptance testing (FAT) could serve as a indicator of the required abilities as well as their potential to deliver on time (with reference to delays caused by fault finding and repair of a test failure). Therefore an evaluation of the Test Failure Rate is considered an important measurement to pre-qualify a factory as part of the overall factory assessment. A factory assessment will also include

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an assessment of their design capabilities, material handling, inspection of the factory floor and evaluating the quality management system.

2. A MANUFACTURER'S POINT OF VIEW

Power transformers are custom build, high end technology products. The combination of human labour and the variety of materials and components used provides ample opportunity for errors and omissions. Ultimately, the successful testing of a power transformer requires a combination of skilled personnel, accurate calculations, material specifications, manufacturing experience, suitable machinery and quality systems.

A problem or failure during testing would include an event such as:

- Non-conformances during routine tests (winding resistances, connections, etc.)
- Dielectric breakdown or unacceptable partial discharge level
- Measured values for losses, temperatures, sound or vibrations exceeding guaranteed levels
- When the unit for any reason has to be drained of oil and corrected
- When acceptance criteria has to be negotiated and changed

The statistical information referred to in this report is based on all the above mentioned incidents over a ten year period [2]. The Test Failure Rate is the ratio of units that failed as a proportion of the total number of units tested on an annual basis. All reputable manufacturers track their successes and failures. The wise ones are honest to their customers about any concerns or recent improvements. A transformer manufacturer may boast of a test floor failure rate of "2%". This is an impressive number, but a prospective purchaser must ask more questions such as:

- How are test failures defined? Does the manufacturer track any minor incidence or anomaly?
- How many incidents or failures required the tested unit to be untanked and disassembled for inspection?
- What was the trend of the test failure over the last couple of years?
- Is the 2% a statistic for this factory or an average for various plants of the same manufacturer (which may include mass produced small distribution transformers).

To ensure equal treatment when evaluating manufacturers a utility might dictate a simple definition of a test failure by including all test room incidents. However, some minor problems are easy and quick to fix making this definition very difficult to track during the supplier audit. Alternatively a utility might decide to define a test failure as a test anomaly requiring the active part to be untanked for repair. This definition is simpler to track and more applicable as a proper assessment criteria but it also presents other complicated matters to consider.

2.1 Impact of test failures

The Test Failure Rate is an indication of the overall quality of the product produced and should therefore be under control. It could also alert prospective purchasers of a higher probability for late deliveries and therefore requires careful attention as part of the factory assessment.

2.1.1 Extend of repair

The extend of repair is categorised into three areas:

- Repair inside tank
- Repair outside tank
- Repair outside tank and disassembled

The third category listed, i.e. to repair outside tank and disassemble implies unstacking of the top yoke (assuming a core type transformer). This type of repair also implies the most amount of rework and longest delay of the delivery date. A repair to damaged insulation at a winding entry lead or to remove a winding in order to repair it will necessitate such a disassembly. Based on an analysis of all test failures from a ten year period it was found that disassembly was required for more than half the total number of failures [2]. The other two repair categories mentioned occur approximately at the same rate.

2.1.2 Type of test

Powertech Transformers (PTT) is equipped to conduct factory acceptance testing in accordance with the requirements of either the IEC 60076-1 [1] or IEEE Std C57.12.00 [3] standards. These standards distinguish between the following types of tests:

- Routine tests

These are test required for every single power transformer before customer acceptance. Typical examples are resistance measurement, voltage ratio, dielectric tests and loss measurement.

- Type- or design tests

Type or design tests are conducted on a transformer which is representative of other transformers, to demonstrate that these transformers comply with specific requirements not covered by routine tests such as the temperature rise test.

- Special- or other tests

Special- or other tests are test other than type- or routine tests agreed to by the manufacturer and purchaser such as measuring zero sequence impedance, sound level measurement, etc.

FAT requirements for the majority of PTT's transformer orders are in accordance with the IEC 60076-1 standard [1]. PTT considers nine test categories when analysing "Type of test failed". These are:

- Loss Measurement [1, 4]
- Separate Source AC Withstand [5]
- Induced Voltage [5]
- Full Wave Lightning Impulse [5, 6]
- Chopped Wave Lightning Impulse [5, 6]
- Switching Impulse [5]
- Temperature Rise [7, 8]
- Sound Level [9, 10]
- Other Tests (e.g. winding resistances, voltage ratio, etc.) [1]

The Full Wave Lighting Impulse is the most frequent FAT failed [2]. It contributes to approximately twice the number of test failures compared to the Induced Voltage test which is the second highest contributor. These two tests dominate the total number of test failures but one cannot discount the other seven test classifications which can individually contribute up to 10%.

As shown in figure 1, for all main test type categories the disassembly of the active part is more often required when repairing the failed area.

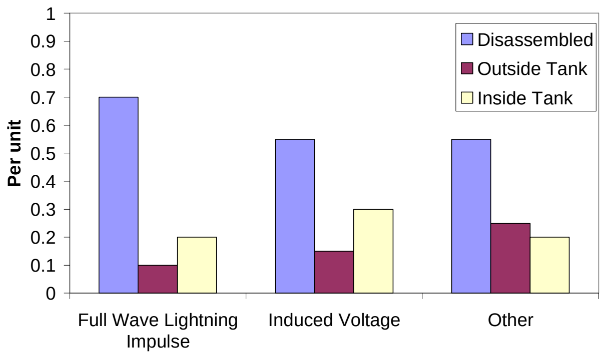

Figure 1: Extend of repair in relation to the type of test leading to failure

2.1.3 Location of failure

PTT considers the ten areas to categorise the location of a test failure:

- Auxiliary Equipment
- Bushings
- Bushing Entry
- Cleats and Leads
- Core
- Main Insulation
- Not Found
- Winding
- Winding Entry
- Tank / Cover
- Tap-Changer

The most common location of test failures is in the windings [2]. The next three most common locations for test failures occur in the Cleats and Leads, Main Insulation and Winding Entry. Test failures in windings occur twice as much as in any other location. The four most frequent test failure locations dominate the overall number of test failures. The combined sum of test failures for the remaining six locations is less than any of the individual first four locations mentioned.

As shown in figure 2, test failures in the three most common failure locations will require disassembly of the active part in order to repair the failed parts.

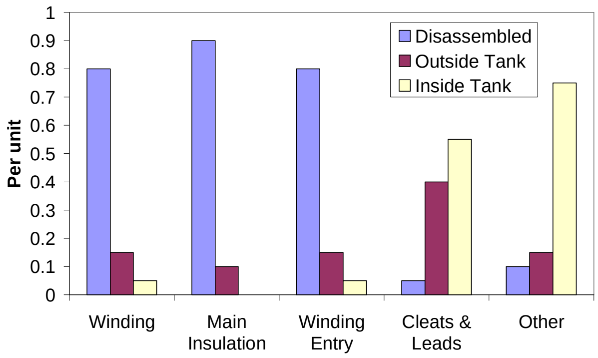

Figure 2: Extend of repair in relation to the location of the test failure

2.1.4 The cause of the test failure

The cause of test failures is categorised as follows:

- Design
- Material
- Production
- Testing Equipment / Procedure
- Consequential
- Not explained

The majority of test failures are Production related [2]. Production related failures could originate from an activity not done according to the drawing, not according to work instruction, no work instruction to work to or bad workmanship.

The next highest cause of test failures are Design related and is approximately one third the number of Production related test failures. Material related failures are approximately half of the design related failures. There is very little overall contribution from the other mentioned failure causes.

As shown in figure 3, the extend of repair is similar for production and design related test failures.

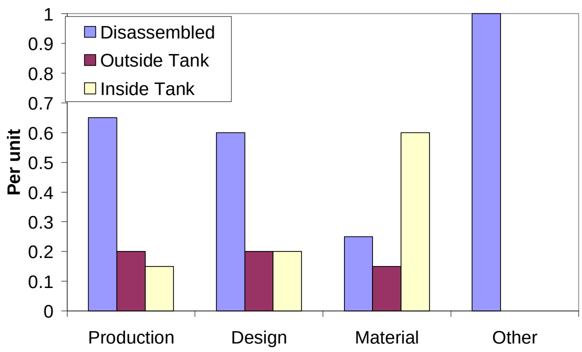

Figure 3: Extend of repair in relation to the cause of the test failure

2.2 Special considerations

Evaluating the Test Failure Rate to compare various transformer manufacturers is further complicated by aspects such as voltage and application, the type of test, batch failures and understanding the cause of the failure. This section will explore these areas in more detail.

2.2.1 Voltage and application

Design complexity and tighter production tolerances can be related to the transformer voltage. This might be a factor to be considered when evaluating test failures. A manufacturer that predominantly produces Extra High Voltage (EHV) transformers would be expected to have a higher Test Failure Rate than a manufacturer predominantly testing low voltage furnace transformers. It is also known that HVDC transformers have a higher incidence of test failures than for instance Generator Step Up transformers.

2.2.2 Type of test

The type of test relates in many cases to the severity of the test and thus the probability of failure. A short circuit test is an extraordinary test and probably represents the most severe test conditions a standard power transformer will ever be subjected to [11]. The average failure rate associated with short circuit tests are known to be significantly higher than the generally acceptable Test Failure Rate. Depending on the purchaser's definition a manufacturer conducting this type of test and fails might be penalised just as severely as one who fails a simple resistance measurement during routine testing. These are two tests that can hardly be compared but may present similar sanctions.

2.2.3 Batch failures

Another incident of FAT failures that could skew a comparative assessment applies especially to manufacturers of higher volume large distribution transformers. If a unit from a batch of similar transformers fails FAT due to a design related error then it is probable that another transformer of the same batch might fail for the same reason before the investigation of the first is completed. This is related to production pressures vs. the time required to find the root cause of a complicated failure. It is often not possible to wait until a conclusion of the first failure is reached and therefore the same failure could occur on the next unit tested (assuming the design error is not obvious early into the investigation). In such an instance the manufacturer might be penalised twice for a single improvement opportunity.

2.2.4 Cause of failure

A test failure may also occur due to material or component defect. If it is a material defect it will often be very difficult to prove.

2.2.5 Defining a test failure for comparison

When including untanking as the definition for a test failure it should be considered that a repair that might be done in tank could also imply untanking. If the location is external to the active part and easy to reach it will be done in tank, the same problem could be in a hard to reach place necessitating untanking the active art. In both cases the improvement opportunity is the same but different sanctions would be applied.

A transformer could fail during impulse testing over the winding necessitating the active part to be untanked, stripped and windings removed. In some cases the insulation can be easily repaired but in another case the winding might have to be replaced. The delay and thus impact on contractual delivery date will be significant if the winding must be replaced. This leads to the question whether both failures should be rated equally since the impact on the utility may differ significantly.

3. THE UTILITY'S POINT OF VIEW

The utility point of view is that it needs to reduce the risk of power transformer field failures to an absolute minimum. One measurement of a transformer factory is the factory failure rate. The ideal measurement would be an accurate, consistent and reliable measurement of in-service failures. However the measurement of in-service failures is often difficult for manufacturers to accurately report on as their involvement after delivery is often limited to the guarantee period.

3.1 Factory Failure Rate

The factory failure rate offers a measure of a manufacturer's performance in terms of the quality of the product. The factory has the detailed record of the failure, cause, repair time and corrective measures taken. The utility view is that the higher the factory failure rate the greater the perceived risk of an in service failure which could result in unserved energy. The cost/value of unserved energy for a large utility is not only the cost of replacement generation, but in times of a low reserve margin, it may result in load shedding that directly affects the country's economy. Factory failures may lead to late delivery and where power transformers are urgently needed due to an ageing and failing fleet this is a significant risk that is undesirable for any power utility.

Measurement of the factory failure rate in a consistent manner across manufacturers is thus important. Therefore it has become necessary to define factory failure rate so that both utility and manufacturer has a common understanding. *"A failure in the factory is defined as a situation arising where major opening/dismantling of the transformer is required to correct a failure caused during factory testing. Thus having to untank in order to repair a failure or defect caused during testing is defined as a factory failure. Untanking is defined as lifting of the active part from the tank."*

Manufacturing factories face different challenges in terms of the type and number of transformers produced per year.

To this end the population of transformers that are considered for the failure statistics is set from 10MVA and above. By so doing, smaller transformers that are less complex and have correspondingly less failures increases the population and large more intricate designs of which fewer are produced has less of an impact on the overall factory failure rate. This was intentionally done to set a strenuous limit of 3% factory failure rate per annum as an acceptance criterion to pre-qualify transformer factories that will be included on the utility's approved transformer vendor list.

The factory failure rate is by no means a perfect measure and in some cases needs to be revisited when considering the type and number of transformers produced per year by a factory.

The difference in performance between factories of one manufacturer necessitates the utility to only approve a specific factory from a manufacturer instead of a blanket endorsement to supply from any factory.

3.2 Factory Acceptance Testing

Testing of a power transformer particularly a Generator Step Up (GSU) transformer is critical to determine whether all design specification goals have been met. Besides the dielectric tests the loss measurement and temperature rise are important determining factors respectively in the efficiency and the long term service life of a power transformer.

In terms of IEC 60076-1 (2000) [1] standard the temperature rise test is defined as a type test, but as any manufacture will confirm *"the combination of human labour and the variety of materials and components used provides ample opportunity for errors and omissions"*. Therefore the temperature rise test is considered critical and does not remain limited to type testing for particularly large units. The importance of the transformer in the system is also a factor to consider and as a utility replacing its GSU fleet the temperature rise test has become a routine test. For smaller less critical units it may remain a type test, but when long term reliability and availability are key performance measurements of an asset certain tests cannot be left to chance.

4. CONCLUSIONS AND RECOMMENDATIONS

The in-service failure rate would be a good measure in terms of the long term reliability and service life of a manufacturer's product and this ultimately is what any purchaser seeks, but determining this accurately remains a challenge.

When assessing the test failure or success rate of a transformer manufacturer there are many aspects to consider since all failures are not comparable. Such an assessment should ideally incorporate parameters such as:

- Type of test failed
- Voltage and application
- Cause
- Extend of repair
- Corrective actions (e.g. whether it is appropriate, implemented, etc.)
- Impact of failure on contractual delivery date
- Trends

The challenge a utility faces is that the evaluation should be well defined and measurable in order to act fair and be transparent towards competing manufacturers. This leaves very little scope for subjective interpretations and therefore the frequently adopted approach is to put a peg in the ground by defining the maximum allowed Test Failure Rate. Some utilities overcome this by an upfront and very through factory assessment of which the actual Test Failure Rate is a major component but not the only deciding factor. This enables them to also consider the parameters already mentioned and more.

The definition of what constitutes a test failure may be related to the extend of the repair required. Relating this to a failure that would necessitate disassembling of the top yoke can enable a consistent measure that is traceable and more directly related to the potential risks it may hold for the utility.

The purchaser's reality is that they are not a transformer manufacturer and cannot go into a manufacturing facility to dictate procedures. A measure of some sort is necessary to screen suppliers and only select the best manufacturers for partnerships. This will be easier with an existing partner, but when trying to foster new relationships, this measurement is vital. The ideal scenario is a long term relationship between the utility and manufacturer that lasts beyond the quotation and warranty period. In such as relationship the two parties would be comfortable to openly discuss concerns, improvement opportunities, operational modification to address field related challenges and extend expected life time, etc.

Power transformers are a major investment and critical component to ensure the supply of uninterrupted energy. Utilities and transformer manufacturers have an obligation to ensure a risk free, quality product that will endure network conditions and outlast its expected lifetime.

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