LARGE POWER TRANSFORMER RELIABILITY IMPROVEMENT IN ESKOM DISTRIBUTION

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ABSTRACT

With re-regulation of the electricity distribution industry, growing demand for electricity and aging infrastructure, reliability delivery in South Africa has become a concern.

Eskom Distribution recognized that reliability improvement required a lifespan performance study on large power transformers.

The paper provides results of a performance study on large power transformers on a section of the Eskom Distribution network. The data is analysed and interpreted in terms of its probability density function (PDF), its survival function and hazard function to determine an onset of unreliability in transformer life and its survival time thereafter. The data is also investigated against the major component failures with its associated PDF, survival function and hazard function. .

The paper then reviews the initiatives taken by Eskom in terms of design, operation and maintenance to improve the reliability of large power transformers.

INTRODUCTION

The distribution network of Eskom, the national utility, covers most of the country's geographical area of about 1.2 million km^2 and is divided into six regions, shown in Fig 1.

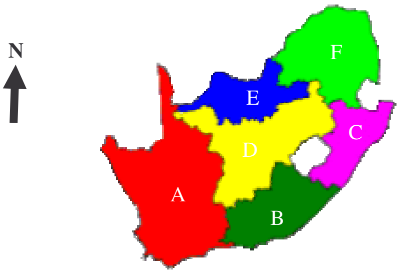

Figure 1: Eskom Distribution Regions

The variation of the risk to and failure modes of large power transformers, rated from 2.5 MVA to 160 MVA, relates to the enormous diversity in terms of type of customer, weather patterns and operating conditions.

Regions A, B and C are predominately coastal with some pockets classified as inland. Regions D, E and F are classified as inland. The South Western coastal belt is more exposed to winter rainfall, heavy marine pollution, high corrosive environment, and high electricity consumption in winter period, while the North-Eastern Highveld (in F) and Eastern coastal belt is more exposed to summer thunderstorms and industrial pollution.

The performance analysis study will evaluate the transformers manufactured up to 1998. The implementation of the reliability improvement initiatives spans from 1998 – 2006. The study was confined to the three regions A, B and C, for which reliable data was available.

The failures have been defined according to the failure definition given in IEC 60050 as:

The termination of the ability of a transformer to perform its specific function.

The data set includes the failures of 58 transformers within the 10MVA - 160 MVA rating range and 22kV - 132kV primary voltage range, manufactured up to 1998 and failing in the period 1996 – 2006. The analysis was set at component level.

The three investigated regions represent a sample space population of 4914 transformers observed over a period of 11 years. This is equivalent to approximately 38% of the number of transformers and approximately 44% of the installed capacity, within the specified rating and manufacturing range, on the distribution network in the period 1996 – 2006.

The performance analysis will be presented and discussed in terms of the probability density function (PDF), survival function and the hazard function to determine an onset of unreliability in transformer life and survival time thereafter. According to [1] studies of this nature provides a more realistic failure model.

From [2], the failure distributions for transformer life in this study can be interpreted as follows:

The PDF gives the probability of failure of a transformer and the survival function gives its probability of survivorship at a certain age. The hazard function gives the failure rate distribution with age.

The nature of the failure rate with age over certain periods provides useful information regarding an equipments life distribution. Periods that could be identified are as follows:

- Higher failure rates in early life that could be associated with design or manufacturing problems.
- Constant or low failure rates, representing normal life
- Increasing failure rates after a certain age that which can be associated with end of life wear out failures

PERFORMANCE ANALYSIS

Transformer Population for 1996 – 2006

Larger parts of the population in the three regions are in the 10MVA, 20MVA, 40MVA and 80MVA rating categories and in the 66kV-132kV primary voltage range.

In figure 2, the bulk of the population is between the ages 0 – 30, with only 8% of the transformers older than 30. The nominal design life is 35 years.

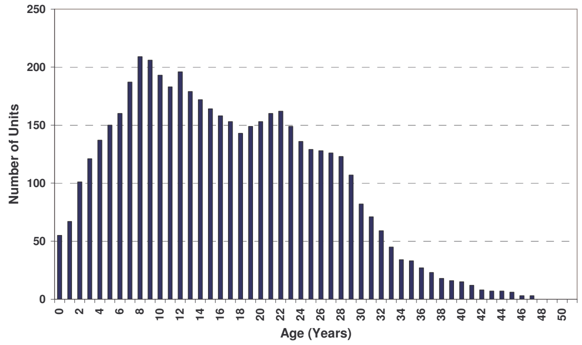

Figure 2: Transformer Population – Age

Transformer Failure Analysis Results

The failure rate for the 58 unit failures out of a sample space population of 4914 units over the 11 year period was calculated as 1.18%. This failure rate was calculated using the formula described in [3].

In the failure distributions that follow, the points on the PDF and the survival function curves are expressed as probabilities and are given by the probability labeled y-axis. The points on the hazard function are given by the failure rate labeled y-axis.

The failure distributions of all the failures in the data set are given in figure 3. Although the failure distributions indicate an onset from 0 years, no periods of high failure rates were observed in early life that could be associated with design or manufacturing problems. The survival time for these units is approximately 45 years.

From the hazard function a period of low failure rates can be observed up to 20 years, representing normal transformer life.

After 20 years, the failure rate increases with age, and is associated with end of life wear out related failures. A large portion of the population would have aged within the next 10 years, thus increasing the risk of failure due to higher failure rates experienced in older units.

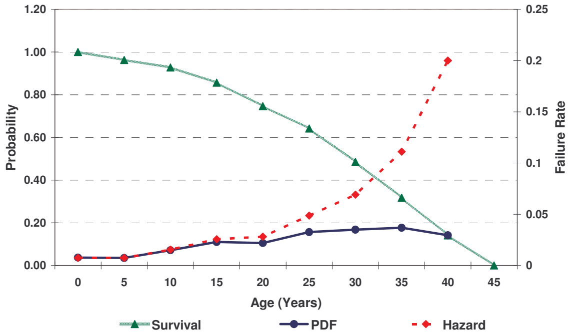

Figure 3: Failure Distributions – All Failures

Bushing, winding and tap changer related incidents shown in figure 4 contribute to 88% of the failures recorded. No core related failures were recorded in the three regions.

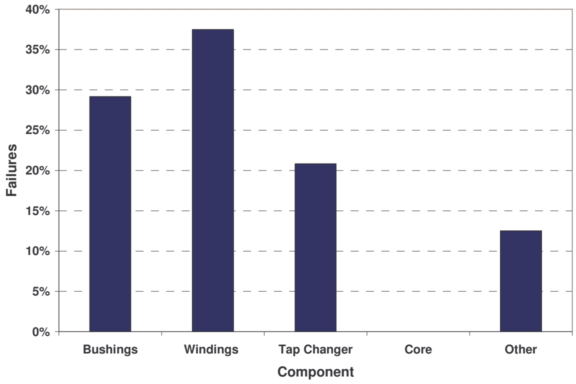

Figure 4: Percentage Failures by Component Affected

In the analysis of bushing, winding and tap changer related failure distributions, an onset of unreliability was observed in early life and increasing failure rates with age. The onset of winding and tap changer related failures are at 0 years, as seen from figures 5 and 6 respectively.

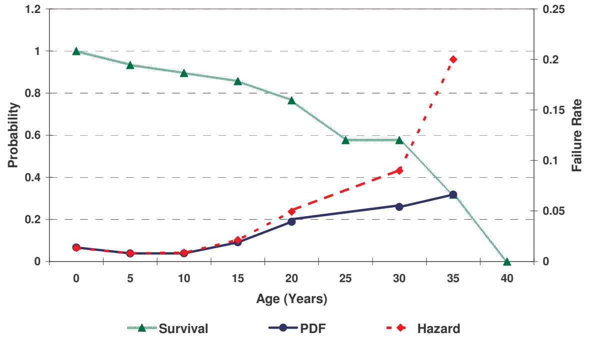

Figure 5: Failure Distributions – Tap Changers

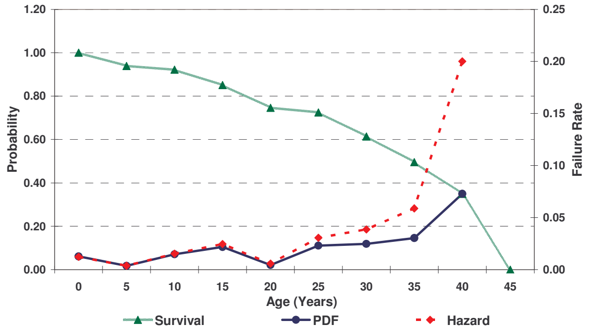

Figure 6: Failure Distributions - Windings

In the analysis of bushing related failures as shown in figure 7, the onset is at 5 years.

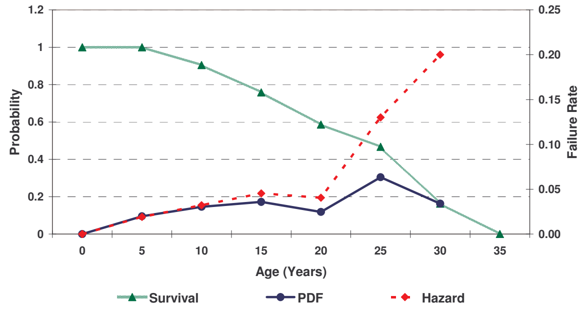

Figure 7: Failure Distributions – Bushings

No periods of high failure rates were observed in early life that could be associated with design or manufacturing problems, although the onset of unreliability for the component related failures occur in this period.
The survival times of the component related incidents are 30, 40 and 45 years for bushing, winding and tap changers respectively. Winding and tap changer related failures experienced lower failure rates up to 15 years whereas with bushings it is up to 20 years.

The failure probability distribution with respect to voltage level shown in figure 8 indicates that failure probabilities are generally higher with increasing voltage levels.

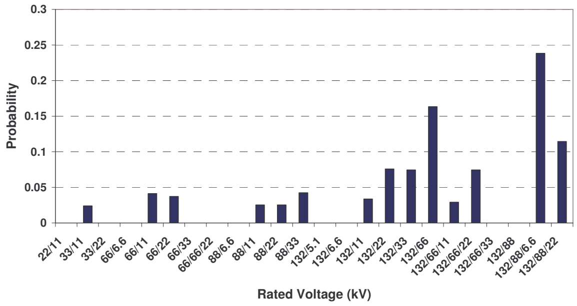

Figure 8: Probability of Failure by Rated Voltage

Transformers older than 35 years are predominantly of the higher primary voltage, larger rating range. No statistically significant changes were observed in the failure probability distribution with MVA rating. However, the failures on larger rating units are considered as a higher risk in terms of MVA-loss and their associated age profiles.

RELIABILITY INITIATIVES

Design Specification

Changes made in this phase of the life cycle review of large power transformers were focused on increasing the reliability of new transformers. Although performance suggests a low failure rate at the infant stage of life, transformers are exposed to a changing customer, environmental and operational environment and are stressed throughout their life.

Initiatives in the design specification phase of large power transformers concerned mainly the bushings, on-load tap changers and winding designs. These changes were effected after 1998 and the effects would not be reflected in the performance analysis above.

Bushings on the secondary side are specified as a minimum on 33kV with 700mm spacing to limit the in-zone faults caused by environmental factors. Bushing insulating material was changed from oil impregnated to resin impregnated as leaking bushings and puncturing of bushing insulator material at bushing test points were critical causes of failure. The bushing specification includes a 31 mm/kV creepage requirement to accommodate the high marine and industrial pollution levels.

On-load tap-changers on 20 MVA and larger transformers are required to be maintained on a 300,000 operation cycle.

The colour of the paint applied to the external body of the main tank was changed from Dark Admiralty Grey to Cloud Grey to reduce the impact of solar heating.

Temperature rise limits in the specification were reduced by 10 °C compared to IEC 60076 to improve thermal performance in the South African environment. In addition, thermally upgraded paper and limiting the ONAN/ONAF ratio to 0.7 p.u. are included in the specification. The maximum flux density in the core legs and yoke is limited to 1.72 T. The cooling duct width was set at a minimum of 3 mm to promote oil flow. Dissolved Gas Analysis tests are required directly after the heat run test.

The short circuit performance of the transformer was strengthened with the inclusion of a fixed winding arrangement. In a two winding configuration the specified order is LV-HV-regulating and in an auto transformer the order is Tertiary-common-regulating-series. The specific stress (σ_{aver}) of the inner winding is set at a minimum of 50 % of the copper conductor yield strength for epoxy bonded CTC windings while the σ_{aver} of the outer winding is set at a minimum of 80 %.

The specification includes digital type thermal indicators, to assist with condition monitoring and aging analysis. Moisture in paper insulation after drying process is set at a maximum of 1% and the onset degree of polymerization value at a minimum of 950.

Detailed design reviews for thermal, insulating and short circuit designs have been introduced recently.

Operating and maintenance

The in-service transformer life management process is supported by an on-going life assessment process as described in [4]. Critical risks are identified and reviewed; maintenance strategies adapted and input given to capital investment committees as far as network reliability is concern.

New initiatives include on-line moisture assessment and removal, assessing the need for on-line tap changer maintenance by the monitoring of oil condition and number of tap operations, and investigations into on-line filtration of tap-changers in the event of moisture being the only indicator to perform maintenance on on-load tap changers.

CONCLUSION

The lifespan performance study on the 58 failed transformers manufactured up to 1998 indicate an increasing failure rate with age, with periods of relatively low failure rates and periods where wear out sets in. The wear out periods starts after about 20 years, with various components behaving differently, so that most of the 58 units failed within the intended design life of 35 years.

No high failure rates were observed in early life that could be associated with design or manufacturing problems, although the onset of unreliability occurs in this period.

Bushing, winding and tap changer related failures contribute to the largest percentage of the failures recorded.

Failure probabilities are higher with increasing voltage levels with no significant changes being observed in the failure probability distribution with rating. Units older than 35 years are predominantly of the higher voltage and larger ratings, and their failures are considered as a higher risk on the network in terms of MVA-loss.

The failure distributions presented were based on the failure data of three regions and the inference drawn from them could differ from that of the entire distribution network.

The effect of the design and operating and maintenance changes introduced to reduce the effects of the operational stresses will only be visible after the start of the wear out period in 15 to 20 years time.

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