THE APPLICATION OF STATISTICAL TOOLS FOR THE ANALYSIS OF POWER TRANSFORMER FAILURES

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Abstract: Taking into account the construction of the transformer, it can be stated that this is very complex device. It consists of many subcomponents such as winding, tap changer, bushing etc. Thus, it follows that failure of transformer can display different modes. The failure in the transformer may occur in two ways. First when abnormal stress occurs, with the level which can not be withstand by the component. Second, aging reaches such a level, at which component is not able to operate when subjected to nominal stress. It is possible to investigate the occurrence of failures in the population of transformers, by means of statistical tools application. In other words, it is possible to estimate parameters of the population by fitting proper statistical model to the data. By the analysis performance it can be seen, what is the stage of life of transformers' population. Secondly, what can be expected regarding failures in coming future. The later issue becomes very important when considering the replacement of transformers. In addition, information about expected failures seems to be valuable when considering the spare transformers policy

1 INTRODUCTION

From the point of view of the power network reliability, transformers are among the most significant components of the network. This is not only because of the price of transformer itself. Also due the fact that failure occurring in the transformer is usually difficult to repair, what finally results in high outage costs and long outage time. Thus, the overall reliability of the network is strongly dependent on the reliability of transformers. Due to the cost and importance of transformers, their redundancy is limited. All these factors lead to a certain criticality of transformers for the electricity supply. The replacement of any single transformer should be justified from economical as well as technical point of view. When taking a closer look into transformer failures, they can be discerned according to the voltage class of failed transformer, as well as according to the different subcomponents of the transformer. The failure occurrence can take different forms, e.g. random failures or failures caused by aging. The investigation was triggered by two major failures 110 kV transformers, which occurred in the transmission network of Liander. The failures were severe and in one case the transformer was lost. Therefore, a detailed investigation into the reliability of this class of transformers was made, as due to the failures occurrence, the concerns about the network reliability arose within the utility. The investigation into failures of different subcomponents was made by application of statistical tools. The information about transformers being in operation as well as about failed transformers were used as an input for statistical analysis. Prior the analysis, the data was categorized according to the ratings, and components failed. By fitting a statistical distribution to the failure and in-service data, the time dependent failure rate function was obtained. Moreover, it was also possible to observe, in which period of life the components are. These enabled to obtain the information what can be anticipated regarding failures in coming future. The flowchart presenting the procedure of statistical analysis is presented in Figure 1.

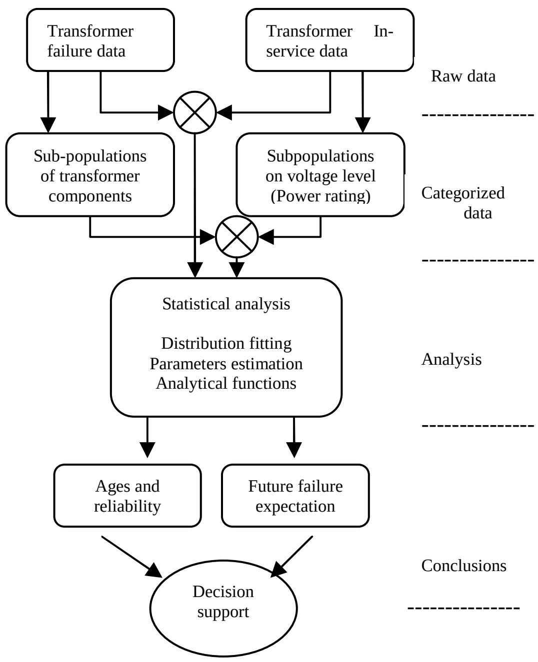

Figure 1: Principle of the data handling, used as an input for statistical analysis [3]

2 TRANSFORMERS BEING IN OPERATION

Rated power span of transformers constituting population subjected to the analysis, is between 15 and 175 MVA. Voltage levels of analyzed transformers are of 110 and 150 kV. The age span is from 5 up to 60 years as the transformers were installed between 1951 and 2006. Number of transformers installed in different years can be seen in Figure 2.

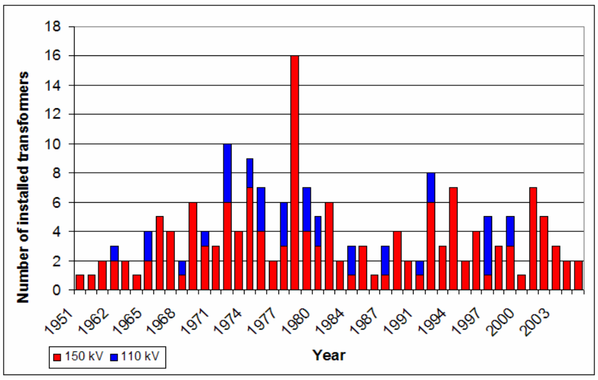

Figure 2: Number of transformers installed in particular years.

From the Figure 2. it follows that majority of the transformers was installed before 1990's. Average age of single transformer is 29 years. The whole population subjected to analysis was split up into two subpopulations according to the voltage level, namely:

- 150 kV transformers – Voltage ratings 150/50/10, 150/50, 150 20 and 150/10 kV
- 110 kV transformers – Voltage levels 110/20 and 110/10 kV

The division has been made, in order to investigate failures not only in the whole population of transformers, but also in the subpopulations according to the voltage level. In particular, this is important, as failure may take different behaviour in the whole population than in the subpopulations. The final results of the analysis can be used as an additional tool, when considering purchase of spare transformers for the utility.

3 SUBCOMPONENTS FAILED

Due to the complexity of the transformer, failure of the transformer can take on different modes. In other words, failures which occurred in the past can be discerned according to the failed component.

3.1 International survey of failure statistics

Each failure occurring in the transformer can be assigned to the failure of different subcomponent. In this way, all failures can be categorized according to failed component. This is done in order to see, which components display the highest criticality from the point of view of failure occurrence frequency. In [2] such categorization can be found, all failures has been related to particular subcomponents as follows:

- Tap changer (On-load and off-load)
- Bushing
- Winding (Short circuit within the winding)
- Leakage (Problems related to main tank)
- Core (Problems related to magnetic circuit)
- Other (e.g. temperature problems)

Proportionate contribution of particular components failures to overall failure statistics is presented in Figure 3.

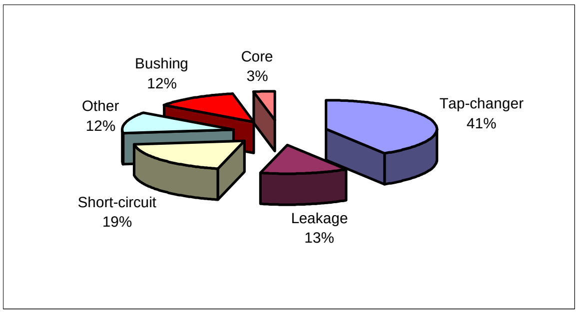

Figure 3: Relative contribution of different subcomponents failures for failures of transformers as reported by CIGRE [2]

3.2 Utility failure statistics

Failures occurring in the past within transformers belonging to the utility are registered in the database.

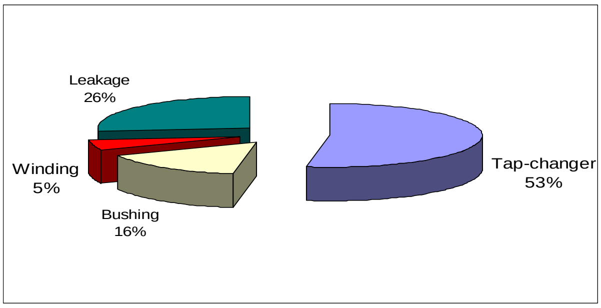

Figure 4: Relative contribution of different subcomponents failures for failures of transformers as reported in the database of utility.

The database contains information about problems related to the transformers, occurring after 1975. However, here, a remark has to be made regarding

Figures 3 and 4. The number of failures included in the survey of Cigre is around 750, and the database of utility contains 16 entries regarding mentioned population. It is worth mentioning that in some cases, after failure occurrence the transformer was lost. In other cases the transformer was brought to service after long-time reparation. Here, due to the limited amount of data, the distinction has not been made. In Figure 4. reported in the database for transformers of 150 and 110 kV are presented.

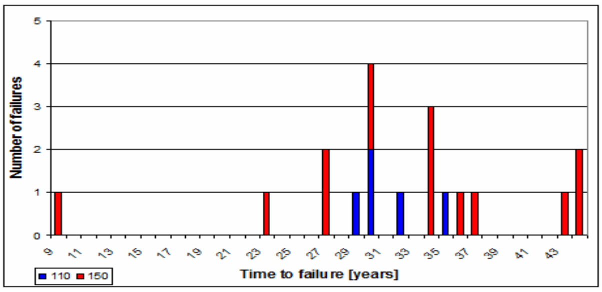

Figure 5: Number of failures together with accompanying time to failure, for failures of transformers as reported in the database.

4 STATISTICAL ANALYSIS OF THE FAILURES

In the beginning the whole population of transformers is analysed. That means that failures reported for 150 and 110 kV transformers, displaying different failure modes are considered together. Secondly, population of 150 kV transformers will be distinguished and investigated. Failures which have occurred for 110 kV transformers will not be investigated, as only 4 failures of different modes occurred and it was not possible to obtain a good fit of statistical model. Moreover, in some population, the outliers were identified by common techniques given in [1] and removed. Outlier is a point which displays very high or very low time-to-failure when compared to the rest of population. Thus, it is affecting the distribution parameters and so the results of the analysis. Prior the analysis, the presence of outliers was investigated. If sufficient evidence was found, the point was rejected from the analysis.

4.1 The whole population of 150 and 110 kV transformers

Hereby, the analysis for the mentioned population will be presented. For the different failure modes, it has to be mentioned that leakages are not interesting from the reliability point of view. This is due to the fact, that they are usually found during visual inspection and their effect on the transformer operation is rather negligible. The number of failures for bushings and winding is insufficient to perform statistical analysis, this is 2 and 1 failure respectively. Result of fitting the 2-parameter Weibull distribution to the mentioned population can be seen in Figure 6. It can be observed that the first point may be outlier. Using methods given in [4] it has been proven that this point might be removed from the analysis.

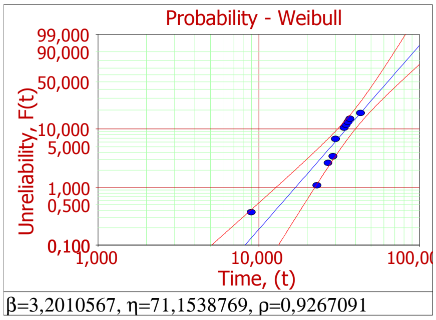

Figure 6: CDF of 2-parameter Weibull distribution with 90% confidence bounds, fitted for the population on 150 and 110 kV

Fitting the distribution to the population where point suspected to be outlier has been removed, resulted in obtaining 3-parameter Weibull distribution. The parameters of the distribution are β=2.17, η=45 years, γ=19 years. The introduction of the third parameter may be explained by the fact that no failures occurred before the age of 20 years. The CDF and failure rate function can be found in Figure 7 and Figure 8 respectively.

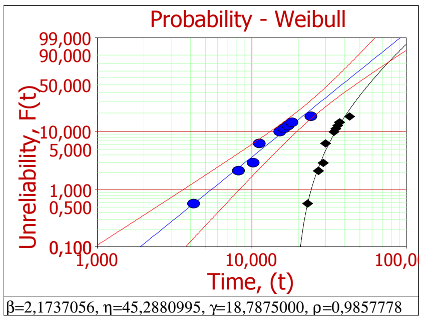

Figure 7: CDF of 3-parameter Weibull distribution, with 90% confidence bounds.

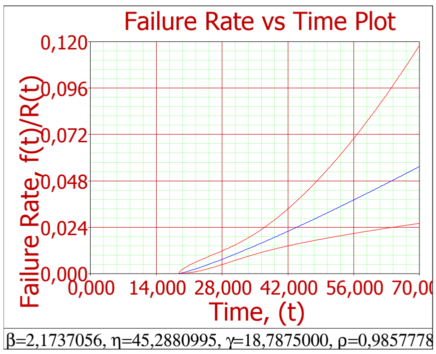

Figure 8: Failure rate function of 3-parameter Weibull distribution with 90% confidence bounds.

4.2 Failures of tap changers reported for 150 and 110 kV transformers

In the mentioned population, 8 failures of tap-changers were subjected to statistical analysis. However, one failure exhibiting low time-to-failure, as presented in Figure 9, was found to be outlier.

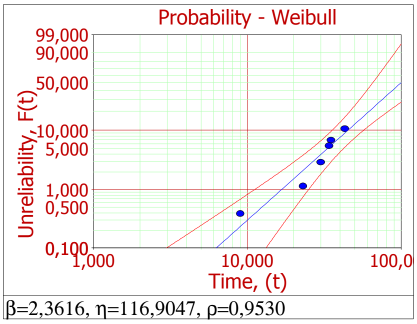

Figure 9: Failure rate function with 90% confidence bounds

By removing this point from the analysis and fitting the statistical distribution, resulted in obtaining 3-parameter Weibull distribution with the parameters of β=1.56, η=99 years and γ=19 years. Also here, the introduction of the third parameter may be justified by the fact that no failures occurred before the age of 20 years. The details of the distribution can be found in Figure 10 and Figure 11.

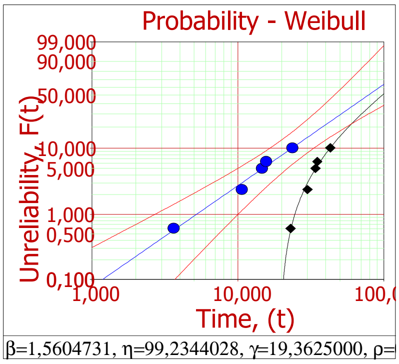

Figure 10: CDF of 3-parameter Weibull distribution with 90% confidence bounds

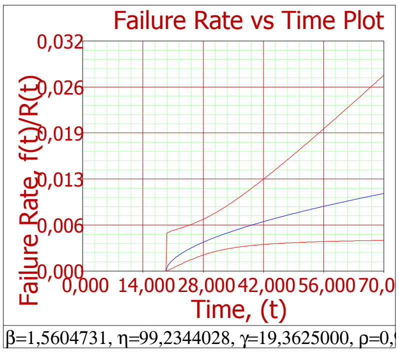

Figure 11: Failure rate function of 3-parameter Weibull distribution with 90% confidence bounds

4.3 Subpopulation of 150 kV transformers

For the group of 150 kV transformers, analysis is made for 12 failures, i.e. one breakdown in bushing, 5 leakages and 6 failures of tap-changer. Similarly as in previous paragraph, leakages are not going to be investigated as their occurrence is negligible on the operation of transformer, also one breakdown in bushing is not sufficient. Thus firstly the whole population of 150 kV transformers will be investigated and secondly the failure occurrence of tap-changers. Also here, one point was found to be outlier. Rejecting the outlier and fitting the distribution resulted in obtaining 3-parameter Weibull distribution with the parameters of β=1.74, η=57 years and γ=20 years. The results can be seen in Figure 12 and Figure 13.

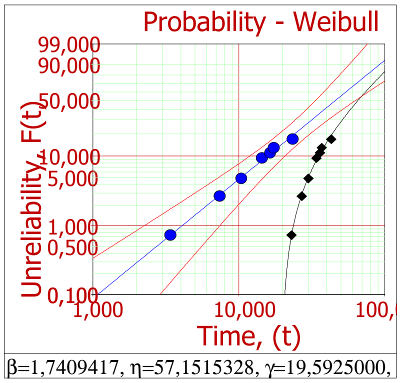

Figure 12: CDF of 3-parameter Weibull distribution with 90% confidence bounds

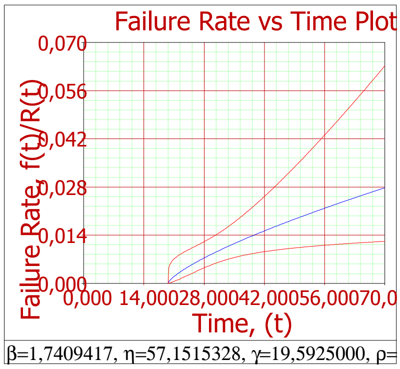

Figure 13: Failure rate function of 3-parameter Weibull distribution with 90% confidence bounds

4.4 Summary

Hereby, the detailed analysis into reliability of 150 and 110 kV transformers, belonging to Liander, was presented. Table 1, presents values of mean lives and particular B-lives for investigated populations are presented. The results are presented in Table 1:

Table 1: Values of mean lives and B-lives obtained through the analysis.

	Transformers of 150 and 110 kV		150 kV transformers	
	The whole population	Tap changers	The whole population	Tap changers
B1 life	24 (22-27)	25 (22-29)	24 (22-27)	25 (19-32)
B10 life	35 (32-39)	43 (36-53)	35 (31-40)	42 (37-48)
Mean life	59 (51-68)	109 (67-177)	70 (56-91)	64 (53-77)

In addition, the population of 150 kV transformers has been discerned. In each case, behaviour of failures assigned to tap-changers was investigated. By doing so, a better view of failures occurrence was obtained. When considering the failure occurrence in the population, another important parameter is B-life. B-life is time after which, particular part of the population will fail. E.g. B1-life refers to the time at which 1% of the population will fail. For this case, it means the time at which the unreliability will reach 1% and the reliability will be 99%. In the Table 1, comparison of B-lives is made. From the table, it follows that B-1 lives displays similar values in all cases. However, when looking at B-10 lives, it can be noticed that it displays higher values for tap-changers than for the whole populations where all failure modes are considered. This may be explained by the fact that times-to-failure for tap-changers are slightly higher than for other components of the transformer.

5 FAILURE EXPECTATION

Different populations were investigated, as presented in previous paragraphs in order to analyze failure behaviour. By using obtained failure rate function and information about in-service population, it is possible to estimate the number of expected failures in the future. The results of the estimation are presented in Figure 14 and Figure 15.

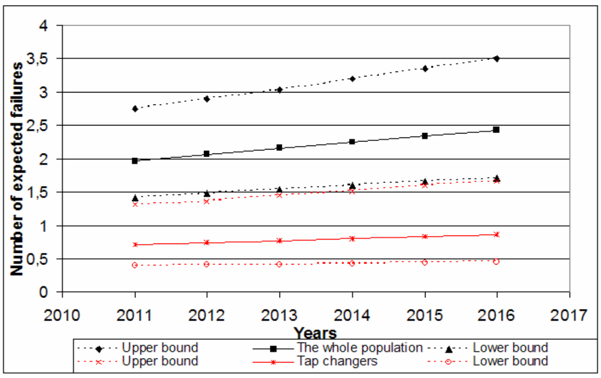

Figure 14: Number of expected failures in coming years, together with 90% confidence bound, as calculated for particular populations.

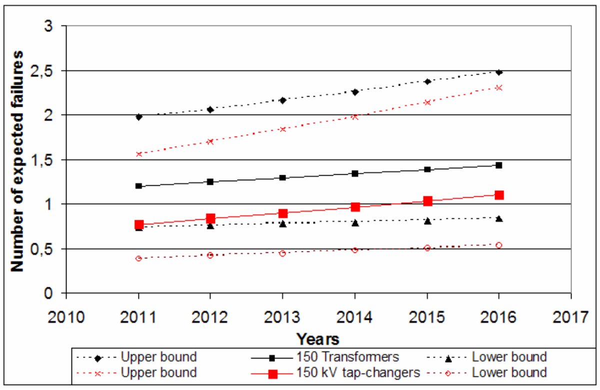

Figure 15: Number of expected failures in coming years, together with 90% confidence bound, as calculated for particular populations.

6 CONCLUSIONS

By statistical analysis it was concluded that:

- Failures are caused by aging. Thus, their number will increase in time. It can be also confirmed by the values of β, in each case higher that 1
- The average failure rate is expected to increase. Over the period of 5 years, only from 2 failures per year to 2.5 failures per year, which is still within 90% confidence bounds in 2011
- The number of failures is comparable to that occurred in the past. The result of the analysis may be used as additional tool when considering the spare transformers purchase.

7 REFERENCES

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