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Chapter

Efficient Asset Management Practices for Power Systems Using Expert Systems

Danilo Spatti, Luisa H.B. Liboni, Marcel Araújo,
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Abstract

Electric power companies have high financial costs due to poor asset management practices. Therefore, it is crucial to use decision-making processes to decrease the global costs of an active asset and to extend its lifetime to a maximum. Asset management programs, which are frequently used to tackle optimization problems, aim to guide the use of the physical assets of a business, mainly by optimizing their lifetime. Efficient asset management practices establish operation and maintenance for each equipment, from the time the equipment is acquired until the appropriate time for its replacement. So, based on these assumptions, we propose a method to assist asset management decision-making in the electric power companies, which is embodied by computer software.

Keywords: expert systems, asset management, power systems

1. Introduction

The big challenge involving asset management in electric systems is to seek a solution that enables the electric sector to reconcile interests with the environmental, economic, market, technological, regulatory and corporate constraints.

Still, the first parameters to be considered in the asset management of electrical systems can be listed as follows:

- Equipment lifetime

- Operating conditions

- External conditions

Additionally, directly or indirectly, operational context aspects must also be considered, such as:

- Type of operation requests (existence of redundancies or equipment in standby)

- Requirement level to be met or minimum performance requirement

- Operational safety risks to be assumed

- Environmental standards

- Equipment life cycle

- Maintenance logistics

- Regulatory standards and legislation

With a large amount of information currently available from assets, it is critical that standalone or semi-autonomous machine learning techniques should be able to extract knowledge and increase the performance or robustness of a system or process. These algorithms and techniques are vast and are also used in non-database applications—for example; such methods can directly interact with the environment to accomplish the tasks discussed above [1, 2].

The computational tools and techniques based on machine learning help to solve problems related to the extraction of information and knowledge from data. For example, machine learning applied to data mining is capable of performing specific tasks such as:

- Pattern recognition

- Data processing

- Data clustering

- Feature selection (selection of the most critical variables in a process, system, or database)

- Regressions

- Data sorting

The purpose of this chapter is to present a case study involving the processing of asset databases of an electrical transmission system in order to create subsidies for the development of an efficient asset management system.

2. Database studies

The databases in this case study are composed of data from power transformers. Such databases contain nominal values from the devices, data from laboratory tests, and maintenance data. The database consists of 6929 records, with the attributes shown in **Table 1**.

Data preprocessing methods consists of database conditioning, inconsistent data correction and the analysis of the data through relational graphs and probability distributions in order to extract knowledge and useful information.

Figure 1 shows a histogram of the transformers with respect to their manufacturing date and **Figure 2** shows a histogram of the transformers with respect to their age. **Table 2** shows the records for the voltage attribute of the transformers.

By using data from maintenance records, one can classify maintenance tasks as Preventive Maintenance and Corrective Maintenance. One of the critical analysis

Manufacturer	Year of construction
Time in operation	Feeder phase
Did achieve its lifetime according to regulation policies?	Power
Location	Voltage
Level of priority of the maintenances	Preventive maintenance dates
Technical maintenance team	Corrective maintenance dates
Age of the transformer when corrective maintenance was performed	

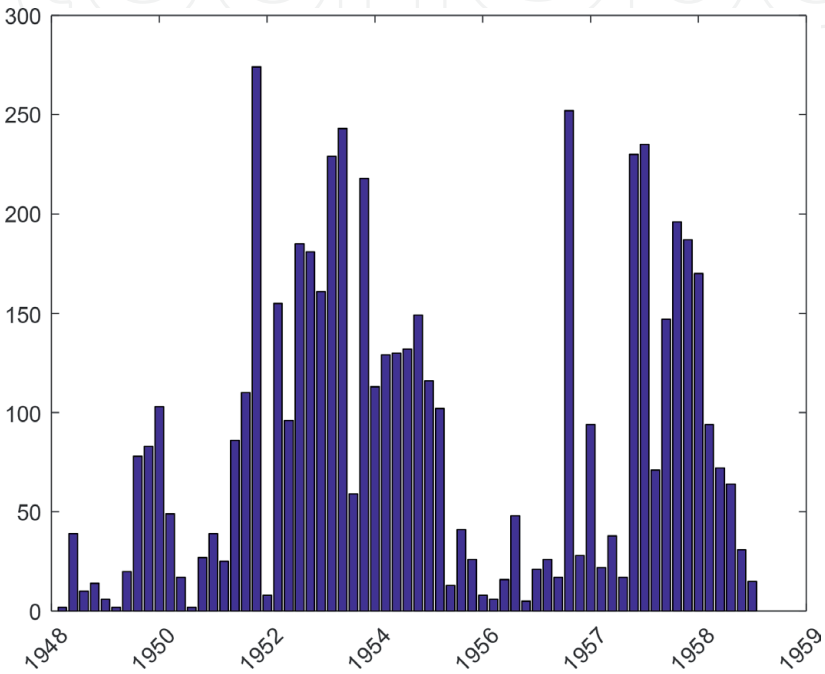**Table 1.**
Attributes from the power transformers database.

Figure 1.
Histogram (count percentage) of the transformers with respect to their manufacturing date.
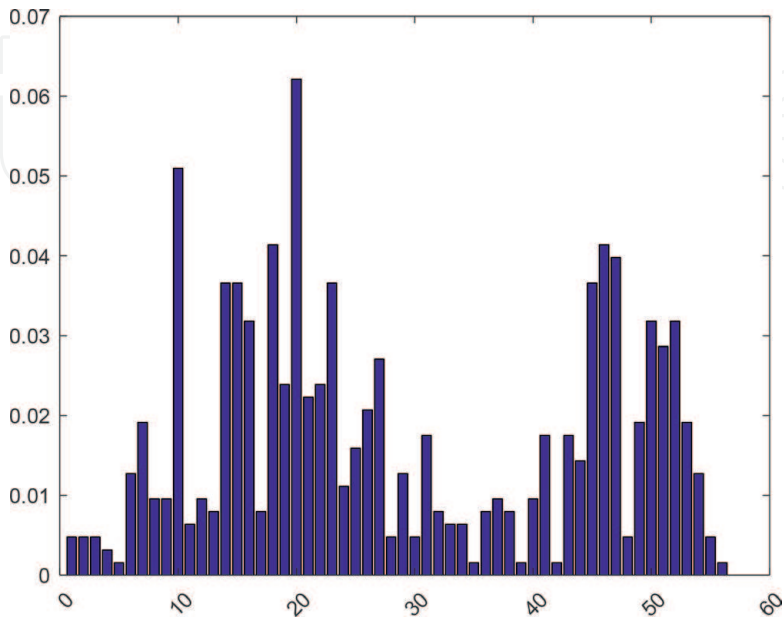
Figure 2.
Histogram (count percentage) of the transformers with respect to their age.

Voltage (kV)	Records
13.8	1221
34.0	194
69.0	95
88.0	1497
138.0	2092
145.0	4
230.0	545
345.0	451
440.0	690

Table 2.
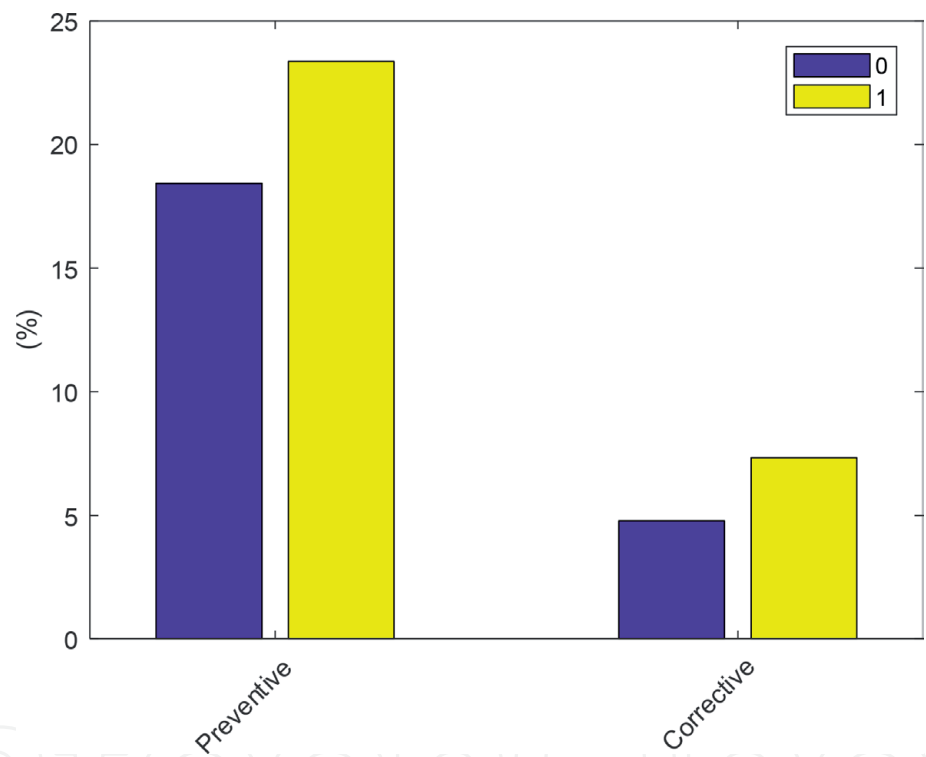*Voltage attribute from the power transformers database.*

Figure 3.
Histogram (count percentage) of the transformers with respect to preventive and corrective maintenance, taking into account if the lifetime was achieved (1) or not (0).

that must be done by an efficient asset management system is to take into account the lifetime of the power transformer and the maintenance procedures held during its lifetime [3, 4]. Such analysis is shown in **Figure 3**.

3. Statistical distribution analysis

One can verify, in **Figure 4**, the relationship between the probability of maintenance as a function of the lifetime of the power transformers. In this figure, the cumulative distribution functions of preventive and corrective maintenance are shown and have, clearly, a bathtub shape (**Figure 5**) [5].

The curves in **Figure 4** raise a management question, and, therefore, explain the importance of such analysis: the more preventive maintenance, the less corrective
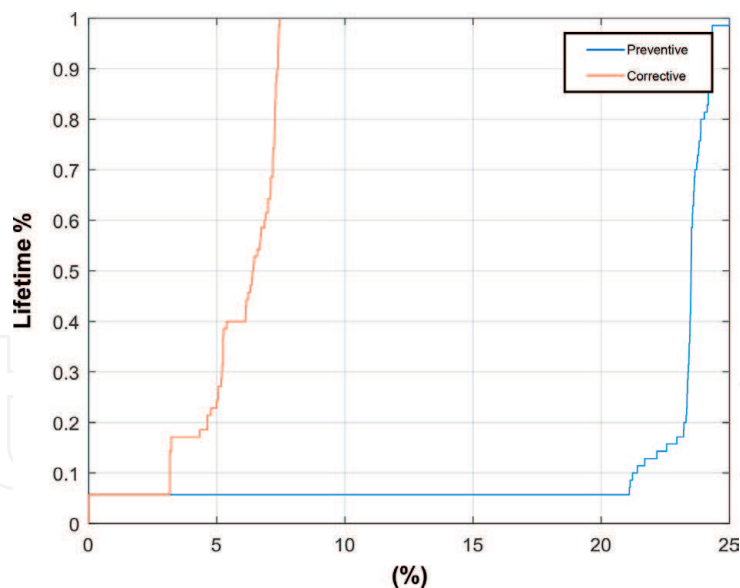
Figure 4.
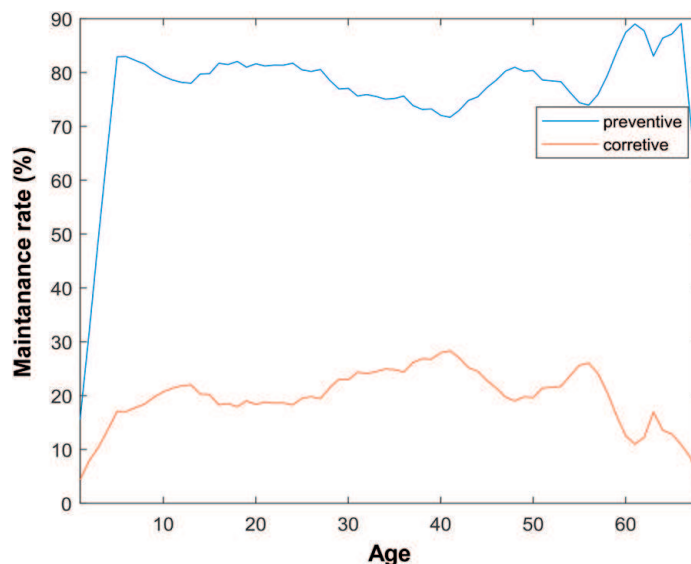*Cumulative probability function of the power transformers.*

Figure 5.
Maintenance rate with respect to the age of the assets.

maintenance? This hypothesis can be tested by a correlation analysis, which indicates a Correlation between preventive and corrective maintenance of -0.9367, i.e., the two types of maintenances are firmly negatively correlated.

One can observe that preventive maintenance in equipment such as power transformers is made in a more uniform way throughout its operating lifespan. This result corroborates with the fact that this kind of equipment is crucial and should be robust and faultless, as is shown in **Figure 6**.

To explore the hypothesis mentioned above, two manufacturers were chosen, namely A and B, and the following analysis was performed. The results are shown in **Figures 7** and **8**.

By analyzing these curves, some questions can be raised concerning asset management in order to help decision-making. For example, in this scenario, would it be possible to purchase more equipment with this specific nominal voltage from Manufacturer 2?

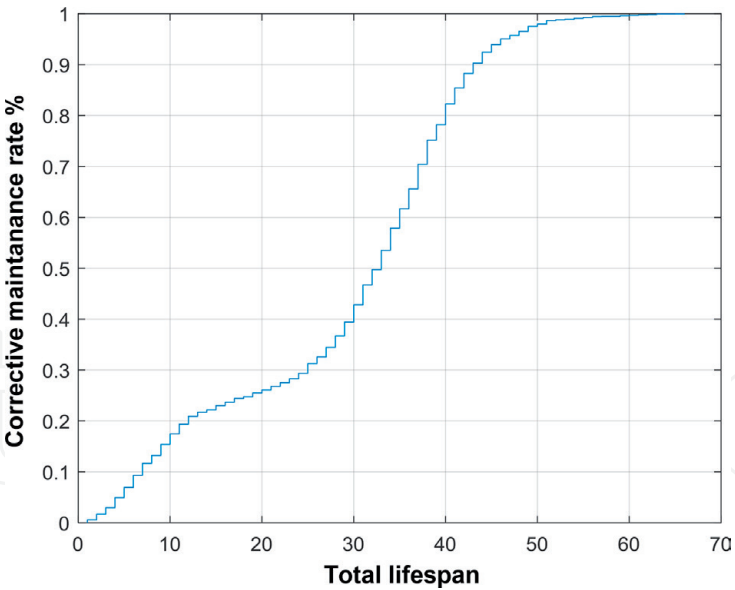These analyses can be extended for other voltage classes, such as 345 and 440 kV, as can be seen in **Figures 9** and **10**.

Figure 6.
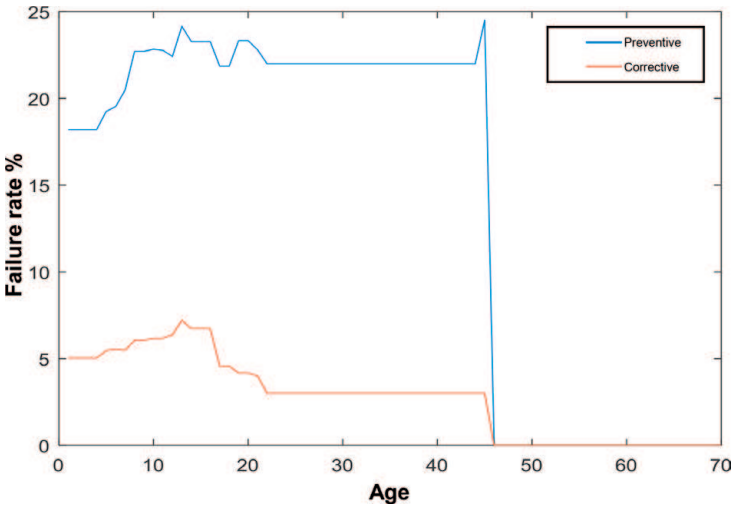*Cumulative probability function for corrective maintenance.*

Figure 7.
Maintenance rate with respect to the age of the assets for manufacturer A.
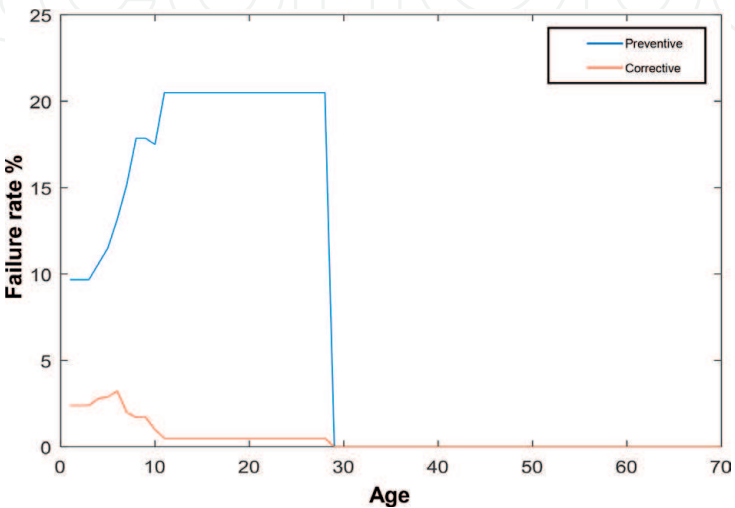

Figure 8.
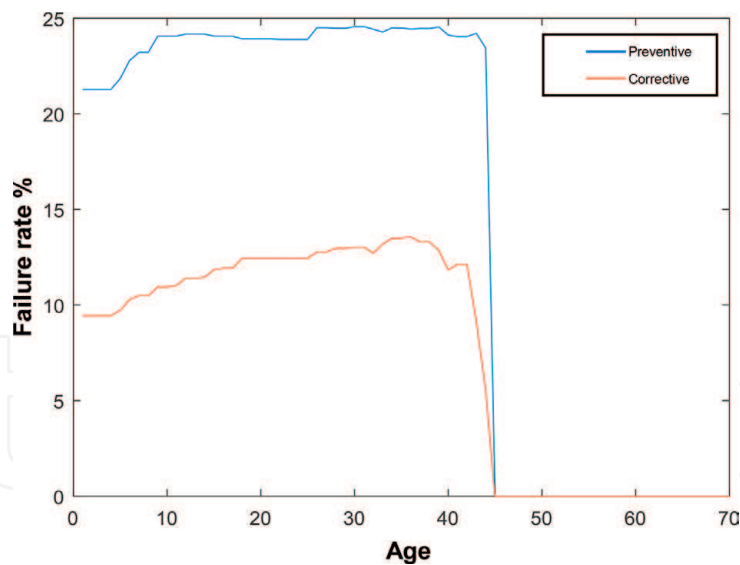*Maintenance rate with respect to the age of the assets for manufacturer B.*

Figure 9.
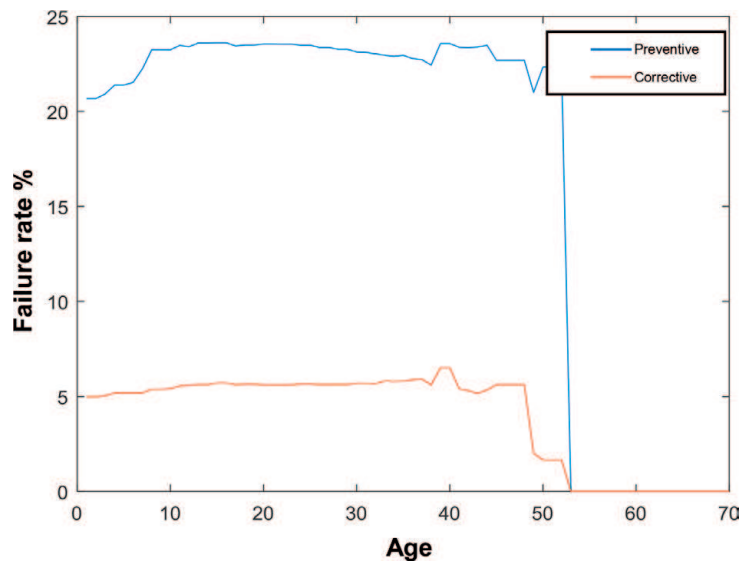*Maintenance rate with respect to the age of the assets for voltage 345 kV.*

Figure 10.
Maintenance rate with respect to the age of the assets for voltage 440 kV.

4. Risk analysis

Defining a process for creating a condition index for an asset is very important since the index can be used for asset management. For example, managers could consider alternative manufacturer scenarios, replacement or new acquisitions. Thus, the condition index of equipment can be an important feedback tool for the electric utility regulator since good maintenance practices dictated by the regulator, such as the frequencies for maintenance, can be updated [6, 7].

Also, risk assessment allows the analysis of failure probability, as shown in **Figures 11** and **12**, in which all power transformers in the database were analyzed.

Alternatively, it can also be established that the reliability function R (t) is given by R (t) = 1 − F (t), where F (t) is the cumulative probability function. Function R (t) can be used to analyze the probability of failure of an asset above a particular range or age, as shown in **Figure 13**.

As a case study, one can then investigate what the failure rate would be for a particular transformer cluster. Now, suppose the cluster composed of all equipment
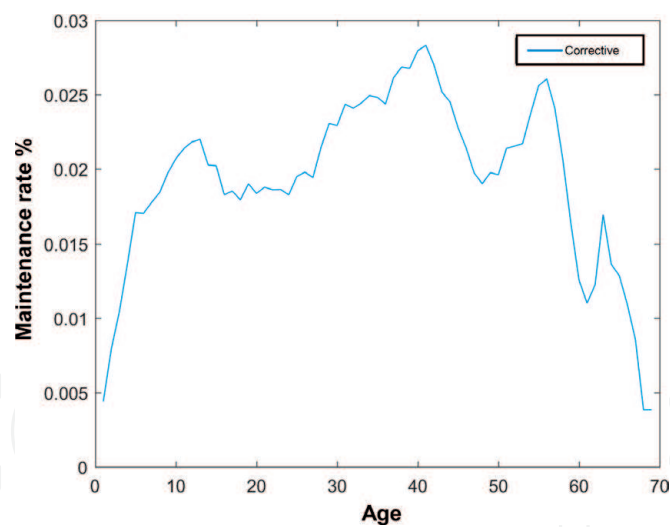
Figure 11.
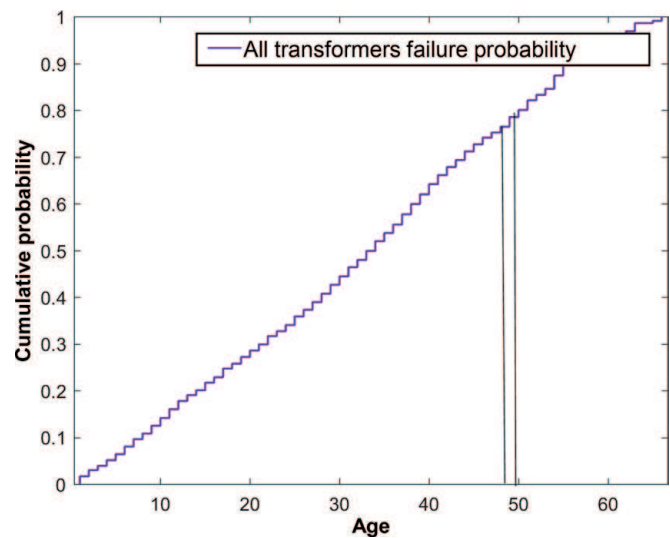*Corrective maintenance rate against operating time.*

Figure 12.
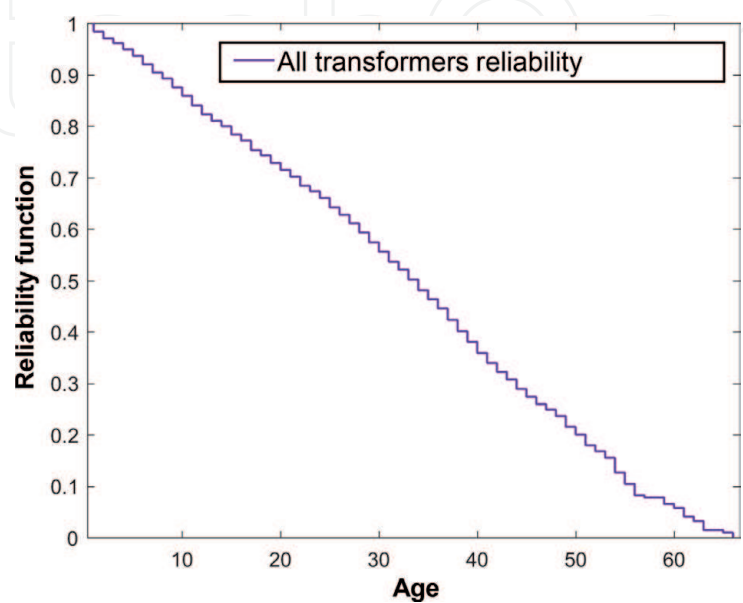*Probability of failure of all transformers with respect to their age.*

Figure 13.
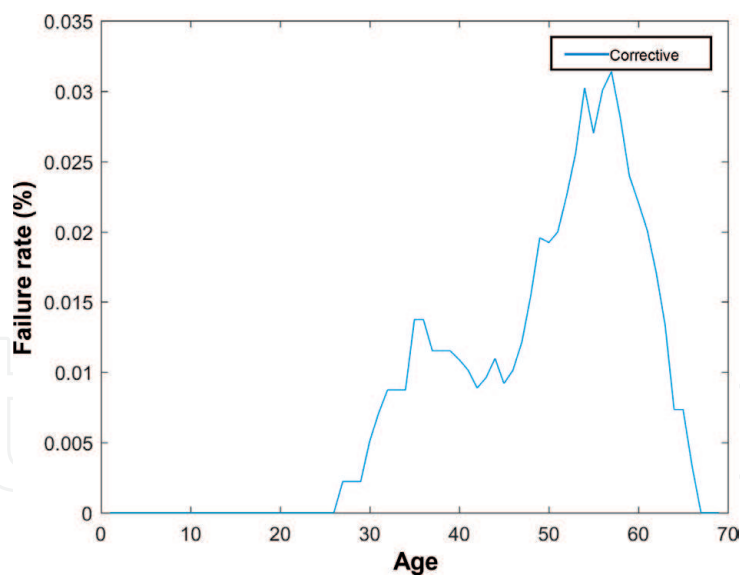*Reliability rate of all transformers with respect to their age.*

Figure 14.
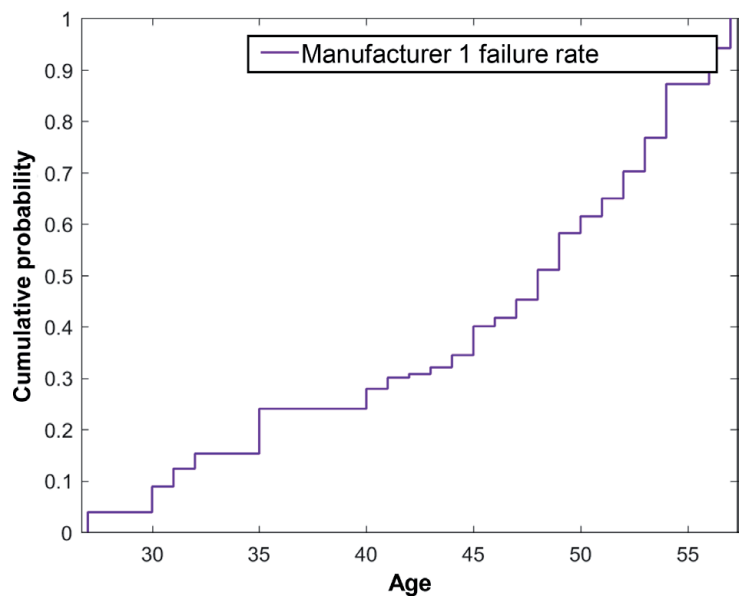*Manufacturer 1 maintenance rate (138 kV) with respect to operating time.*

Figure 15.
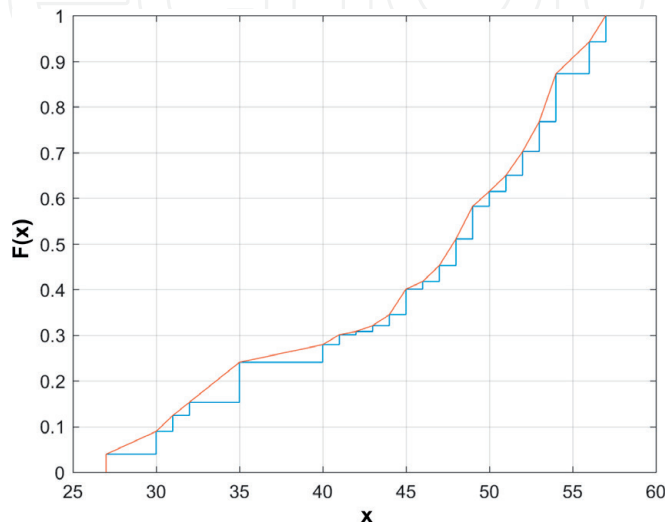*Failure rate of manufacturer 1 transformers (138 kV) with respect to their age.*

Figure 16.
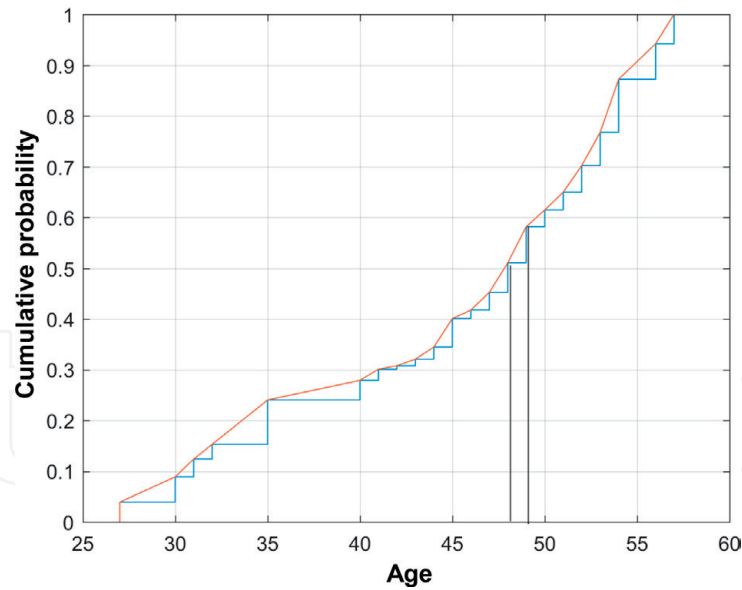*Empirical distribution approximation.*

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Figure 17.
Transformer ID 147511 (manufacturer 1) failure rate will increase by 7% between 48 and 49 years of age of the asset.

from Manufacturer 1 and with nominal voltage of 138 kV. We then obtain the results shown in **Figures 14** and **15**. **Figure 16** shows the approximation of this distribution.

In this case, for a particular transformer, i.e., transformer ID 147511 (manufacturer 1 // voltage class 138 kV // age 48 years), one can observe that the failure rate of this asset will increase 7%, between 48 and 49 years of age. The results of such analysis can be seen from the examination of **Figure 17**.

5. Critical state index estimation

The so-called critical state index allows one to verify if the failure rate of the asset is coherent with the moment in its life cycle. Thus, it becomes possible, by considering the age of the asset and its history of failures, to point out the assets that require distinguished attention [7].

There are different methodologies for identifying and determining the type of defect or failure in equipment immersed in insulating mineral oil based on the results of chromatographic analysis. These methods, such as those listed as follows, are directives for estimating a state index for transformers:

- Key Gas

- Roger

- Doernenburg

- IEC ratio

- IEEE

- Duval triangle

These methods analyze gas concentration limits to estimate the state of the transformer, i.e., gas concentrations are used to diagnose the equipment. To make

Gas	Limit L1 (ppm)	Limit G2 (ppm per month)
H_2	100	50
CH_4	75	38
C_2H_2	3	3
C_2H_4	75	38
C_2H_6	75	38
CO	700	350
CO_2	7000	3500

Table 3.
Duval criteria for identifying transformer defects.

this diagnosis, that is, to quantify the probability of a transformer defect, the following information in **Table 3** can be employed.

To confirm the existence of a fault, one of the gases shown in **Table 3** must have a concentration equal to or higher than L1 and more significant than the value indicated by G2. Thus, this methodology has an appropriate way to evaluate the condition of a transformer based on the historical data about its chromatographic assays.

When the historical data are not available, the IEEE method can be more efficient, since it uses four conditions to identify failure states:

- Condition 1 refers to a normal operating condition, that is, if the dissolved gases are at levels below those presented in **Table 3**, then the transformer is considered to be operating correctly.

- Condition 2 indicates a possible failure and many mineral oil samples should be taken to determine the tendency of gas growth.

- Condition 3 indicates a high level of cellulose and/or mineral oil decomposition, and there is probably a transformer failure.

- In condition 4 there is an indication of excessive cellulose and/or mineral oil decomposition. Continued operation under Condition 4 may result in a total fault.

The joint assessment between the equipment critical state index and its risk analysis, which is based on the history of maintenance procedures, allows for a more assertive decision-making process. To illustrate how the decision-making process can be enriched with both information, consider a 440 kV power transformer that entered into operation in 1981. The graph shown by **Figure 18** illustrates the number of accumulated failures since the last total fault, which has required intervention, as a function of the operating time.

Figure 18 shows that a number of failures between 1.3 and 1.6 failures were expected since the last intervention. This analysis is made with a 90% confidence level by considering the asset history and the database of similar assets.

In order to construct curves involving the operating state of the devices, more than 25,000 gas chromatography assays were evaluated. The tests date from 1977 to the present day, and each test was evaluated according to the standards: IEEE, IEC, Duval, Doernenburg, Roger, and Key Gas. The IEEE criterion was adopted to evaluate the operating condition, as represented by **Figures 19–22**.

The integrated Analysis, which is made by considering the mean behavior from all assays can be shown in **Figure 23**.
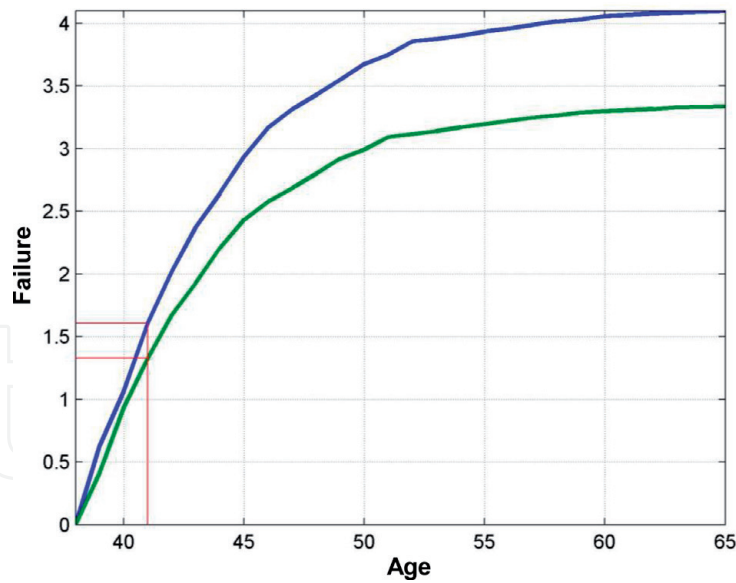
Figure 18.
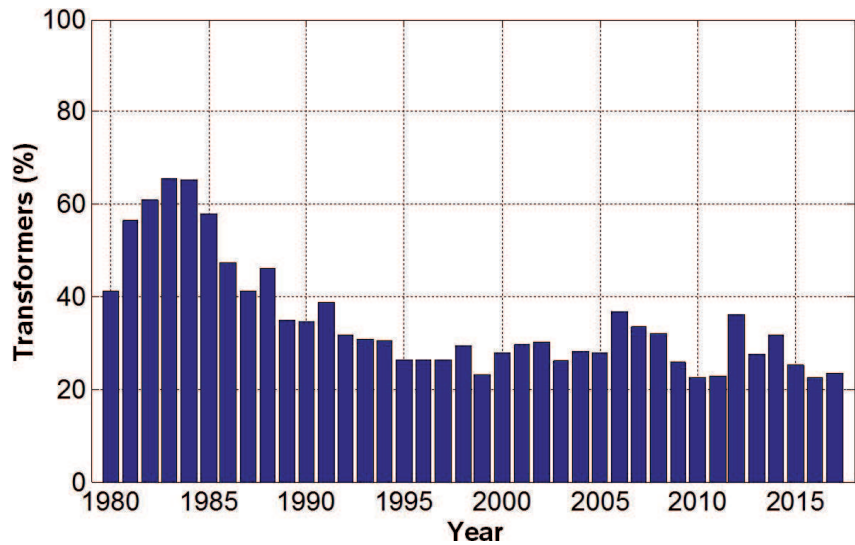*Number of failures since the last intervention for a given transformer.*

Figure 19.
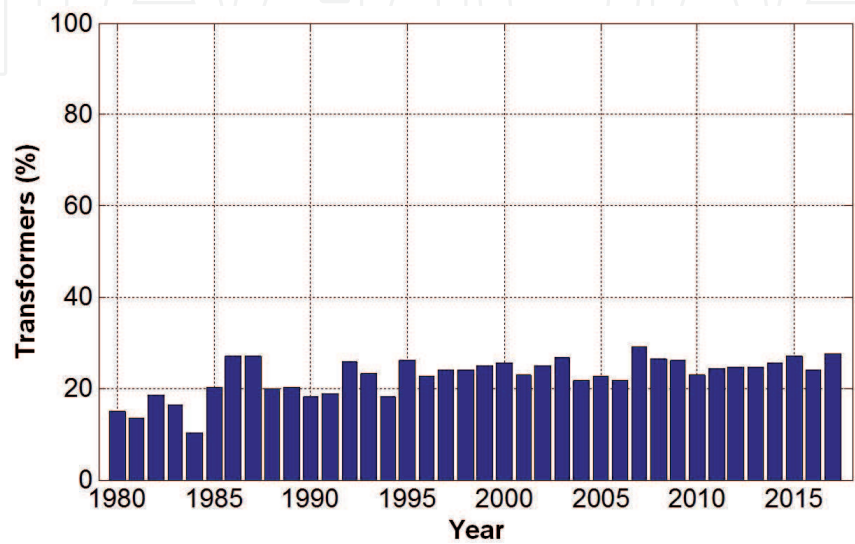*Percentage of transformers in condition 1.*

Figure 20.
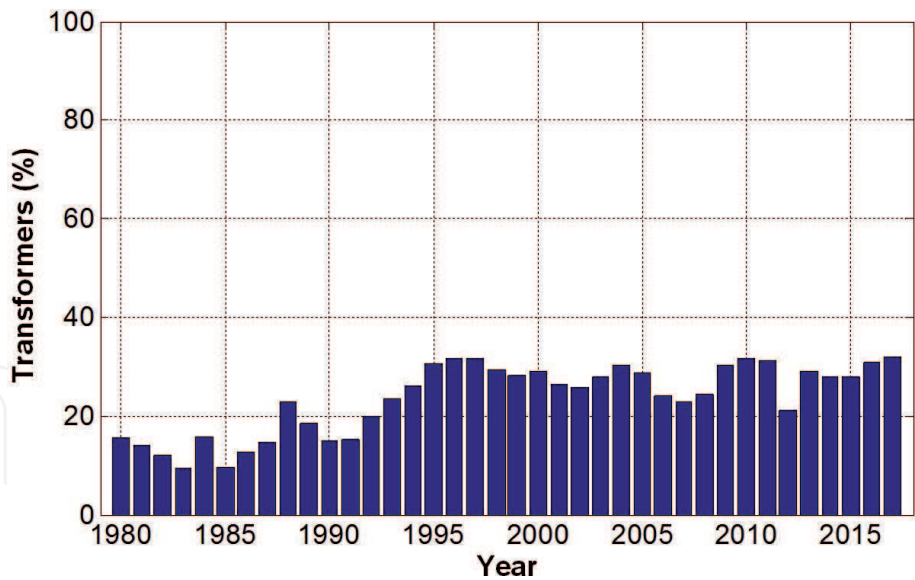*Percentage of transformers in condition 2.*
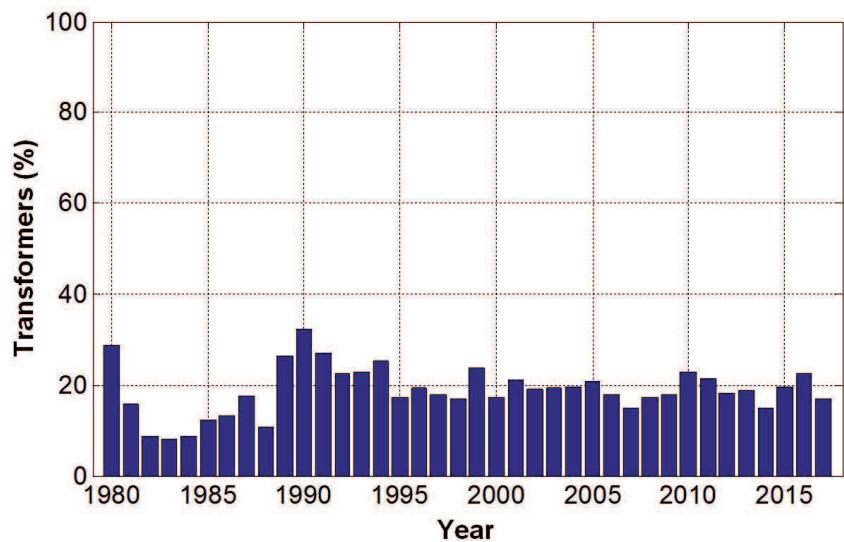
Figure 21.
Percentage of transformers in condition 3.

Figure 22.
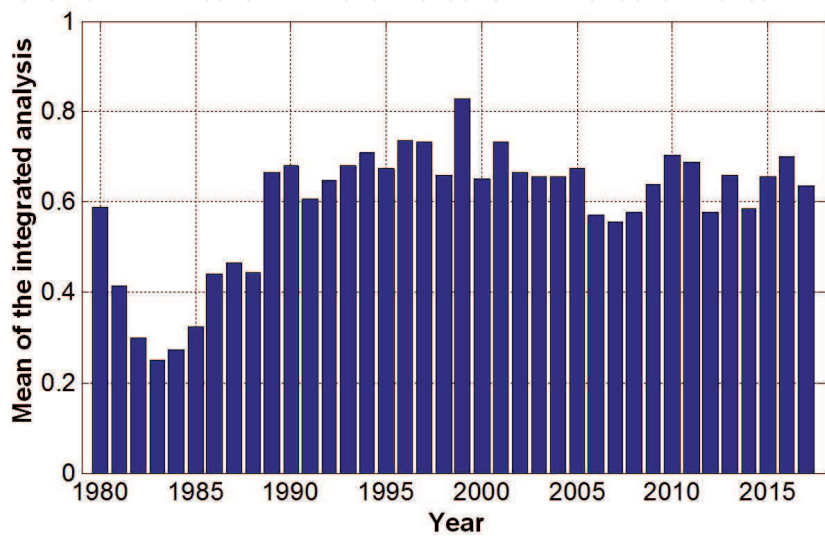*Percentage of transformers in condition 4.*

Figure 23.
Integrated analysis.

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6. Conclusions

Critical assets in the transmission and distribution industries need special care and attention, mainly regarding the aging of the equipment since their lifespan impacts profits as well as the reliability and safety of the electric system.

As the lifetime of these devices become longer, it is justifiable to develop methods to identify their health condition, taking into account not only historical data but also all available asset management tools that companies currently own.

As the vast majority of companies still struggle to learn from the abundant data acquired, such a method should have significant implications in helping managers evaluate and question in-company policies regarding manufacturers and preventive maintenance practices.

In this context, the methodology presented in this chapter can be applied to determine the lifespan of transmission system equipment, based on the determination of failure rates, by using statistical analysis.

Acknowledgements

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