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PREF. SUBJECT :PS 3
QUESTION N° : 2

Consideration of data uncertainty for condition assessment of power transformers

In order to receive a systematic assessment model for an objective condition assessment (CA) of an asset, the uncertainty of the underlying data needs to be taken into account. Many different sources of information are available in varying quality and informative value. There are “soft facts” like visual inspections with a higher subjectivity and “hard facts” e.g. electrical measurements with less uncertainty. These heterogeneous indications of a condition and the inherent different data quality of the sources can be combined into a unified statement by applying of the *“evidence theory”(ET)*. ET extends the classical probability theory by the uncertainty (grey part of probability in diagram below). The existing approaches for CA (like 2-D-approach), can be extended by this mathematical approach. The uncertainty can be used as an additional parameter for maintenance and replacement decisions for the Asset Manager (AM). For this reason, a pragmatic approach can be applied so that the necessary level of data quality can be achieved in a most efficient way:

1st Level Assessment (no transformer outage required)
The available historical measurement data (Visual inspection, oil analysis, electrical measurements, IR-thermography) is used. Depending on the situation the data quality can differ significantly (completeness and age of the data).

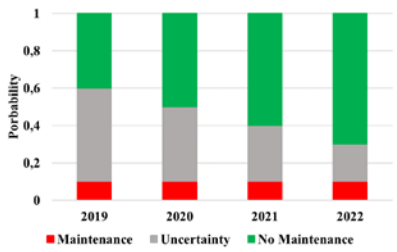

Fig. 1: CA with data uncertainty

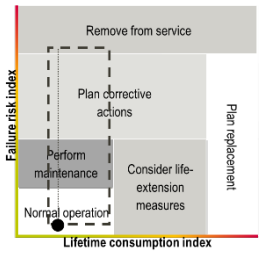

Fig. 2 : Impact of age on evidence theory

Practical Example: Four years old oil and DGA results are available. The values were within the given limits and did not show any abnormalities. The transformer is evaluated as normal operation (black dot), but due to a large amount of missing data and the aged data, there is a high data uncertainty, whose range is indicated by the dotted square. The level of acceptance for data uncertainty depends on the individual case and criticality of the asset. As soon as the possible condition state, because of the uncertainty reaches areas that would require action, the data quality should be increased to check the actual condition. Therefore, the recommendations for the responsible AM relate mostly in increasing the data quality to confirm the condition: Acquisition of up-to-date data (e.g. new DGA analysis) and further inspections and measurements.

2nd (no outage required) **and 3rd** (outage required) **Level Assessment**
These two levels differ by assessment during operation (non-disruptive) and disruptive test (e. g. electrical measurements). Both levels have an increased data quality because of up-to-date data, more used assessment methods and the combination via the ET, considering the accuracy of the measurement method, data availability and conflicting information from different measure methods. The combination is realized with the *worst-case rule* (see Fig. 3).

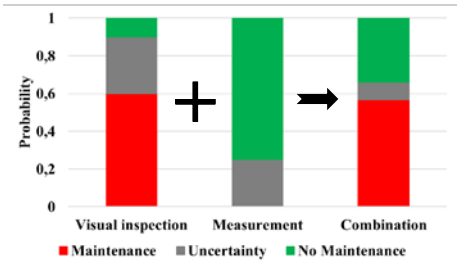

Fig. 3 :Combination of various data sources

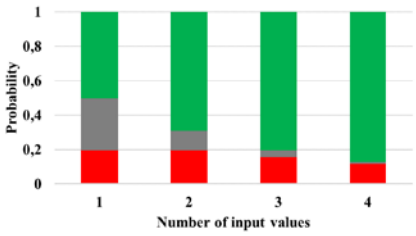

Fig. 4 :Reduction of DU with additional data

In addition, an adapted form of the *dempster rule* reduces the uncertainty with every added input value. The result runs against the dominating evidence (see Fig. 4).
Practical Example: The missing assessment points of the visual inspection, the values from the thermography, updated oil analysis including DGA as well as furan analysis have been obtained as recommended. In this turn, some abnormalities (e.g., leakages, increased moisture in oil, reduced breakdown voltage) could be detected. By performing the electrical measurement PDC/FDS (confirmation of moisture in the insulation), the data uncertainty could be reduced further, leading to the result shown in the 2-D-matrix (Fig. 5 left).

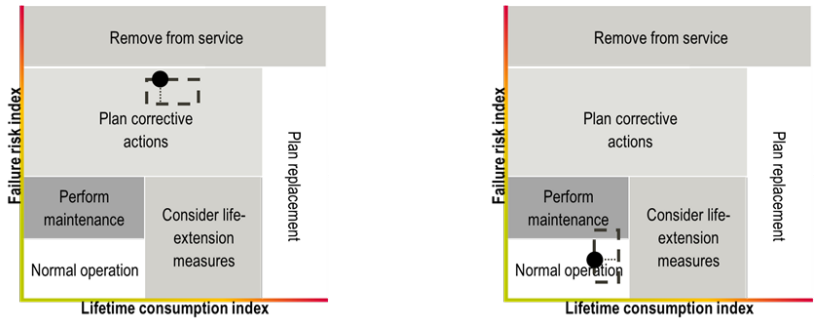

Fig. 5:CA with higher data quality and several abnormalities and after performing countermeasures to improve the condition of the transformer.

By means of the higher data quality, the condition of the asset could be evaluated with required certainty. The responsible asset manager can rely on given recommendations and improve the overall condition of the transformer (move to a safe condition in “normal operation” by performing necessary measures (Fig. 5 left). Repairing leakages, refilling silica gel in dehydrating breather, performing a long term online drying process of the oil and paper isolation. Performing a reassessment can confirm the effectiveness of the accomplished measures (Fig. 5 right).

Conclusion: the role of data quality is essential. An appropriate approach enables asset managers to optimize their maintenance strategies and budget plans in the scope of the company policy or e.g. ISO 55000 standards.