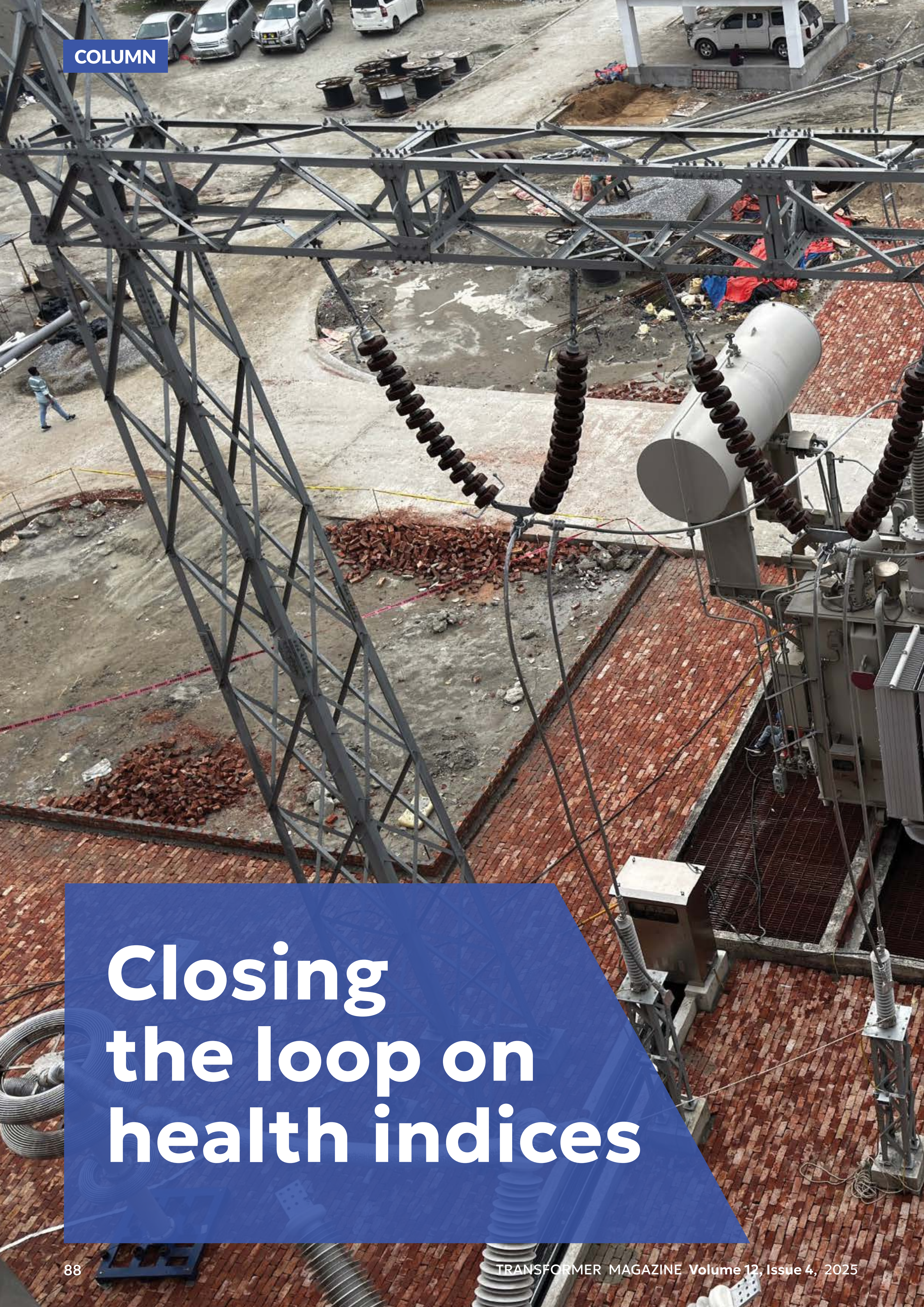

Closing the loop on health indices

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ABSTRACT

Health Indices can help with prioritising asset maintenance, replacement and risk management. But how accurate is the index? And how do you check? Cases from the real world show how indices can help but need to be treated with caution.

KEYWORDS:

Asset Health Index, transformer failure, condition assessment, forensic analysis

COLUMN

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Introduction

I was thinking about Asset Health Indices (AHIs) recently after undergoing a cancer screening test, which had yielded, fortunately, negative results. It was made very clear that the result did not mean that I did not have the disease, just that they hadn’t found any indications of it in their tests. Likewise, a “good” AHI result does not mean the asset won’t fail tomorrow; we just haven’t found any indication in our data that it is likely to fail tomorrow. So, what are the characteristics of “good” AHIs? See Box 1.

Box 1. What makes a good AHI?

There are 5 key characteristics for an AHI used to prioritise interventions:

- **Focus** - we are addressing one clearly stated and agreed question
- **Monotonicity** – a worse index is always a more urgent intervention
- **Calibration for time** – all assets with the same index are equally urgent
- **Auditability** – we can see exactly which data caused the index to be what it is
- **Justifiability** – the index is what it is for a good technical reason

The only thing that should link different AHI’s is the urgency: how soon should we act? And with what precision do we have that timescale? This is a technical interpretation, but in an asset management context we need risk analysis: the technical input tells us the urgency, but the risk analysis may mean we delay, or bring forward, an intervention...

With all that said, a good AHI *supports* specific business decisions – it does not make them for you!

Asset Health Indices are quite common in the electric supply industry, particularly for large assets, as the index is a simple means to boil down a lot of data into a single number, letter, or category to aid in the prioritisation of asset interventions. So far, so good. But there are several aspects to the approach which need to be carefully considered:

- What exactly is “the asset”? For a power transformer, do we include bushings and the tap changer, or are they separate, maintainable items?
- Exactly what question does the AHI address? What does “healthy” mean? “Asset operation” as defined by the original specification, or under contingency, or only with normal maintenance, and so on?
- How do the data and the analyses, and thus the index, relate to the probability of failure (PoF) of the asset over the next week, month, or year? And with what precision do we give that PoF? And what will the PoF be used for?
- How accurate/precise is the AHI? We know the AHI is a “model” or “estimate” of the actual “health” and thus, it will be wrong [1]. The question is: how wrong can it be before it becomes unacceptably wrong [2]?

It is this last question which is rarely addressed in practice: we often see cases where AHIs are assumed to be extremely precise and accurate and are used in planning tools such as maintenance scheduling and risk matrices.

Has anyone checked the AHI for accuracy/precision? Have the results of those checks been included in subsequent use of the AHI? If not, how do you know the results are any good?

Evaluation

We will evaluate the effectiveness of an Asset Health Review on a population of approximately 800 large transformers and shunt reactors owned by a transmission company with the aim of prioritising units for replacement that were in poorer condition. Of those 800 units, 14 were replaced in a single year, and we can compare the AHI assigned to them with what was found in practice when the units were scrapped and forensic analysis undertaken.

Box 2 indicates the methodology used for AHI and the categories which were used to group assets.

Cases

The cases presented here show that it can be difficult to predict the end of life with the information/tools available, even when pursued “manually” with subject matter experts rather than through some automated analyses.

Case 1

A 750 MVA 400/275/13 kV unit, built in 1977, was the last of four transformers of the same design installed at the same station. The unit had evidence of severe oil and solid insulation ageing from oil tests (2-furfual 2.47 ppm, acidity 0.21 mg KOH/g), and evidence of poor dielectric condition from electrical tests (CHL power factor 0.62%). It was given a priority of 2a, was retired and retained as a spare, and was scrapped

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We will evaluate the effectiveness of an Asset Health Review on a population of approximately 800 large transformers and shunt reactors owned by a transmission company

and forensically reviewed. During the review, the solid insulation was found to be severely aged with the worst degree of polymerisation (DP) below 200, and it should have been priority 1.

Case 2

A 240 MVA 400/132/13 kV unit, with a loaded shunt-reactor on the tertiary, built in 1966, had evidence of severe solid insulation ageing based on oil tests (2-furfual 2.29 ppm). Unfortunately, there was no electrical test data available for this unit, thus, assessment relied on anecdotal evidence and "tribal knowledge". It was assigned a priority 2b.

During scrapping, the solid insulation was confirmed to be severely aged, as had been expected (worst DP 124), confirming the earlier 2b priority assignment.

Case 3

A 240 MVA 400/132/13 kV unit, built in 1967, showed evidence of localised overheating from oil tests (ethylene 350 ppm); electrical tests were performed but were inconclusive, with suspicion falling on possible core/frame/tank circulating currents. An attempted "fix" with current limiting resistors was not successful, and suspicion moved on to possible overheated stress shield rings and a priority of 1 was assigned.

During scrapping, the cause of the localised overheating was found not to be overheated shield rings nor even a circulating current in the core/frame/tank, but an overheated tertiary busbar joint. A subsequent review found that the spread in winding resistance results from the tertiary winding at the time it was electrically tested was approximately 9%, but it was not clear due to poor test data. The typical spread in results for a new transformer is less than 2%, with spreads of up to 5% in some older transformers.

A clearer set of electrical tests would have afforded an opportunity to repair the tertiary busbar joint in the field, but the unit was already scrapped. Note that a new DC winding resistance bridge was acquired soon after this to improve the data from the electrical tests. Although the condition of the insulation was reasonably poor, with a DP of 337, the review was correct about the fault and its severity but incorrect about its cause. With that knowledge, the priority should have been a 2a.

Case 4

A 180 MVA 275/66/13 kV unit, built in 1968, had a sister unit fail 4 years earlier due to severe solid insulation ageing: it was thus reasonable to expect this unit would have similar issues, even though oil tests were inconclusive (2-furfural 0.93 ppm). There were some indications of localised overheating, with ethylene at 82 ppm in the main tank, but no other indications of a significant problem. The unit was assigned a priority of 1, mainly due to the failure of the sister unit, and a planned replacement ensued.

During the scrapping of the unit, localised overheating was found to be caused by a circulating current in the tank/frame assembly, but it was noted that there

Five real-world transformer cases were reviewed to highlight discrepancies between assigned health indices and actual conditions found during forensic analysis

Box 2. Asset Health Evaluation

Every one of the 800 units was assessed using a Delphic approach, allowing subject matter experts to discuss and weigh the available data/evidence and assign each unit to a category. The data included:

- specification/design, known "issues", and family histories
- maintenance/inspection history
- offline test results, including oil analyses
- online monitoring data where available, including PD surveys
- fault histories
- subject matter expert opinions and expertise
- whatever else seemed relevant

Each unit was assessed "manually" by the group and then assigned to a category from 1 to 4:

- **1:** most serious issues requiring replacement within 5 years
- **2a:** highly likely to require replacement within 10 years (noting "highly" was not well defined
- **2b:** may require replacement within 10 years
- **3a:** plan to replace ahead of anticipated asset life; design defect or similar
- **3b:** same as 3a but less serious (so less urgent)
- **4:** unit expected to last at least 15 years under normal operation

Within each category, the individual units were prioritised based on evaluation of the urgency of intervention. Note the approach of data-analysis-AHI assignment:

- "Based on the available data, its interpretation and estimates of PoF and remaining life: we need to do something in 5 years so this unit is a category 1"

The presented cases show that it can be difficult to predict the end of life with the information available, even when pursued "manually" with subject matter experts

Figure 1. Failure point: wrapped discs (at left), no overwrapping (at right)

were differences in the detailed winding design between the two sister transformers, resulting in differences in solid insulation ageing. The differences are shown in Figure 1. Note the use of crepe paper over-wrapping on the discs in the failed sister transformer. This resulted in overheating of the solid insulation and advanced solid insulation ageing (worst DP 131).

The prediction of the review was correct regarding the circulating current but not about the advanced solid insulation ageing, which was caused by an unknown design change. With that knowledge, a priority of 2a would have been assigned.

Case 5

A 240 MVA 275/132/13 kV unit, built in 1965 and refurbished in 2005, showed no indication of significant deterioration but only moderate solid insulation ageing, based on offline electrical tests and oil analyses (2-furfual 0.92 ppm).

The unit was assigned a priority of 4, but failed suddenly and unexpectedly and was forensically reviewed. The common winding was found to have very advanced solid insulation ageing at certain points, believed to have been caused by unusual flux leakage resulting from tertiary loading with a shunt reactor. The information used during the review and generation of the AHI was incorrect as accumulated 2-furfural in the oil was lost when it was changed during the refurbishment, and it can take some years for 2-furfural to reach equilibrium once more and then only at a lower level. The oil change during a refurbishment may have destroyed valuable evidence concerning the condition, especially solid insulation ageing and a priority of 2b could have been assigned if that information was available.

Discussion

It can be seen from the cases here that an asset health review and assignment of an AHI is not a simple process. In fact, of the 14 units replaced 6 were misassigned to an adjacent category for various reasons, but in one case, missing by 2 categories.

How do we define "accuracy" in this approach? How do we define accuracy where the categories are 1 through 10 and are calculated numerically based on input data and algorithms? How wrong does an AHI have to be before it becomes unacceptably wrong?

In any application of AHIs, it is of paramount importance to check the validity of the data collected, the analyses performed, and the outcomes resulting from it

In any application of AHIs, it is of paramount importance to check the validity of the data collected, the analyses performed, and the outcomes resulting from it. An AHI needs to be updated and reviewed on a regular basis to ensure it is not "unacceptably wrong", whether it is derived through machine learning through standard algorithms and guides or through a Delphic approach. As always, ABC applies: Assume nothing; Believe nobody; Check everything!

References

[1] Box, G. E. P. (1976), "Science and Statistics" (PDF), *Journal of the American Statistical Association*

[2] Cox, D. R. (1995), "Comment on 'Model uncertainty, data mining and statistical inference'", Journal of the Royal Statistical Society

Authors

Dr. Tony McGrail of Doble Engineering Company provides condition, criticality, and risk analysis for substation owner/operators. Previously Dr. McGrail spent over 10 years with National Grid in the UK and the US as a Substation Equipment Specialist, with a focus on power transformers, circuit breakers, and integrated condition monitoring. Tony also took on the role of Substation Asset Manager to identify risks and opportunities for investment in an ageing infrastructure. Dr. McGrail is an IET Fellow, past-Chairman of the IET Council, a member of IEEE, ASTM, ISO, CIGRE, and IAM, and a contributor to SFRA and other standards.

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He currently manages a team of 50 specialist engineers outside of North America for Doble Engineering. Responsible for managing all aspects of the company financial, environmental, health and safety requirements. Including site assessment of all equipment types, such as Transformers and Generators. Additionally, he managed the delivery of a broad range of other testing and consultancy services for high-voltage substation equipment to clients across the world to compile condition assessment reports to recognise and validate replacement schemes.