A Practical Approach for Assessing Transformer Asset Health Indices for Fleet Asset Management

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EFFECTIVE HEALTH SCORING IS ESSENTIAL SO THAT THE ASSET MANAGERS RANK WHICH TRANSFORMERS ARE HIGH RISK, HAVING THE MOST URGENT NEEDS, VERSUS TRANSFORMERS WHICH ARE LOW RISK.

To identify transformers in the fleet which warrant attention for maintenance, refurbishment, or replacement, asset managers often use transformer assessment indices, or health scores to rank transformers within the fleet. However, there are no industry standardized methods for health scoring and methods used vary. Effective health scoring is essential so that the asset managers rank which transformers are high risk, having the most urgent needs, versus transformers which are low risk.

Many traditional methods used to generate health indices tend to focus on laboratory oil analysis: dissolved gas analysis (DGA) and oil quality tests. Oil analysis can provide valuable insight into developing fault conditions in the transformer main tank or the load tap changer (LTC). However, some failure modes in the Main Tank and LTC may be difficult to diagnose specifically from oil quality and DGA tests alone. Also, transformers can fail from defects in components outside of the Main Tank or LTC. Transformer bushings, and cooling system problems can also cause failure, and these are not properly evaluated using health indices that focus solely on oil analysis.

This article presents a practical method for calculating transformer asset health indices called Condition Index which evaluates condition on all major transformer components including Main Tank (Active Part), LTC, bushings, and cooling system. The method is holistic and combines data from oil analysis along with inspection data, electrical tests, and transformer online monitoring, integrating these into a single health score metric.

Holistic Assessment

Parameters utilized in the Condition Index are shown in Table 1. With this comprehensive scope of parameters considered in the asset health indices evaluation, more accurate and detailed health assessment is possible.

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WITH THIS COMPREHENSIVE SCOPE PARAMETERS CONSIDERED IN THE ASSET HEALTH INDICES EVALUATION, MORE ACCURATE AND DETAILED HEALTH ASSESSMENT IS POSSIBLE.

Component	Parameter/Diagnostic Test
Active Part (Main Tank)	DGA (Lab Analysis) DGA (Online Monitoring) Moisture (Online Monitoring) Oil Quality (E.g. Furans, Acidity, Particle Counts, Color, etc.) Electrical Tests (E.g. Winding resistance, Core Insulation, Ratio, etc.) Partial Discharges (Online Monitoring) Temperature (Online Monitoring) Analytical Models (E.g. Aging Models, Hotspot, Bubbling Temp., Instant BDV etc.)
Cooling System	Visual Inspection / Infrared Cooling Efficiency Cooling System Operations (Operating Time, Counts)
On Load Tap Changer	DGA (Lab Analysis) DGA (Online Monitoring) Operation Count Oil Quality (E.g. BDV, Moisture) Temperature (Online Monitoring)
Bushings	Electrical Tests (E.g. Power Factor, Capacitance, DFR) Bushing Monitoring (Online Monitoring Cap/Tan Delta) Visual Inspection/Infrared Partial Discharges (Online Monitoring)

Table 1.

Photo: Camlin Energy

Condition Index Health Score Method

Methods for calculating transformer assessment scores vary among utilities and in industry. Asset Managers use different methods, with some developed in-house by subject matter experts, and others developed by external 3rd Party services. Although there are no standardized approaches across industry, some concepts and strategies are described in the Cigre Guide 761 – Condition Assessment of power transformers[1].

The Condition Index method in this article is categorized as a hybrid scoring method by Cigre 761. Hybrid methods use two components to evaluate transformer health. The first component, called the Condition Group, indicates the 'Worst-case' condition of any component: Active Part, Cooling System, On Load Tap Changer, and Bushings. The second component is called the 'Overall Health Index' and is a weighted sum of all the transformer diagnostic parameters indicating the overall health.

Condition Group is an integer value between 1-5, with 1 indicating 'Good' condition, and 5 'Short Term Risk' indicating equipment is at high risk for failure. Overall Health Index is a decimal value from 0.00 to 0.99, with 0.00 being the best overall health and 0.99 being the worst overall health. The two components are combined in a single quantitative metric ranging from 1.00-5.99:

Condition Index Format:
X.YY
Where,
X – Condition Group of the transformer (worst case method)
YY – Overall health index (weight scoring method)

Condition Group and Overall Health Index scores are assessed based on thresholds applicable to components and parameters listed in Table 1. For brevity and proprietary reasons, thresholds which determine the Condition Group and are not shared.

Qualitative descriptors for Condition Groups are provided in Table 2, these are based on information from Cigre Guide 227 – Life management techniques for power transformers[2].

An example of an evaluation for Condition Index is shown in Table 3. In this example the Bushings component is 'Worst-Case', yielding a Condition Group score of 4, and the weighted sum of all parameters yields an 'Overall Health' score of 0.284. The final Condition Index score is rounded to 4.28.

Camlin Condition Group	Method description	CIGRE Classifications	CIGRE TB227 Description
1	Good	Normal	No obvious problems, no remedial actions justified. No evidence of degradation
2	Normal for service	Aged/Normal in service	Acceptable, but does not imply defect-free
3	Long Term Risk	Defective	No significant impact on short-term reliability, but asset life may be adversely affected in long term unless remedial action is carried out
4	Medium Term	Faulty	Can remain in service, but short-term reliability likely to be reduced. May or may not be possible to improve condition by remedial action
5	Short Term Risk	Risk of Failure	Cannot remain in service. Remedial action required before equipment can be returned to service (may not be cost effective, necessitating replacement)

Table 2.

Condition Group	Group	Parameters	Parameter Score (P_i) (0.00 - 0.99)	Weight (W_i)	Weighted Index ($W_i \cdot P_i$)
2	DGA	DGA (Online)	0.25	0.30	0.075
		DGA (Lab)			
2	Partial Discharge	PD Persistence	0.25	0.10	0.025
4	Bushings	Capacitance	0.90	0.20	0.18
		Tan Delta			
1	Models	Est. Moisture in Paper	0.01	0.05	0.0005
		Insulation Aging			
1	Visual	Infrared Scan	0.01	0.05	0.0005
1	Oil Quality	IFT	0.01	0.10	0.001
		BDV			
		Color			
		Moisture			
		Furans			
1	Electrical Test	Winding Resistance	0.01	0.10	0.001
		Insulation Resistance			
1	OLTC	Temp. Differential	0.01	0.10	0.001

Table 3.

Overall Score = $\sum_{i}^{N} (W_i \cdot P_i) = 0.284$

Benefits for Fleet Ranking

A key benefit of the Condition Index health assessment indices is for use in fleet ranking transformers. Because the Condition Group value represents the 'Worst Case' component, if any single component has a serious defect this immediately drives the asset health score to higher risk in the fleet regardless of the Overall Health.

The metric also enables transformers to be ranked even when not all transformers in the fleet have the same data available for assessment. Some transformers may be equipped with online monitoring whereas others are not. Or some transformers may have recent electrical tests while others have not been tested for many years. The Condition Group determined by the worst-case component assures that based on the information available the asset is ranked roughly where it belongs relative to other transformers in the fleet. Beyond this coarse ranking from Condition Group the Overall Health Index then allows for more fine-tuned ranking within the list.

Figure 1.

Type	Location	ID	Condition	Company	Condition Index
Transformer	Sequoia Street	GTX1	Short Term Risk	Bushmills Electricity North	5.12
Transformer	Acacia Avenue	GTX2	Medium Term Risk	Bushmills Electricity South	4.47
Transformer	Grove Avenue	GTX2	Medium Term Risk	Bushmills Electricity South	4.29
Transformer	Hickory Lane	GTX1	Medium Term Risk	Bushmills Electricity South	4.23
Transformer	Elm Street	GTX2	Medium Term Risk	Bushmills Electricity South	4.18
Transformer	Juniper Road	TX1	Medium Term Risk	Bushmills Electricity North	4.17
Transformer	Beech Street	TX2	Medium Term Risk	Bushmills Electricity South	4.14
Transformer	Juniper Road	TX2	Medium Term Risk	Bushmills Electricity North	4.14
Transformer	Hickory Lane	GTX2	Medium Term Risk	Bushmills Electricity South	4.14
Transformer	Dogwood Drive	TX2	Medium Term Risk	Bushmills Electricity South	4.12
Transformer	Sequoia Street	GTX4	Medium Term Risk	Bushmills Electricity North	4.1
Transformer	Juniper Road	GTX2	Medium Term Risk	Bushmills Electricity North	4.1
Transformer	Redwood Road	GTX2	Long Term Risk	Bushmills Electricity North	3.18
Transformer	Redwood Road	GTX1	Long Term Risk	Bushmills Electricity North	3.17
Transformer	Ivy Lane	TX1	Long Term Risk	Bushmills Electricity North	3.13

Figure 1 shows a set of assessed transformers with Condition Indices ranging from Short-Term to Long-Term Risk. The Location and Company names fictitious to maintain customer anonymity. The transformer with the highest Condition Index score of 5.12 has a relatively low Overall Health Index of 0.12 (close to good) but is elevated to the top of the list because of one component exceeding the Short-Term Risk Threshold. Multiple transformers are operating at Condition Group 4 but with Overall Health scores ranging from 0.47 to 0.10.

The Condition Index health assessment indices allow the asset manager to see which transformer has the most significant health risks, while also allowing for more detailed ranking and prioritization among transformers in similar condition.

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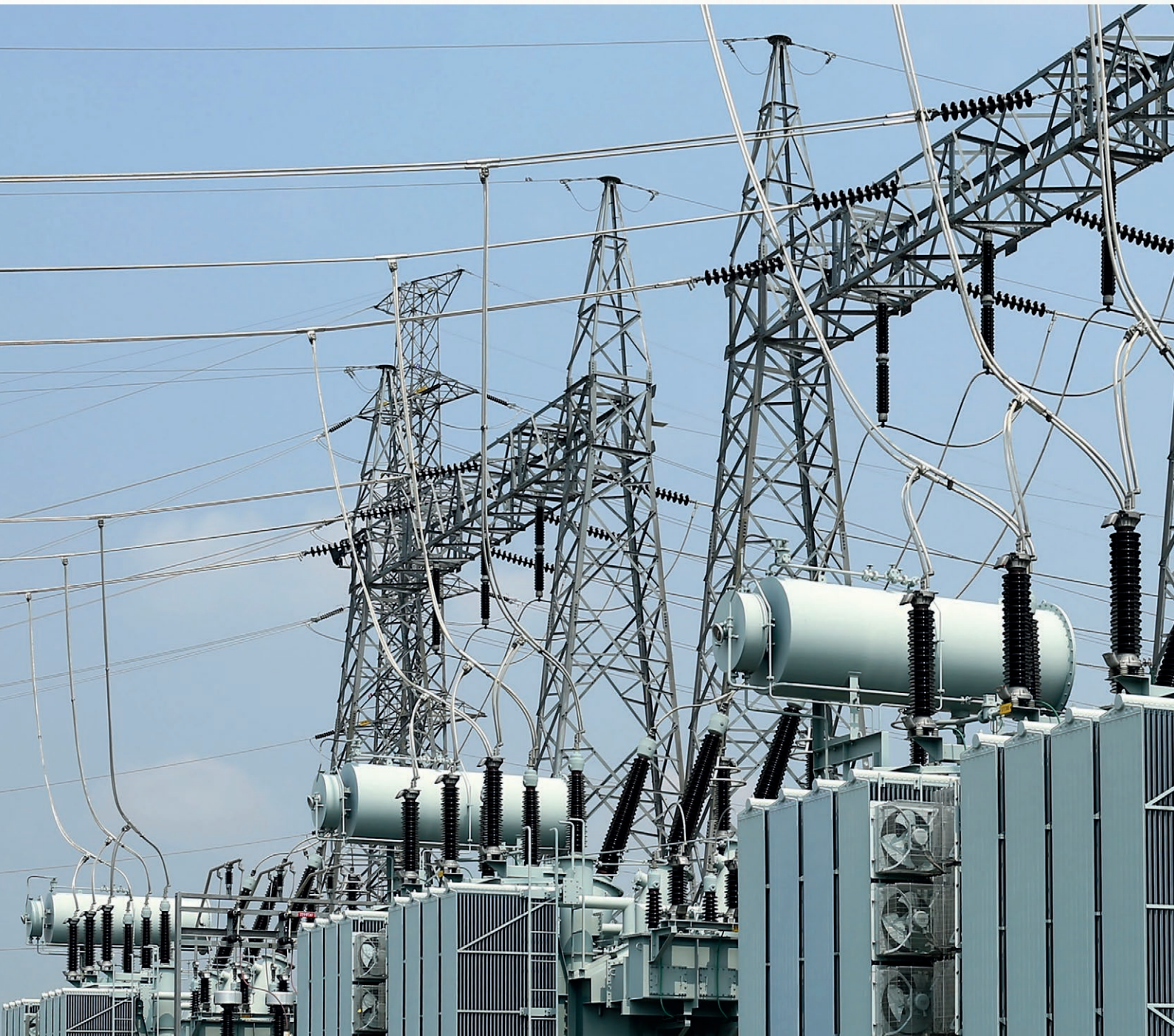
CAMLIN Condition Index	Condition Description	CIGRE TB 227 Classification	CIGRE TB227 Description	Cigré 248 Condition Rating	Range of Estimated Failure Rates Based on Cigré 248
1.00 - 1.99	Good as new	Normal	No obvious problems, no remedial actions justified. No evidence of degradation	Good	0.3 % - 0.99 %
2.00 - 2.99	Normal for service	Aged/Normal in service	Acceptable, but does not imply defect-free	Satisfactory	1.0 % - 1.49 %
3.00 - 3.99	Long term risk	Defective	No significant impact on short-term reliability, but asset life may be adversely affected in long term unless remedial action is carried out	Fair	1.50 % - 1.99 %
4.00 - 4.99	Medium term risk	Faulty	Can remain in service, but short-term reliability likely to be reduced. May or may not be possible to improve condition by remedial action	Poor	2.0 % - 2.99 %
5.00 - 5.99	Short risk term	Failure	Cannot remain in service. Remedial action required before equipment can be returned to service (may not be cost effective, necessitating replacement)	Bad	> 3.0 %

Table 4. Estimation of PoF based on Condition Index Health Assessment Indices



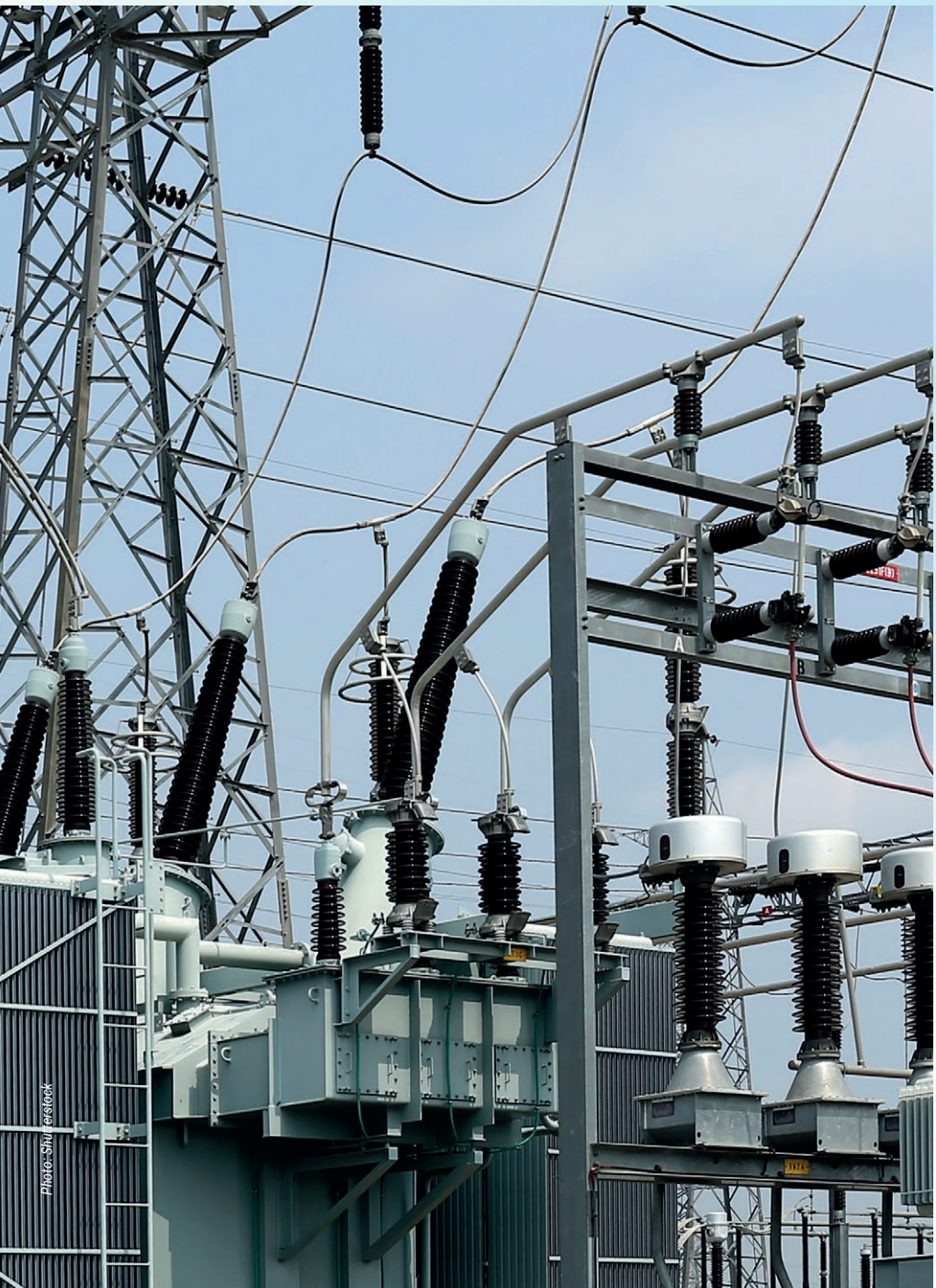
Benefits for Evaluating Risk

The format of the Condition Index metric lends itself well to evaluating Risk. Because the metric is a continuous parameter ranging from 1.00 to 5.99, it is possible to translate the Condition Index metric to estimate probabilities of failure (PoF). Risk is commonly calculated as follows:

$ Risk = $ Cost of Event × Probability of Failure

The consequences of a transformer failure and associated costs is not the same for all transformers. These consequences depend on multiple factors including the number of customers impacted, cost of equipment repair/replacement, and the cost of collateral damage to other equipment in the substation if the transformer fails under explosion and/or fire.

Table 4 illustrates an example of how the Condition Index score can be translated to estimate PoF. The PoF ranges are suggested based on estimated failure rates from Cigre 248 – Economics for Transformer Management[3]. The actual failure rate can be interpolated within the range based on the Condition Index value. Note, the PoF figures from Cigre 248 are intended only to illustrate the application of this method; actual PoF rates in transformers can differ widely based on region, application, and operational history.



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Conclusion

With the critical importance on transformer reliability, for asset managers it is important to leverage transformer data and information as best they can to maximize availability. The Condition Index method for evaluating transformer asset health indices has advantages over traditional approaches that focus only on oil condition due to the Condition Index holistic assessment. Data from online monitoring and electrical tests can be ingested along with DGA and oil quality to evaluate health. Additionally, the hybrid scoring approach allows for better distributed ranking of assets and adapts well to raising risk score on worst case condition, as well as handling ranking where not all assets have all the same parameters available. The Condition Index metric can also be translated to estimate the PoF for evaluating Risk, when managers want to understand the Risk in terms of consequences and dollars.

THE CONDITION INDEX HEALTH ASSESSMENT INDICES ALLOW THE ASSET MANAGER TO SEE WHICH TRANSFORMER HAS THE MOST SIGNIFICANT HEALTH RISKS, WHILE ALSO ALLOWING FOR MORE DETAILED RANKING AND PRIORITIZATION AMONG TRANSFORMERS IN SIMILAR CONDITION.

References

[1] CIGRE WG A2.49, "Condition assessment of power transformers," Technical Brochure, 2019.

[2] CIGRE WG A2.18, "Life management techniques for power transformer, 2003.

[3] CIGRE WG A2.20, "Guide on economics of transformer management", June 2004.