Study Committee A2

A2.49 Conditon Assessment of Power Transformers

Condition Assessment of Power Transformers

Brian Sparling (CA) on behalf of WG A2.49 Members

The Focus

- The focus of Working Group A2.49 was to investigate information used to derive Transformer Assessment Indices, its' consolidation, and the uses to which the output can be utilized.
- Help identify transformers which most urgently need attention or intervention.
- To understand failure modes of transformers to asses the condition of the transformer.

Approach

- Transformer Assessment Indices (TAIs) can be generated by calculating a score, for each transformer in the fleet, then using the assigned scores to rank the transformers.
- The scores are calculated using an appropriate and sensible method, and using timely and accurate data, the asset manager can easily identify those transformers which most urgently need attention or intervention.
- An example of a scoring matrix, has been developed by the working group. This matrix effectively has five levels. (The 6th level - labelled F - is not used when generating a TAI but is noted to consider very-short term failure criteria)

F	De-energize as soon as possible. Don't return to service until problem is repaired. Component at end of life
E	Very Poor condition – high likelihood of failure. Component is near end of life. Repair or replacement as soon as possible is recommended. De-rating or restricted operation of transformer may be appropriate, and operation under extreme conditions may not be appropriate until replacement is possible
D	Poor Condition. Repair or replacement should be considered within the short term. Reliable operation may be impaired or compromised. Performance or component may be causing deleterious effects. Consider review of rating and operating condition.
C	Acceptable condition with significant signs of aging or deterioration. Reliable operation expected for medium term – but consider condition-based maintenance if applicable
B	Good condition. Some signs of aging or deterioration are evident. Reliable operation expected for a lengthy period.
A	Minimal Signs of ageing or deterioration. As new condition

SCORING MATRIX

Objectives of the Work

- Assist in managing fleets of transformers
- Consistent methodology to assess and prioritize
- Help identify candidates for repair (major or minor), refurbishment, or replacement, and the timing of such activity.
- Options for dealing with UNCERTAINTY in data and information
- How to utilize On-Line Condition Monitors
- Suggest methods to estimate Probability of failure

Structure and setup of the Brochure

CONTENTS.....

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- **Chapters 1 to 7** introduces a process that can be used to assess a transformer and to develop Transformer Assessment Indices to suit the needs of the user.
- **Chapters 8 to 12 and Annex A**, details the FMEA for all the sub-components and methods of diagnosing their failure modes.
- ANNEX'S, provide the tables of diagnostic information, sourced from various IEC & IEEE Guides as well as Cigré TB's, as well as expertise from the Working Group.
- **Examples on how to develop a TAI**
- An overview of some of the current documents that have been published about this topic and methodologies.

Conclusion

- This guide condenses a lot of information and knowledge into one document, that at the time of publication bears out what is known of failure modes, and methods of detecting the symptoms of these failure, and translate this into a format that can be applied across organizations.
- **It is very important at the beginning to understand WHY and for what purpose a TAI will serve**
- **The user need not wait for full condition assessment to act if smoke is observed from transformers!**

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Transformer Failure Modes

- Identify the failure modes and failure mechanisms, consequences and interventions that can be implemented to change them.
- Failure mechanisms have been categorised into
    1. Active part of the transformer into thermal, mechanical and dielectric.
    2. Bushings (and other terminals)
    3. Tap-changers
    4. Cooling systems, and the tank.
    5. Transformer dielectric fluid

*Note dielectric fluid has a special significance because it is not only critical to transformer operation and has deterioration mechanisms, but it influences the rate of deterioration of other parts most notably the solid insulation, *and it provides a vector for much of the condition information.*

- This guide does not address any economical evaluation of the different TAI purposes, it seeks to identify candidates for such evaluations.

Determine the Purpose of the TAI

- Identify the candidates that are in poor condition that **cannot** be easily repaired as these are candidates for replacement.
- To identify candidates in poor condition that **can** be easily repaired or major repair, or refurbishment.
- Ensure all users understand the purpose of the index so that it is not incorrectly used!!!

If you are developing a Replacement Index

- What are the business/technical drivers for replacement in your organisation?
    - If a Winding Temperature Indicator failed on your transformer – would you replace the transformer or replace the WTI?
    - Do not include failure modes or mechanism in the Replacement Index if they are not drivers for replacement.

Likewise for other indices

- Deciding what to include is not always easy
- Should OLTC's and bushings be included in a replacement index? These can often be replaced, but may not be economical if other work is required.

Dielectric													
Failure Mode			Degradation Mechanism	Condition Indicator	Test	Unit	Applicable to which insulation liquids?[1]	F	E	D	C	B	A	Reference
Core			Core Ground	DC Resistance	Insulation resistance	MOhms	MO, NE, SE	< 1	1 - 10	11 - 25	26 - 50	51 - 500	> 500	C57.152 Z1
Winding Insulation	Insulating Liquid		Arcing	Acetylene	DGA	ppm	MO, NE	> 50	36 - 50	11 - 35	1 - 10	< 1	Non-detectable	C57.104, IEC 60599, C57.155
			Aging, Moisture, contamination	Dissipation factor	DF @25 C	%	MO, NE, SE	See insulation liquids tables						C57.106, IEC 60422, C57.147, IEC 62975
			Partial Discharge	Hydrogen	DGA	ppm	MO, NE, SE	> 3000	1800 - 3000	700 - 1799	100 - 699	30 - 99	< 30	C57.104, IEC 60599
			Moisture Content of Liquid	Moisture Content	Karl Fisher Moisture Content	ppm	MO, NE, SE	See insulation liquids tables						C57.106, IEC 60422, C57.147, IEC 62975

Example of Annex A TRANSFORMER CONDITION ASSESSMENT TABLE

TAI is NOT for Alarm Management

- **When diagnostic information indicates a serious or severe problem – an immediate response is required.**
- Test results or other diagnostic information should be considered by an experienced transformer engineer and the appropriate action should be determined!
- A **"Mitigated Index"** may be useful in determining if the transformer should be repaired or maintained. Can be used to assess the transformer's condition after one or more problems are mitigated.

Quality & Timeliness of the data

- Cautions are pointed out regarding data quality/timeliness to develop a **QUALITY SCORE.**
- Chapter 4 '**Dealing with Uncertainty in Information**", is important to review

Dealing with Uncertainty

- The level of uncertainty is directly related to the quality and timeliness of the data used in the assessment. Unavailability or incorrect data, will adversely affect the result.
- An indication of the uncertainty should accompany an assessment or TAI, in the form of a Quality or Confidence score
- Uncertainty may be expressed using: an uncertainty index | a colour code |colour intensity | the TAI score can be shown as a range | TAI scores falls between a minimum and maximum.

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Other Considerations

- On-line monitoring devices can be a valuable tool for the condition assessment of power transformers. The assessment can be updated more frequently as updated information becomes available from the monitoring devices.
- The consequence of a transformer failure will often need to be considered in conjunction with the condition assessment. Some of the consequences of a transformer failure are listed in Chapter 6.
- The assessed relative conditions of a fleet of transformers (e.g. from a TAI or PoF) can help identify the different families of transformers that have a higher probability of failure. This information can be useful in determining repair and replacement plans, and spare transformer holding levels for reliability and budgeting purposes.
- **Users should be mindful of the complexity of calculating or estimating a probability of failure of a given apparatus and of the potential impact of other actions**

Methods of Calculating a TAI Score

- Summation of Individual FM Scores
- Weighted Average
- Non-linear mathematical Approach
- Numerical Score using PoF probabilities
- Worst case Approach
- Hybrid Score
- Count per Category
- Machine Learning

Each method is described together with advantages and disadvantages of each

Examples of each scoring method and their limitations are detailed in the guide

Conclusion

- This guide condenses a lot of information and knowledge into one document, that at the time of publication bears out what is known of failure modes, and methods of detecting the symptoms of these failure, and translate this into a format that can be applied across organizations.
- **It is very important at the beginning to understand WHY and for what purpose a TAI will serve.**
- **Equally important is to share with others in your company, the purpose of and limitations of the assessments made.**

Examples

Replace, Repair or Refurbishment Indices

Cooling System								
Failure / Degradation Mechanism	**Criteria / Condition Indicator**	**Diagnostic Method**	**Replacement Index**	**Repair Index**	**Refurbishment Index**	**Transformer 1**	**Sub-Component**	**Sub-Component Score**
Failure of fan / Pump Cooling control circuit failure Wrong direction of fan / Pump	Inadequate air or oil flow volume (overheating)	Routine Inspection and Testing, Visual Inspection	No	Yes	Yes	**Green**	**Cooling System**	**Pink**
Dirty radiators and cooling fins	Inefficient heat transfer (overheating)	Routine inspection	No	Yes	Yes	**Orange**		
Leaks caused by: galvanic corrosion thermal expansion and contraction	Lower oil level (transformer trip)		No	Yes	Yes	**Pink**		
	Moisture ingress Oxygen Ingress (Premature aging of insulation)		No	Yes	Yes	**Pink**		

Scores for Sub-Components

Sub-Component	Main Tank - Repairable	Main Tank - Non Repairable	Bushings	OLTC	OLTC Insulating Fluid	Cooling System	Tx Tank	Ancillary Comp.	Corrosive Sulphur	Mineral Oil
TX 1 Score	Pink	Pink	Orange	Orange	Pink	Pink	Pink	Green	Green	Red
TX 2 Score	Green	Green	Red	Green	Yellow	Yellow	Orange	Yellow	Green	Orange
TX 3 Score	Red	Orange	Red	Yellow	Yellow	Pink	Pink	Orange	Green	Red
TX 4 Score	Yellow	Orange	Green	Yellow	Green	Yellow	Orange	Green	Red	Yellow
TX 5 Score	Red	Red	Orange	Orange	Red	Pink	Pink	Orange	Green	Red
TX 6 Score	Yellow	Yellow	Green	Green	Yellow	Yellow	Yellow	Green	Green	Yellow
TX 7 Score	Yellow	Green	Green	Green	Yellow	Yellow	Yellow	Green	Green	Green
TX 8 Score	Pink	Red	Red	Orange	Pink	Pink	Pink	Yellow	Red	Pink
TX 9 Score	Yellow	Yellow	Green	Green	Green	Yellow	Yellow	Green	Green	Orange
TX 10 Score	Red	Orange	Orange	Yellow	Orange	Red	Red	Red	Green	Orange

Replacement Index

This example illustrates the TAI of 10 units, together with different scoring methods.

NOTE the differences in ranking based on different scoring approaches, may reorder priorities, of replacements

	Main Tank - Non Repairable	Bushings	OLTC	Simple Score
TX 1 Score	Pink	Orange	Orange	1 Pink
TX 2 Score	Green	Red	Green	1 Red
TX 3 Score	Orange	Red	Yellow	1 Red
TX 4 Score	Orange	Green	Yellow	1 Orange
TX 5 Score	Red	Orange	Orange	1 Red
TX 6 Score	Yellow	Green	Green	1 Yellow
TX 7 Score	Green	Green	Green	3 Green
TX 8 Score	Red	Red	Orange	2 Red
TX 9 Score	Yellow	Green	Green	1 Yellow
TX 10 Score	Orange	Orange	Yellow	2 Orange

Red	*Pink*	*Orange*	*Yellow*	*Green*	Simple Numeric Score	Hybrid Score	Non Linear Score
0	1	2	0	0	7	7 (Pink)	45
1	0	0	0	2	4	4 (Red)	83
1	0	1	1	0	7	7 (Red)	93
0	0	1	1	1	3	3 (Orange)	13
1	0	2	0	0	8	8 (Red)	99
0	0	0	1	2	1	1 (Yellow)	5
0	0	0	0	3	0	0 (Green)	3
2	0	1	0	0	10	10 (Red)	171
0	0	0	1	2	1	1 (Yellow)	5
0	0	2	1	0	5	5 (Orange)	21