The Condition Monitoring Maze Made Easier With a Selection Tool

By

Kerry Williams

SECOND PAGE IS LEFT BLANK

The Condition Monitoring Maze
Made easier with a Selection Tool

Kerry Williams
Western Power

Abstract

With a greater focus on condition based asset management within the electrical industry and an ever increasing number of condition monitoring products available, it is difficult for engineers to decide what is best suited for their assets. It is also difficult not only to justify what condition monitoring devices to put on any one asset, but whether the long term benefits are worth the cost of monitoring and how to standardise the condition monitoring across the asset fleet.

This paper details the development of a simple spreadsheet tool that supports the user in making such decisions. It uses an asset criticality factor to determine what level of condition monitoring is required on the asset in any given network location. The condition monitoring spreadsheet tool allows the user to input various parameters to suit the network or application. The output is a range of techniques that are ranked according to the criticality of the asset. The output provides the user with a list of highly recommended techniques, additional optional techniques and those which are not essential but may be used if desired. The net benefit is a user determined standard that outlines what condition monitoring techniques are needed for the asset. From there the asset engineer can choose from a widening range of products on the market that provide the desired techniques.

The paper discusses the various parameters that provide the input and how this impacts the criticality factor which in turn determines what techniques are recommended. The paper steps through some typical scenarios for selection condition monitoring techniques suggested for use on transformers in various network locations. It further discusses the on-going development for application on other network assets such as circuit breakers and instrument transformers.

Background

The successful transmission and distribution of electrical energy is a critical part of the world today. Customers expect their electricity to be safely distributed and highly reliable. Planned and unplanned outages in the supply are generally seen as an inconvenience for domestic customers but when it comes to larger industrial customers, major CBD businesses, essential services and critical infrastructure, the outages can have a profound impact on the way those customers perceive the supply authority. Whilst planned outages can be managed well with customers; the unplanned outages require a completely different level of management with those same customers. An unplanned outage usually occurs when an asset failure within the electrical network. The number of customers affected is directly related to the location of the fault in the network. For example, a small pole mounted transformer failure may have an impact of a local area with as few as 10 to 200 domestic customers; whereas the failure of a 500MVA transmission transformer can cause the loss of supply to hundreds of thousands of customers over a greater area. Whilst it would be ideal to be able to reduce those smaller outages by having every key asset in a distribution network condition monitored it is not very practical in terms of cost to the consumer. Therefore, the utilities invest their limited funds on the larger and more expensive assets where there is a greater "Bang for Buck".

In the CIGRE Brochure 227, Life Management Techniques for Power Transformers [1] the authors deal with reasons why condition monitoring devices are fitted to a transformer. The one clear theme that comes through is that without any indicators and a lack of basic maintenance the risk of failure increases rapidly. It is stated that the basic failure modes normally stem from reductions in dielectric and mechanical strength properties of the transformer. Figure 1 below is taken from Brochure 227 and shows that "failure occurs when the withstand strength of the transformer with respect to one of these key properties is exceeded by operational stresses" [1].

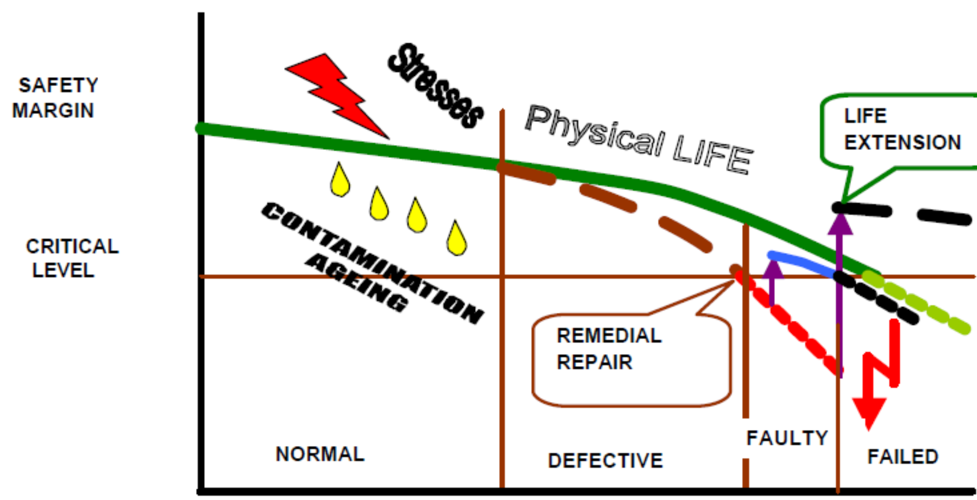

Figure 1
Condition of a Transformer in the Course of its Life Cycle [1]

Ideally, every asset in the network should be monitored and assessed in detail to correctly estimate when and how a failure might occur, so that intervention, as seen in figure 1 above, can occur before the actual failure. If sufficient condition monitoring information is obtained, an asset could either undergo maintenance or be replaced depending on the cost and likelihood of failure. Although an outage is likely to be needed it can be planned so customers get sufficient notice and the outage time is greatly reduced.

The question then is what is the best condition monitoring to do on any given asset? The answer is not so easy to obtain because asset engineers and managers are bombarded with different products that do the monitoring of all sorts of parts of their asset. In short it is a maze of techniques products and needs. What the real answer is lies in what the asset does, its criticality to the utility and application in the network. By looking at these and assessing how critical the asset is one can then decide what the best condition monitoring technique is for that asset. From understanding the best techniques for the asset, an assessment of available products can be made and thus finding a path through this seemingly endless maze.

This paper provides information on a simple spreadsheet that applies user defined parameters to help make an assessment of the most appropriate techniques for the asset. In this instance the development of the spreadsheet has been done around the application of transformers in the network. It allows an engineer to input basic information on any transformer being installed in their network and get a consistent view of the condition monitoring techniques required across the fleet.

Application of the Condition Monitoring Spreadsheet

The condition monitoring selection tool is a spreadsheet designed to be an easy-to-use and useful tool for asset management. The purpose of the spreadsheet tool is to do nothing more than to assist in the decision making process for condition monitoring techniques that could be used on a particular transformer. It has a basic enhancement that allows the user to further add to the list of devices on the market that provide some or all of the required techniques. This allows the engineer to quickly see and build a range of products that can provide the services needed. It does not look at the product cost or additional supporting data acquisition or analysis tools needed to support a product.

There has not been an attempt in this paper to detail how the techniques are used nor the details of what they are. Much of this information has been written in engineering papers over many years however, in the CIGRE Brochure 343 [2] there is a very comprehensive overview of many of the techniques mentioned in this paper. The Brochure discusses the different techniques and their advantages along with monitoring system outputs. It provides in Table 1 a summary of recommended condition monitoring facilities for various parts of a power transformer. This table and comments within the document have been used as a basis for developing this spreadsheet tool.

Benefits for the User

Having a standardised decision making process for the purchase of condition monitoring devices is extremely beneficial for the end user. Since there are so many condition monitoring techniques, it is very difficult to decide which technique should be employed in certain situations. The spreadsheet has an expandable range of techniques that have a rating and thereby recommend techniques using a standardised method across the asset fleet. When the asset manager wants to install a transformer in a given location in the network he can run the tool and use the information to justify the purchase of devices based on his predetermined standard needs for the network.

As the network evolves so can the tool as the technique ratings can be adjusted by the user. It is, however, recommended that the asset engineers develop a standard policy around the changes that can be made, how often they should be reviewed and the impacts on existing transformer monitoring techniques. Using a risk based methodology is likely to be the way forward in balancing the ratings against the network needs and failure rates. The risks associated with a particular transformer must be weighed against the additional costs when determining the monitoring technique rating. There is no point buying a great number of monitoring instruments or applying many techniques for a transformer that is likely to have a relatively easy life.

Decision Making Process Applied

There are a number of inputs implemented in the spreadsheet that are used in the decision making process. Figure 2 shows a flow diagram with inputs and outputs for the tool. The inputs are weighted and each input has a specific rating that is calculated. For a complete list of weightings and ratings see Figure 4 in Appendix A. The ratings can be reviewed by the end user so that they reflect the importance that the users place on specific criteria.

The user must fill data in each field highlighted so that a rating can be calculated for each field. These input fields are rated in terms of importance and from this and the weighting, an overall importance or criticality factor for the transformer can be found.

For example, if the user enters 20MVA as the MVA rating of the transformer, a rating of 3 is given for that input. This number is then multiplied by the weighting which is 12%. So 0.36 is the weighted rating of that input. This is done for every input and all the weighted ratings are added to obtain the overall criticality rating for the transformer. The Criticality Factor is based on a scale of 1 to 10 with 10 being the most critical. Factors such as transformer age, overload frequency, network redundancy and location in the network are taken into account when assessing the overall criticality of the transformer. The “End User Importance” is very much a judgement call by the engineer as it relates to the application of the transformer. That is, the unit may be critical with significant outage constraints to a unit that is low importance with good levels of spare capacity in the network.

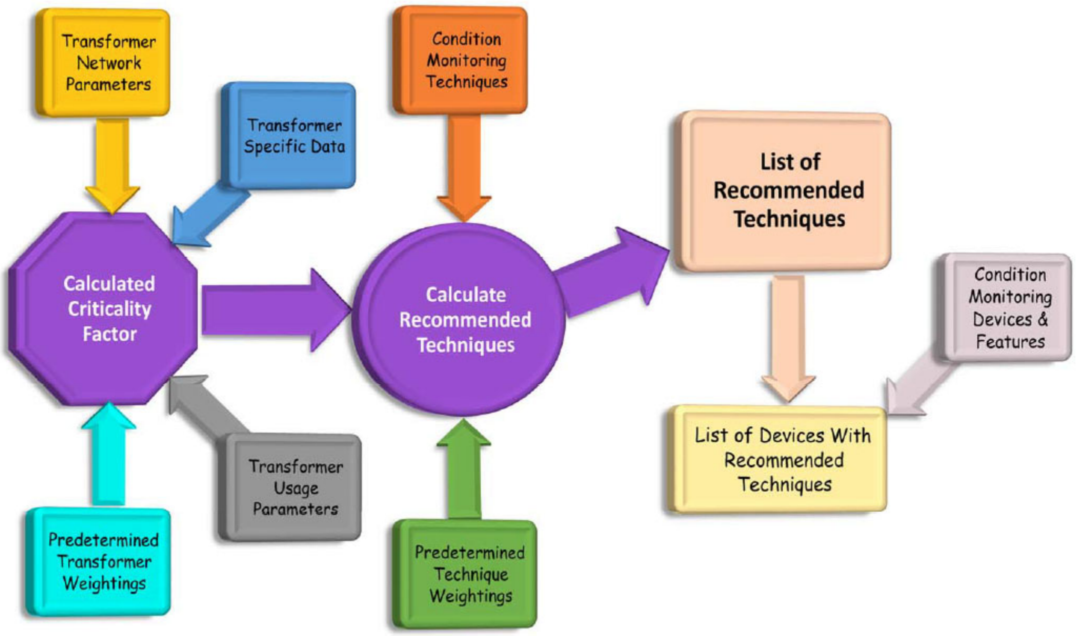

Figure 2
Decision Making Process of Transformer Condition Monitoring Selection Tool

Figure 3, below, shows the Weightings of User Inputs that contribute to the overall importance or criticality of the transformer. These weightings can be adjusted according to the user's needs; however, it can have a significant influence on the value of the Criticality Factor. Sound judgement needs to be used when assessing the value of the weighting applied to each of these inputs. From Figure 3 it can be seen that by changing the distribution of the weightings the end user can have greater influence over the importance of specific transformer parameters within the network. That is, if more weighting where applied to the Cost of the Transformer then a lesser value must be placed on another parameter.

Once all these factors are weighted and analysed the spreadsheet automatically calculates the Criticality Factor which is then used as an input to the Condition Monitoring Technique analysis and selection. The second worksheet displays a recommendation of all the features that could be installed on the transformer. The number and type of these features are directly related to the importance of the transformer, the cost of the technique, ease of fitting, and data management.

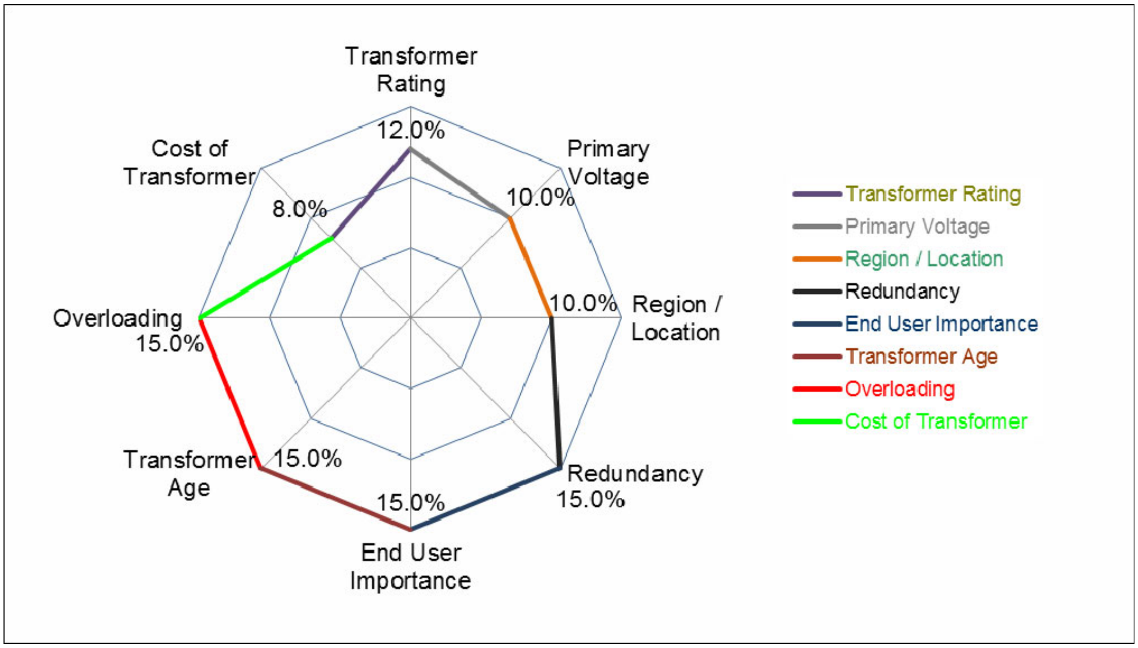

Figure 3
Weighting of User Inputs

The worksheet displays the features in different colours depending on the recommendation with the recommendation levels being:

- Highly Recommended – Features that definitely should be employed
- Recommended – Features that should be employed if cost and need is justified
- Useful – Features that are useful but not necessary to have and would not add value to the monitoring.

A worksheet titled “Features List” can be maintained by the user to add or delete features and if desired to change the ratings of the techniques. The list can have hundreds of techniques if desired. This way the user can better target the features or techniques that are not only important to their company but those for which they have the capability to manage and analyse the data. By changing the ratings the user can also have a direct impact on what techniques should be fitted to transformers in their network. It should be noted that this list also allows the user to review what products maybe on the market that provide all or some of the recommended techniques. Figure 5 in Appendix A provides a basic list of these techniques and there ratings. The “Update” button sorts the list into alphabetical order for ease of use.

The features list does not necessarily need to be defined for on-line or off line monitoring and can include testing techniques such as OLTC resistance, SFRA, DLA and many others as desired.

There is a worksheet which displays a list of devices that are available from suppliers. This list is far from complete and is designed to be expandable so the user can add products as they find them. Once the recommended features have been highlighted then the “Update” button at the top of this worksheet will highlight the recommended techniques so it is easy to see which products have them. The user can then easily research these products to understand if that product is suitable to their system needs. There is no intention here to include or exclude any specific product and this sheet is user dependant. The more products added here the wider the options the end user can choose from. There is an issue with this type of feature in that it does require regular maintenance and the need to ensure product features are kept up to date.

Information Management

The condition monitoring spreadsheet outputs its recommendations according to the calculated importance or criticality of the transformer. It may be useful to use this Criticality Factor and possibly some of the ratings for the transformer for applications outside this application; however this would be entirely at the end users discretion. The list of condition monitoring techniques provided as an output of this spreadsheet is a good indicator of which types of techniques are suitable for a transformer in any given network application. The spreadsheet tool does not extend to information management and many utilities struggle with managing their data. To coin a phrase: “We are drowning in data but starving for information”. Therefore this simple selection tools does as it says only provides a method by which to standardise the selection of condition monitoring techniques across a fleet of transformers. It does not go beyond the techniques to delve into how products deliver their data or how the utility needs to manage that data. This is an area where the engineer needs to understand what the features within the product delivers and how they can interface that data with their analysis tools. This part of the condition monitoring maze is probably the most significant and will no doubt be the subject of much research in years to come.

Future Directions

There are many aspects of this spreadsheet tool that could be expanded or redeveloped for improvement into the future. The decision making process is one of these areas. In the future, a number of inputs could be added that would be useful in determining the criticality of the transformer. This could increase the accuracy of the decision making process. For example, inputs such as the history of the transformer can be implemented to take into account elements such as what kind of life the transformer has had. A transformer with a hard life would be more prone to failures. Much of the assessment of the input data could be based on a risk matrix that allows the weightings and ratings to be adjusted according to the risk profile of the asset. Whilst the author has not provided full details of how this could be done there has been some work done in that area to obtain some of the key ratings given in the tool.

The techniques and devices lists should also be expanded but as stated previously this will require considerable maintenance as the available techniques and products increase. To assist with clarity for this paper many condition monitoring techniques have not been listed in the spreadsheet, however a sheet in use to trial the effectiveness has a good deal more techniques listed.

At present, the spreadsheet does not define any differences between online and off line condition monitoring other than in wording or engineering knowledge. These could well be separated into differing categories and allow for a better understanding of when best to apply a specific technique.

Conclusion

Condition monitoring is extremely important in assessing the life of the transformer and this is evident with the experiences throughout the power industry. CIGRE Working Groups have studied and published Brochures on the subject and confirm there are many techniques that can be used. It is daunting for asset managers to decide when and how often to use a particular technique and for this reason the Condition Monitoring Selection Tool was developed to aid asset managers in this decision making process. The spreadsheet calculates a criticality rating for a particular transformer in a particular location and automatically recommends condition monitoring techniques. This information can then be used in reducing the effort in selecting techniques for the transformer fleet. It will allow the asset engineer to have visibility of what techniques are considered important when purchasing a new unit or relocating a unit within the network. Network parameters are used to help in the process as two identical transformers used in different locations within a network may well have differing condition monitoring needs.

In conclusion, this Condition Monitoring Selection Tool was developed to help find a way through the maze of techniques and decide how and when they should be used. An added benefit is that it allows assessment of what products may be purchased for fitting to the transformer to deliver the desired result.

Appendix A – Details of Weights and Ratings Criteria.

Transformer Rating (MVA) -	Weighting:	12%	Rating
0 -> 10			1
10 -> 25			3
25 -> 40			5
40 -> 80			6
80 - > 150			8
150 -> 300			9
300+			10
Primary Voltage (kV) -	**Weighting:**	**10%**	**Rating**
<11			1
11 & 22			2
33			3
66			5
110 & 132			7
220 & 275			9
>275			10
Region/Location -	**Weighting:**	**10%**	**Rating**
Rural/Remote			2
Urban			4
Small Township (<500)			5
Large Industrial			7
Large Township (>500 <5000)			8
CBD			10
Redundancy -	**Weighting:**	**15%**	**Rating**
n			10
n - 1			5
n - 2			1
End User Importance -	**Weighting:**	**15%**	**Rating**
Low importance - good spare capacity			1
Normal Importance - spare capacity avialable			4
Important Unit - Low spare capacity available			7
Critical Network Unit - outage constrained			10
Transformer Age -	**Weighting:**	**15%**	**Rating**
New or < 2 years			8
> 2 & < 10years			4
> 10 & < 15years			5
> 15 & < 20years			6
> 20 years			8
Refurb < 2years ago			7
Refurb 2-5 years ago			6
Refurb > 5years ago			5
Overloading -	**Weighting:**	**15%**	**Rating**
Rare			1
< 2 per year			2
2 or 3 times per year			4
> 3 to 6 times per year			6
> 6 < 12 times per year			8
>12 times per year			10
Cost of Transformer -	**Weighting:**	**8%**	**Rating**
below $100,000			1
$100,000 to $499,999			4
$500,000 to $ 1 million			7
Above $1 million			10

Figure 4
List of Ratings and Weightings applied to selection criteria

Condition Monitoring Techniques	Rating
Acetylene Monitoring	9
Acoustic Partial Discharge	5
Ambient Temperature	10
Bottom oil temperature	10
Bushing DLA	8
Calculated Hwinding temperature (load current)	4
Calculated Xwinding temperature (load current)	4
Calculated Ywinding temperature (load current)	4
Carbon Dioxide Monitoring	9
Carbon Monoxide Monitoring	9
Cooling Bank Currents	7
Cooling Bank Motor currents	2
Cooling System Monitoring	1
Dissolved Gas Analysis (DGA)	10
DLA measurements	9
Ethane Monitoring	9
Ethylene Monitoring	9
Fibre optic temperature probes	5
Hydrogen Monitoring	9
Main tank, OLTC tank temperature difference	7
Make and break load currents of each tap	3
Methane Monitoring	9
Moisture in oil probe	6
Moisture Monitoring	9
Number of tap changes history	6
OLTC Motor steady state and inrush currents	5
OLTC Resistance measurements	9
OLTC tank temperature	8
OLTC Vibration Monitoring	8
On Line Bushing PD monitoring	8
Oxygen Monitoring	9
Ratio Test	9
Simulated Hwinding temperature	2
Simulated Winding temperature	2
Simulated Xwinding temperature	2
Simulated Ywinding temperature	2
Sweep Frequency Response Test	7
Top oil temperature	10

Ratings are from 1 to 10 with 10 being the highest rating.

Update

Figure 5
Basic Condition Monitoring Techniques List with Ratings

Acknowledgements

The author would like to acknowledge the assistance of Mr Harshana Edirisinghe and Mr Murali Govindaswamy for their assistance in helping with the rewriting and debugging of my poorly written macros within the worksheet. Their assistance has helped develop this from a simple idea and rough working model into a more efficient 2nd generation tools.
Additionally I would like to acknowledge Mr Brad Trethewey for his wonderful saying: "We are drowning in data but starving for information" to which I often refer.

References

1. CIGRE Working Group A2.18, *"Life Management Techniques for Power Transformers",* CIGRE Brochure 227, June 2003.

2. CIGRE Working Group A2.27, *"Recommendations for Condition Monitoring and Condition Assessment Facilities for Transformers",* CIGRE Brochure 343, April 2008.

Biography

Kerry is a Team Leader in the Operational asset Assessment Group of Western Power. He has worked in the power industry since 1975 and has been able to develop an extensive background in substation and transformer design, manufacturing, refurbishment and maintenance. In his many roles, Kerry has been responsible for innovation, development and implementation of new technologies and plant into Power Utilities. In his current role he is responsible for a team of professional engineers who manage the transmission and distribution assets and maintenance of plant within Western Power's substations.

Kerry recently completed a Master of Power systems at University of Southern Qld, he has a degree in Electrical Engineering, certification as a Project Management Professional, is an Associate Fellow of the Australian Institute of Management and Member of Engineers Australia and IEEE. He is the author of a number of engineering papers on subjects such as mobile substations, condition monitoring techniques, switchgear failures and applications, and modular systems for substation maintenance and network support.