Doble PRIME Transformer Aging Analysis

Doble PRIME & Transformer Aging

Doble PRIME Analytics accepts transformer load and temperature information to allow for calculation of transformer ageing factors and loss of life according to IEEE standards; the calculations are refined by factors for both oxygen and moisture. Analysis includes an ability to perform 'what if' calculations on future load cycles.

Transformer Ageing

As transformers age, their paper insulation degrades through the effects of heat, moisture and oxygen, weakening the transformer. The three parameters reduce the strength of the paper insulation by causing the molecular chains within the paper to break – reducing the degree of polymerization (dP) of the paper[1]. Standards such as IEEE C57.91 (2011) indicate how to calculate loss of life through an accelerated ageing factor (F_{AA}) based on the transformer hotspot temperature, which may be measured or calculated.

$$F_{AA} = e^{\left[\frac{15000}{110+273} - \frac{15000}{HST+273}\right]}$$

HST is the hot spot temperature – measured if fiber optic sensors are available, calculated if top oil and load values are available. Oxygen acceleration factor is given by a value between 1 and 3, depending on the level of oxygen within the unit. Moisture acceleration factors depend on the weight of moisture, as a percent, in dry paper:

$$C_{paper} = 2.173 \times 10^{-7} \times e^{\left[\frac{4725.6}{(T+273)}\right]} \times \left(\frac{C_{oil}}{18 \times 0.702 \times e^{\left[\frac{1498}{(T+273)}\right]}} \right)^{0.6685} \times 100$$

With the resulting Moisture acceleration factor, MAAF:

$$M_{AAF} = 0.72 + 0.934 \times C_{paper}$$

Data from SCADA is used to supply load, and temperature information where available. Condition monitoring will supply moisture, oxygen and may be used to calculate temperature data. The calculation of the loss of life is performed through the Doble PRIME Analytics.

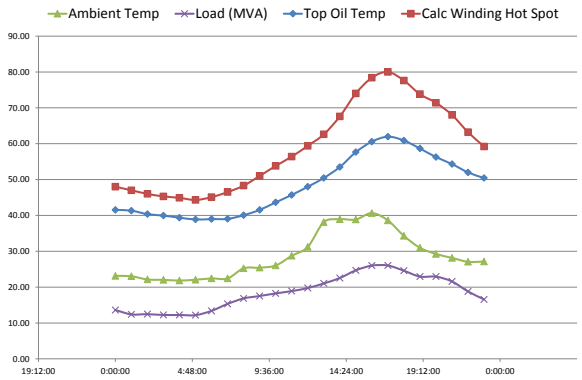
Doble PRIME Analytics

Doble PRIME is a state of the art condition monitoring platform which uses advanced analysis of condition data to give actionable information in a timely manner. The Analytics unit also includes its own analog and digital I/O and extensive communication/hub capabilities and data back up; Doble PRIME Analytics will accept data from any standard condition monitoring device.

Calculation Requirements

Winding Hot Spot

The first requirement is to perform load cycle calculations to generate HST values. The figure shows the calculated hot spot temperature for a combination of ambient and top oil temperatures and load. Data is displayed through a built in web server and native graphics, with results exportable to be used in spreadsheets, or other applications.



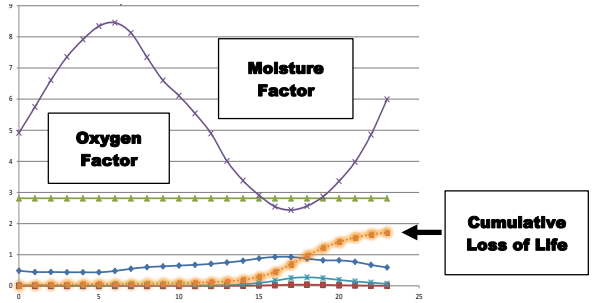
The calculation of HST can also be used in 'what if' calculations where predicted load and predicted ambient are used with known transformer load response curves. Predicted HST and subsequent loss of life calculations require transformer nameplate data and heat run data. These values may not be available, and estimated or

[1] Lewand "Assessment of Bushing Paper Through Degree of Polymerization (DP) Analysis" , 2013 Doble Client Conference,

default values used, but the resulting calculations are less precise.

Ageing Factor Calculations

Doble PRIME Analytics uses measured values of oxygen and moisture, and the measured or calculated value for HST, to calculate the accelerated aging factor and associated moisture and oxygen factors. These are used to calculate the loss of life for a transformer. In the chart below, the data is used to give a cumulative loss of life in per unit values. In this case, over a 24 hour period, the cumulative loss of life of the unit is 1.75 pu, or 40 hours.



Calculation of loss of life is one aspect of transformer calculations; the same data can be used to calculate the risk of bubble formation.

Bubble Formation Calculations

Doble PRIME Analytics performs a bubble formation calculation in line with C57.91. Predicting the hot spot temperature, and knowing the local atmospheric pressure and the dissolved gas content, a bubble formation temperature may be calculated[2]. Loading may then be managed to reduce risk of bubble formation.

$$\theta_{bubble} = \left[\frac{6996.7}{22.454 + 1.4495 \ln W_{WP} - \ln P_{pres}}\right] - \left[\left(e^{0.473 W_{WP}}\right)\left(\frac{V_g^{1.585}}{30}\right)\right] - 273$$

The calculations are predictive, identifying at which level of load bubbles are likely to form – a 'what if' calculation.

Transformer Performance Prediction

Each utility or operator has its own guidelines and standards for transformer operational limits: hot spot temperature, top oil temperature, loss of life per 24 hours. By using 'what if' analyses on transformers, based on latest loading, condition and temperature information, Doble PRIME Analytics may determine where optimal loading lies. The Doble PRIME Analytics approach is to calculate predicted losses for a range of load values, predicting resulting temperatures and ageing factors.

Yellow	120.00	105.00						1750	10
Red	130.00	110.00						1800	1
Maxpu	Max HS	Max Top Fluid	Thermal Equivalent aging hours	Thermal aging factor	Avge O2 multiplier	Average H2O multiplier	Overall aging factor	Overall Equivalent loss of life hours	Hot Spot θ above Bubble θ
0.701695	84.78	71.79	0.32	0.01	2.81	4.13	0.96	2.69	94.64
0.845951	87.27	74.37	0.44	0.02	2.81	4.04	1.18	3.33	88.57
0.990207	91.30	78.16	0.71	0.03	2.81	3.95	1.61	4.53	79.12
1.134463	101.24	83.94	1.36	0.06	2.81	3.88	2.45	6.91	67.78
1.278719	112.27	91.20	3.07	0.13	2.81	3.81	4.18	11.77	53.42
1.422976	124.29	99.41	7.86	0.33	2.81	3.77	8.99	25.30	38.31
1.567232	137.32	108.57	21.95	0.91	2.81	3.75	23.18	65.23	23.41
1.711488	151.43	118.71	64.85	2.70	2.81	3.72	65.92	185.47	7.51
1.855744	166.68	129.89	198.78	8.28	2.81	3.70	200.01	562.76	-8.41

Where a particular limit is exceeded, the data is colored red; where we are approaching the limit, data is colored yellow. This gives a broad indication of how much load can be added to a transformer under spike or increased ambient temperature conditions.

Doble PRIME Condition Monitoring

Doble PRIME Analytics is one module in the Doble PRIME range, which includes the PD Guard, the IDD bushing monitor and the Delphi DGA and Domino Moisture in oil devices. The Doble PRIME range provides comprehensive condition monitoring and data analysis for transformers and other substation assets.

Doble Expertise

More than any other company in the world, Doble experts have been dealing with issues in transformers and insulating fluids for over 80 years. Doble is always willing to help our customers with the equipment that we provide and interpretation of data from the Doble PRIME sensors.

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[2]Yturralde, Lukin: "Transformer Operations & Loading – A User's Perspective", 2013 Doble Client Conference, Boston, MA