

Transformer Loading Evaluation Using Enhanced Condition Monitoring

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Loading of transformers to nameplate value and beyond has been the subject of loading guides and standards, such as C57-91, recently revised and republished in March of 2012. Such guides provide a means to determine the loss of life of a transformer based on thermal considerations. Work at San Diego Gas and Electric, in partnership with Doble Engineering, has developed practical algorithms to extend the loss of life calculations to account for the deleterious effects of moisture and oxygen. Understanding hot spot temperature, combined with the moisture and oxygen content of the oil, predictive loss of life for various scenarios can be calculated. The effects of dissolved gases are monitored to allow for variation in the steady state of the transformer. Together, the project team has linked condition data to SCADA data to allow for automatic update and 'what if?' scenario analysis under high system stress conditions. The results were successfully validated against data measured from sensors installed on SDG&E's transformers. The ideas, challenges, results and benefits will be presented and discussed.

Thermal modeling requires the following: ambient temperature and load profiles, nameplate data, and factory test report values. The model calculates hot spot and top oil temperatures, as well as thermal aging factors. It has the ability of integrating with real-time data for forecasting/predictive analysis capability, can be used to analyze historical performance and used to evaluate temperature gauge accuracy.

Figure 1 shows the two thermal models, A and B, that were evaluated and compared to actual thermal well hot spot and top oil temperatures values. The results show that model A, which was developed using IEEE C57.91 Annex G [1], correlated very closely to the actual hot spot winding temperatures and was then selected as the preferred simulation method/model. Although SDG&E has the top oil and hot spot temperatures available in real-time, in order to do any type of predictive analytical studies, reliable calculated temperatures are needed. Calculating top oil and hot spot temperatures allows for dynamic rating capability where predictive temperature values are necessary. SDG&E chose model A which came very close to the actual measured thermal well values [2].

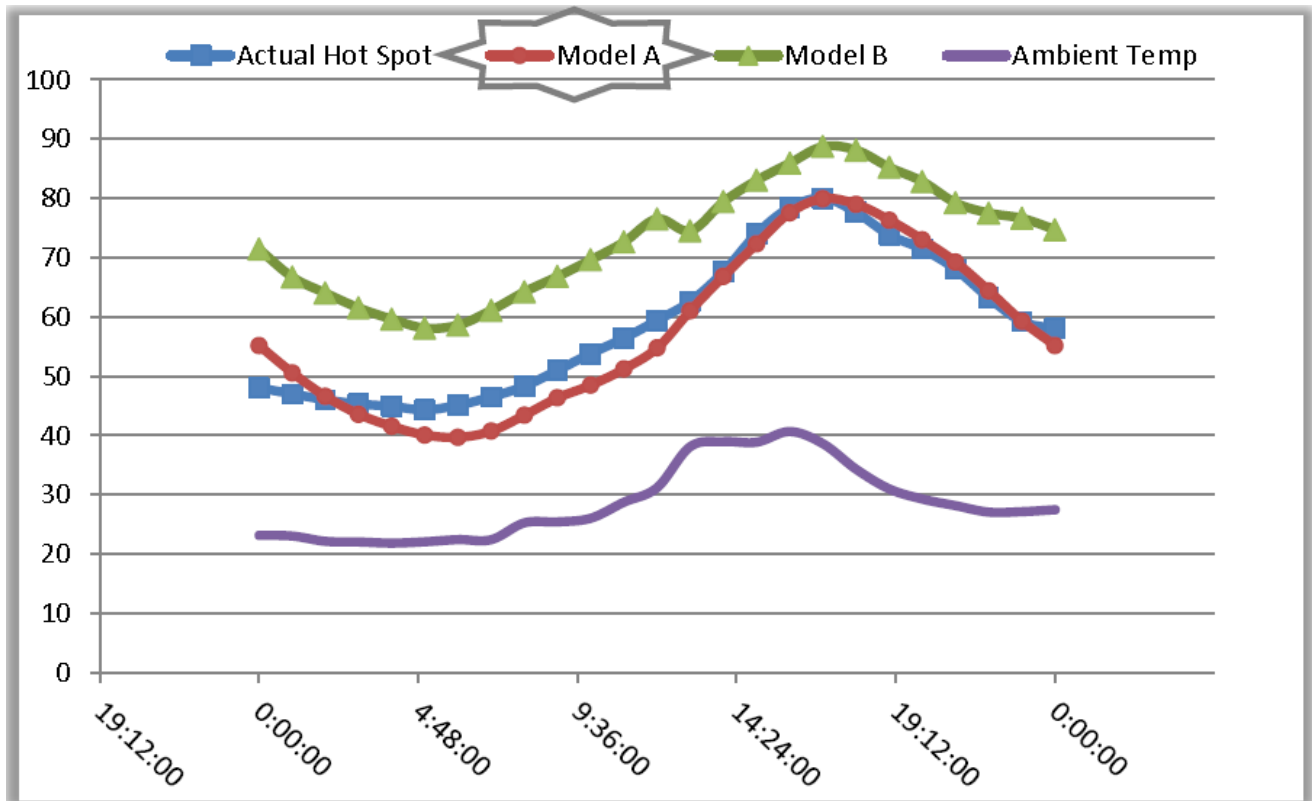


Figure 1: Thermal Model Comparisons

The aging of transformer insulation is influenced by three processes: pyrolysis, hydrolysis, and oxidation. Pyrolysis is the heating of the paper insulation. Hydrolysis is the deterioration of the insulation due to moisture in the paper and oil, which can cause aging to be increased by a factor of between 10-15 when water reaches 3%. Oxidation is the introduction of oxygen to the oil, which can increase aging 2-3 times [3].

To estimate the loss-of-life (LOL) due to pyrolysis, a thermal accelerated aging factor, FAA from IEEE C57.91 is calculated and is a function of the real-time hot spot temperature. For the LOL due to oxidation, the calculation uses W.J. McNutt's oxygen acceleration factors for Kraft paper which is based on the measured oxygen level. The losses for thermally upgraded (TU) paper are less than that of simple Kraft paper. [4]

To estimate loss of life due to the effects of moisture at particular oil temperatures, a formula published by Electric Power Research Institute (EPRI) was used to estimate the percentage of moisture in the paper. The equation uses oil temperature and moisture in the oil, both real-time values. [5]

To understand how transformer loading accurately ages a transformer in real time, SDG&E uses online condition monitoring data, in conjunction with SCADA data, to calculate an approximation of how many hours of life the transformer loses per hour of overload condition. Some of the required inputs include ambient temperature, top oil temperature, load in MVA and per unit, water content of the oil, oxygen content in ppm, carbon monoxide, carbon dioxide, and nitrogen. These inputs can be used to estimate the loss of life due to hydrolysis, pyrolysis, and oxidation. Figure 2 below details some of the inputs necessary to calculate thermal loss of life.

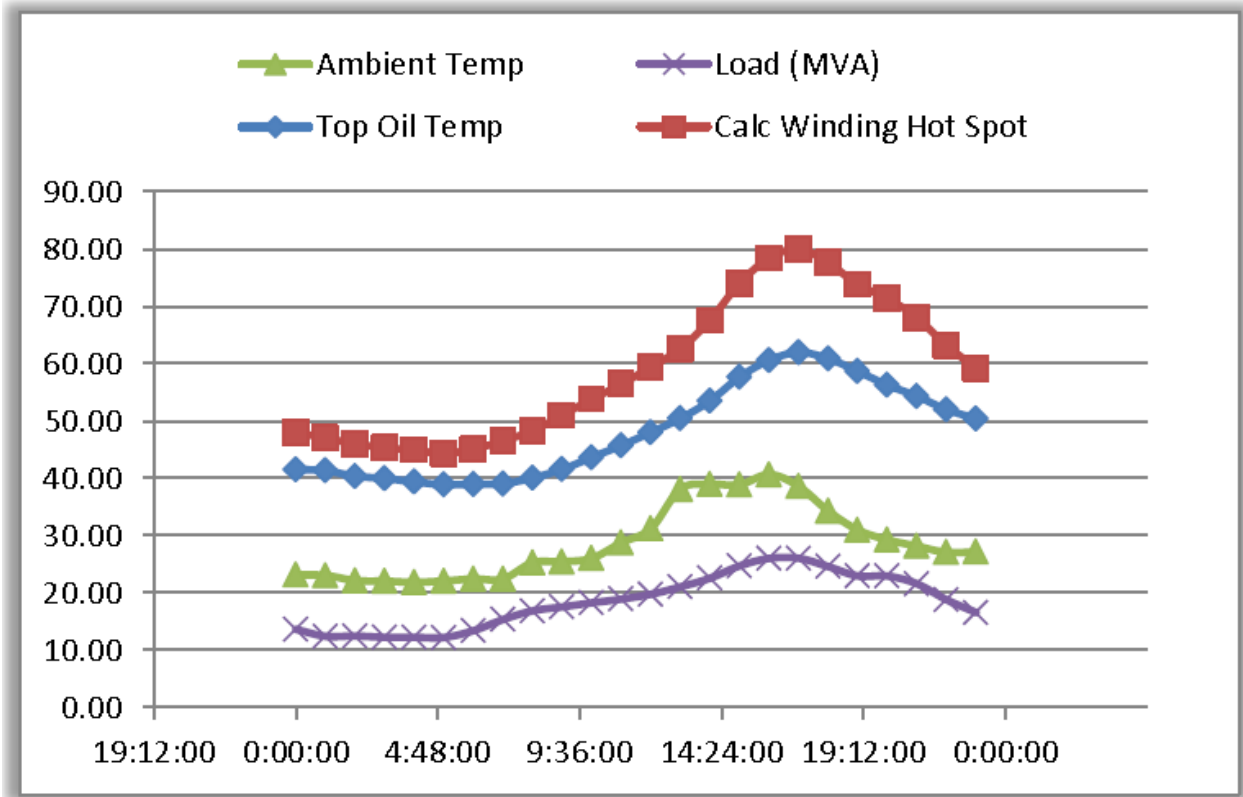


Figure 2: Inputs to Thermal Loss of Life calculation over a 24 hour period

SDG&E uses the calculations to determine dynamic ratings of transformers, based on current conditions. These are based on normal life expectancy, planned loading beyond nameplate, long term emergency loading, and short term emergency loading. It is important for an organization to have these determinations made before emergency conditions occur, and transformers need to be loaded beyond their rated capabilities. To determine how much load a transformer can safely handle, it is important to understand what the limiting factors are. What is the ambient temperature now, and expected to be over the duration of the overload? What is the current loading? How much insulation life are we willing to lose? What temperatures are too high for the top oil and windings? The algorithms developed based on the IEEE C57.91 guide give the user the ability to specify ranges on the limiting factors, run overload calculations, and visualize where the limiting factors can come into play. An example is shown in Figure 3 below, where the high limit is shown in yellow, and the upper high limit is shown in red. The user can enter their limits at the top of the chart, run the calculation, and see in the results where their limits were exceeded.

Yellow		120.00	105.00			1750	10
Red		130.00	110.00			1800	2
Maxpu	Maxactual	MaxHS	MaxTop Fluid	Thermal Equivalent aging hours	Extra Hours lost for O2 & H2O	Overall Equivalent loss of life hours	Bubble θ above Hot Spot θ
1.0007418	28.020771	91.25	77.83	0.66	3.68	4.34	54.85
0.9491147	26.575212	84.78	71.79	0.32	2.37	2.69	61.47
0.9491147	26.58	87.27	74.37	0.44	2.89	3.33	59.36
0.9902073	27.73	91.30	78.16	0.71	3.82	4.53	54.93
1.1344634	31.76	101.24	83.94	1.36	5.55	6.91	44.84
1.2787195	35.80	112.27	91.20	3.07	8.70	11.77	33.80
1.4229756	39.843317	124.29	99.41	7.86	17.44	25.30	21.78
1.5672317	43.882487	137.32	108.57	21.95	43.28	65.23	8.75
1.7114878	47.921658	151.43	118.71	64.85	120.62	185.47	-5.36

Figure 3: Results of Overload Calculations, With Limiting Factors Applied

CONCLUSION

With the proper information, transformer loss of life can be estimated based on real time conditions. Using this knowledge, transformers can be properly rated for overload conditions, using limiting factors to determine how far it can be safely loaded. This allows for improved utilization of existing assets, as well as the ability to plan and/or defer replacement when necessary.

REFERENCES

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- [5] EPRI, “Guidelines for the Life Extension of Substation Equipment”, 2009 Technical Content and Practices Update, Volume 1, December 2009, pp1-80

BIOGRAPHY

William Yturalde holds a Master’s Degree in Power Engineering from the University of Southern California. He is a Principal Engineer for San Diego Gas & Electric’s Substation Construction & Maintenance Department where he focuses on asset management responsibilities, replacement of obsolete substation equipment, and the development of analytics for transformer monitoring using SDG&E’s CBM system. In his 5 year experience he has worked in Substation Engineering, Transmission and Distribution Planning, District Operations, and was a key player in initiating activities that lead to SDG&E’s Interconnection with Mexico. He is an active member of IEEE and a licensed engineer in the state of California.

Kristina Lukin holds a Bachelor of Science degree in electrical engineering from California State Polytechnic University of Pomona with a specialization in power systems. She’s been an engineer with San Diego Gas & Electric (SDG&E) for 3 years and has worked in various areas of the company including substation asset management, the electric vehicle program under the customer innovations department, system protection and control engineering, and most currently substation construction and maintenance. Her current responsibilities include implementing projects that yield substation reliability improvements, assessing the health and risk of substation equipment, replacement of obsolete substation equipment, equipment failure investigations, and developing analytics for transformer aging and health monitoring by utilizing SDG&E’s CBM system.

Kenneth R. Elkinson, P.E., received his Bachelor of Science in Electrical Engineering degree from the University of Massachusetts at Lowell. Kenneth has held a number of positions at Doble Engineering, as Field Engineer, Client Service Engineer, and now Apparatus Analytics Engineer. Previously, Kenneth worked with National Grid in the US as a Substation Engineer. Mr. Elkinson is a licensed Professional Engineer in the state of Massachusetts.

Tony McGrail is the Doble Engineering Solutions Manager for On-Line diagnostics, providing condition, criticality and risk analysis for utility companies. Previously, Tony has spent over 10 years with National Grid in the UK and the US; he has been both a substation equipment specialist, with a focus on power transformers, circuit breakers and integrated condition monitoring, and has also taken on the role of substation asset manager and distribution asset manager, identifying risks and opportunities for investment in an ageing infrastructure. Tony is a Fellow of the IET, a member of the IEEE, ASTM, CIGRE and the IAM, is currently on the Doble Client Committee on Asset and Maintenance Management, and a contributor to SFRA and other standards. His initial degree was in Physics, supplemented by an MS and a PhD in EE and an MBA. Tony has a commitment to lifelong learning and is an Adjunct Professor at Worcester Polytechnic Institute, MA, leading courses in power systems analysis and Distribution Design.