A Solution for the Efficient Utilization of Power Transformers

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Background

Overloading power transformers beyond nameplate rating has commonly been used by utilities to mitigate contingency conditions. However, inadequate condition monitoring regularly leads to premature ageing and increased operational and maintenance costs. The model proposed uses winding hotspot and insulation ageing calculations outlined in IEC Standard 60076-7 to determine the maximum load a transformer can withstand for short periods of time. The model uses transformer loads, ambient temperature, transformer specifications and factory heat run test results sourced from three sites in regional NSW. The temperature modeling equations are applied to three network operation areas: Real time network monitoring, network outages and network planning

Transformer Ageing

The stresses placed on in service transformers range from dielectric and thermal stresses to mechanical impacts and chemical changes [1]. Ageing occurs in all components of a transformer, however due to the relatively slow ageing of the metallic structures, transformer life is dependent on the health of the Insulating mediums; the paper and oil. The degradation of the paper-oil insulation system is attributed to three processes, hydrolysis (water), oxidation (oxygen) and pyrolysis (heat)[2]]. While exposure to water and oxygen can be controlled, temperature is dependent on transformer loading with the highest rate of thermal ageing occurring at the point experiencing the highest insulation temperature. Known as the hot spot temperature, it provides a good correlation with the relative ageing and loading capacity of a transformer.

Temperature Modeling

The top oil and hotspot temperature can be modeled using the differential solution outlined in the IEC standard 60076-7[2].

$$\theta_{TO}(t) = \left[\frac{1+K^2R}{1+R}\right]^x \times \Delta\theta_{or} + \theta_a + \frac{dt}{k_{11}\tau_o}\left\{\left[\frac{1+K^2R}{1+R}\right]^x \times \Delta\theta_{TO,R} - [\theta_{TO}(t) - \theta_a]\right\}$$

$$\Delta\theta_H(t) = \left[k_{21} \times K^y \times (\Delta\theta_{H,R}) + \frac{dt}{k_{22}\tau_w}[k_{21} \times K^y \times \Delta\theta_{H,R} - \Delta\theta_{H1}(t)]\right] - \left[(k_{21}-1) \times K^y \times (\Delta\theta_{H,R}) + \frac{k_{22}dt}{\tau_o}\{(k_{21}-1) \times K^y \times \Delta\theta_{H,R} - \Delta\theta_{H2}(t)\}\right]$$

Where,

$\theta_o(t)$ – *Hotspot temperature (°C)*

$\Delta\theta_o(t)$ – *Hotspot temperature rise over top oil (°C)*

$\Delta\theta_{H1}(t)$ – *Fundamental hotspot temperature rise over top oil (°C)*

$\Delta\theta_{H2}(t)$ – *Hotspot temperature rise (flow rate of oilpast hotspot)(°C)*

$\Delta\theta_{H,R}$ – *Rated hotspot temperature rise over top oil (°C)*

$\theta_{TO}(t)$ – *Top oil temperature (°C)*

$\Delta\theta_{TO,R}$ – *Rated top oil temperature rise ove ambient (°C)*

θ_a – *Ambient temperature (°C)*

R – *Ratio of load losses to no load losses = $\frac{Load\ loss}{No\ load\ loss}$*

K – *Load factor = $\frac{Load}{Rated\ load}$*

x – *Oil exponent*

y – *Winding exponent*

k_{11}, k_{21}, k_{22} – *Thermal constants*
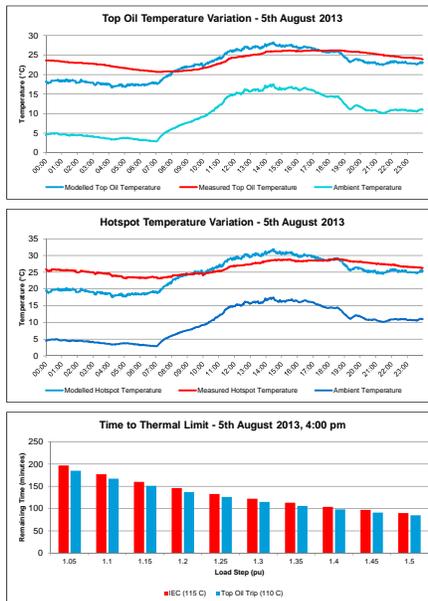
dt – *Sampling interval (min)*

Thermal Modeling Program

Real-time Monitoring Module

Continuously monitoring the thermal performance of transformers can provide important insights into developing overloads, overuse, and accelerated ageing. Anticipating the impact of impending load steps before they occur can also give system operators time to take preventative action.

The real time loading module is designed for the control room space. Its primary function is assessing the current condition of transformer assets by providing real time ambient, top oil and winding hotspot temperatures. Relative and cumulative ageing calculations and the remaining time of operation for different step loads are also assessed to enhance transparency.

The transformer selected to demonstrate the real time monitoring module wasTX2 at Coleambally Zone Substation. The graphs below show the variation between the modeled top oil and hotspot temperature and the values measured directly using thermal sensors. The bottom bar chart shows the remaining time to limit for a number of load step jumps.

Top Oil Temperature Variation - 5th August 2013

Hotspot Temperature Variation - 5th August 2013

Time to Thermal Limit - 5th August 2013, 4:00 pm

Network Outages Module

The network outages module allows system operators and control room engineers to understand the stresses placed on transformer assets as a result of network switching and system outages.

Given the date, time, duration and size of load transfer, the top oil and hotspot temperatures and resultant thermal ageing are calculated. The program uses historical transformer load and ambient temperature data to predict the pre event conditions.

Test Case: 19th Octoberr,10:00am
Pre-Event Loading: 6.72 MVA
Load Transfer : 30 MVA, 6hrs

Transformer Load
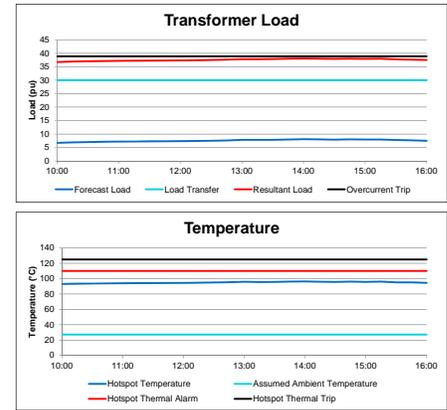
Temperature

Results:
Maximum Load: 38.05
Maximum Top Oil Temperature: 90.47 °C
Maximum Hotspot Temperature: 96.36 °C
Total Ageing : 4.44hrs

Network Planning Module

Traditionally, DNSP's use a probabilistic approach when planning electricity networks, relying on the nameplate rating of transformers to determine whether they can accommodate increases in demand. Such an approach assumes the system peak provided in the demand forecast must be maintained continuously. In reality such peaks may only last for several hours per year. Given the large thermal inertia of large power transformers, demand peaks exceeding the nameplate rating of a transformer can be safely supplied for short periods of time without exceeding the thermal limits.

The planning module provides short-time and long-time emergency ratings based on the transformers thermal limits to maximize transformer utilisation. By comparing the demand forecast with the short and long-time emergency ratings of a transformer, network planners can defer expensive network upgrades and reduce capital investment.

Forecast Demand
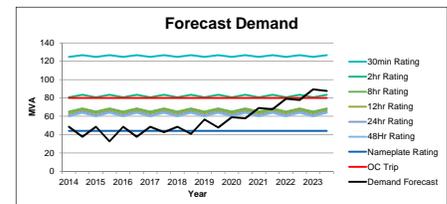
References
[1] - E. C. Z. Radakovic, K. Feser, "The influence of transformer loading to the ageing of the oil-paper insulation," presented at the XIII International Symposium on High Voltage Engineering, Rotterdam, Netherlands, 2003.
[2] - IEC, "Power Transformers," in *Loading guide for oil immersed*, ed. Geneva, Switzerland: IEC, 2005.