The Doble Engineering Company

Study Committee B3

Substations and Electrical Installations

Paper ID 288

Lessons from Action Planning Based on Transformer Condition Monitoring

Phillip PROUT[1], Steven RHOADS[1], Jamie BEARDSALL[2], Mark ROWBOTTOM[2], Tommy SALMON[3], Tony MCGRAIL[4], Philip BOREHAM[5]

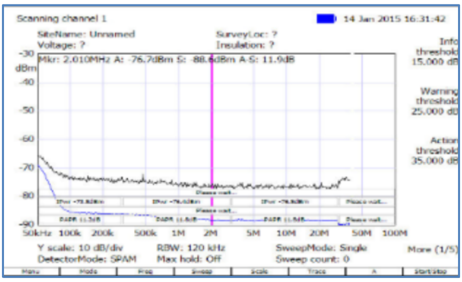
1: National Grid USA, 2: Drax Power UK, 3: Dominion Energy USA, 4: Doble Engineering USA, 5: Doble Engineering UK

Motivations

- Condition monitoring may provide significant benefit to an organization – including asset failure avoidance
- Examples are often given with simple 'linear' progression of measured parameters indicating a problem
- Monitoring data may be less clear, and a formal response plan is required as consequences of failure may be severe
- Cases here are 'real' and indicate the need for forethought

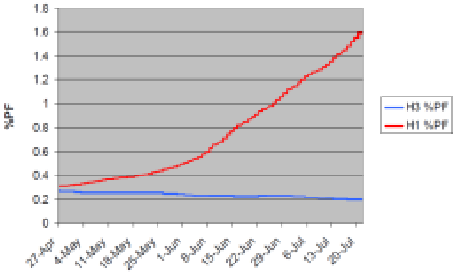
PD Spectra for PD Detection

- Broadband PD spectra allow for PD detection
- Each frequency in the spectrum is analyzed for peak to average power ratio (PAPR) which is a statistic to indicate the presence of PD within the spectrum
- More detailed diagnostics can then occur



Straightforward monitoring example

- Online bushing power factor rises over several months
- Offline tests performed to confirm deterioration



Case 1: PD on Generator

- Broadband spectra and PAPR values were recorded on a 660 MW generator for each phase and neutral
- Initial results showed low, acceptable levels of PAPR for each spectrum

Case 1: PD on Generator

- After refurbishment of the generator, higher levels of PD were recorded yielding alerts on the monitor
- Diagnostic data was reviewed with the OEM who indicated that a new but acceptable level of PD was occurring
- The generator remained in service and continues to operate successfully

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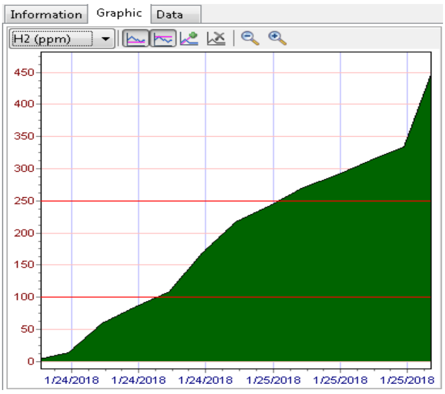
Case 2: Rise in DGA

- A 1991 500/230 kV 280 MVA auto transformer had consistently low gas levels recorded by laboratory DGA
- Hydrogen and Hydrocarbons totaled below 30ppm
- An online monitor showed a rapid increase in level of H2, as shown below, and moderate increase in levels of CO



Case 2: Subsequent Response

- It was decided to take a further sample for laboratory analysis to confirm the diagnosis
- While the sample was being taken the transformer failed
- The failure led to a tank rupture, showering field staff with hot oil
- Fortunately, there was no fire

Case 2: Response Plans Revised

- The company revised response plans, formalizing the approach to be taken by Engineering and Operations
- Plans were put in place for normal operation and two alert levels depending on the gases detected and their levels
- Increased frequency of automated sampling by the monitor allowed for more frequent updates if necessary
- Levels were set for developing contingency plans and for removal of a unit from service
- All plans agreed with relevant parties

Dissolved Gas Analysis (DGA)

- Analysis of gases dissolved in transformer oil may be used to detect and diagnose incipient faults
- Rises in individual gas levels act as a detector
- The relationships between gases serve as a diagnostic
- DGA Condition monitoring may begin as a ‘detector’ supported by laboratory samples for detailed diagnosis

Case 2: Initial Response

- As is often the case with online DGA monitoring, a sample for laboratory/field analysis is taken
- The sample was taken without de-energizing the unit, and analyzed using a high quality portable analysis unit
- The results indicated a ‘high energy electrical discharge ’ as per Duval interpretation D2

Gas Name	Gas	ppm	C57.104 Condition
Hydrogen	H2	95	1
Carbon Dioxide	CO2	4788	3
Carbon Monoxide	CO	982	3
Ethylene	C2H4	63	2
Ethane	C2H6	20	1
Methane	CH4	55	1
Acetylene	C2H2	112	4

Case 2: Response Levels

- Level 1: response: generate or review contingency plans when levels exceed thresholds
- Level 2: remove transformer from service immediately

Alarm Thresholds					
	Hydrogen (H_2) ppm	Ethylene (C_2H_4) ppm	Acetylene (C_2H_2) ppm	Sample Interval[2]	Action
Normal Condition				12 Hours	
Level 1	100	100	5	4 hrs	Increase awareness. Develop Contingencies
Level 2	1000	200	10	2 hrs	Remove from Service

Trend Thresholds	
Gas	Rate of Change
Hydrogen (H_2)	25 ppm/day
Ethylene (C_2H_4)	10 ppm/day
Acetylene (C_2H_2)	5 ppm/day

http://www.cigre.org

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Case 3: Bushing Monitoring

- A transmission class auto-transformer with tertiary was being monitored for DGA, bushings, PD, temperature
- Both relative and true power factors began to rise gently over several weeks for the Y3 bushing

Bushing Condition Monitoring

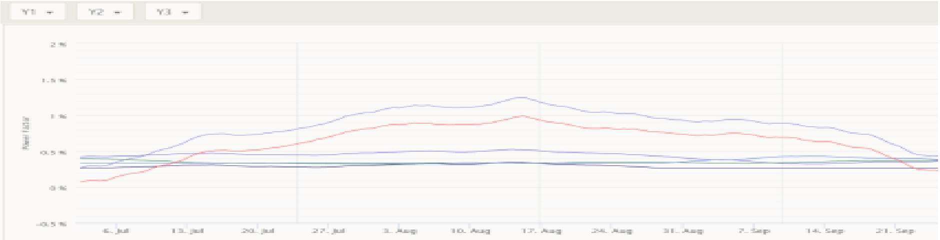
- Offline bushing tests usually focus on power factor (tangent delta) and capacitance of the bushing
- In online measurements we do not supply the voltage to perform the measurements, it comes from the system
- Relative power factor uses the magnitude and relative phase of the leakage current of three bushings in a set
- True power factor uses leakage current with a voltage reference from an instrument transformer on each phase

Bushing expectations

- It is expected for one bushing to deteriorate at a time
- It is unusual, but possible, for two or three bushings to deteriorate simultaneously
- It is unusual for bushing power factor to fall below nameplate; it is possible for the value to go negative

Case 3: Subsequent Progression

- The variation in data was an indicator of a change in state of the insulation, possibly deterioration
- The fact that both relative and true power factor varied indicate that the cause was, in fact, the individual Y3 bushing
- The deterioration seems to ‘reverse’ itself with the power factor returning to acceptable levels



Case 3: Actions

- There is a scenario where moisture ingress would cause an initial deterioration in bushing power factor
- The moisture may settle on the insulation surface and provide an alternate path to ground
- The bushing was taken out of service and tested: and found to be in advanced stage deterioration due to moisture ingress due to a cracked oil fill plug gasket
- All three bushings were replaced

Conclusion: Lessons Learned

- It is very important to have agreed response plans in place for condition monitoring alerts specific to each location
- Plans should be agreed by all stakeholders involved and be socialized appropriately
- Data may need to be analyzed in detail for confirmation of asset condition and root cause determination
- Not all alerts follow from a simple progression in the measured parameters: some are more complex