Proposed introduction to transformer DGA guide

J. Dukarm
Delta-X Research Inc
2006-03-20

Transformer dissolved-gas analysis (DGA) is the measurement of gases dissolved in the insulating fluid of a transformer, and the interpretation of the measurement data so obtained, in combination with other information about the transformer and its environment, to detect and diagnose faults and to obtain a rough estimate of the risk of short-term failure. The scope of this Guide is limited to DGA for in-service transformers filled with mineral oil.

In practice, transformer DGA is used in four distinct ways.

- **Initial assessment**. DGA is performed for the first time, generally after repairs or installation, to obtain "baseline" data for comparison with future DGA results.
- **Screening**. DGA is applied as a periodic (usually annual) screening technique to identify transformers whose risk of short-term failure may be unusually high and which may require surveillance and additional testing, or even immediate load reduction or removal from service.
- **Surveillance**. For transformers which are newly energized or which have been identified as high-risk units, possibly because of screening DGA results, DGA is used with an increased sampling frequency as a surveillance technique for failure risk assessment and diagnosis.
- **Monitoring**. DGA performed several times a day by a hydrogen or multi-gas monitoring device is used to provide extremely detailed information for continuous tracking of a transformer's condition and its response to varying load and environmental conditions.

The overall justification of DGA is that it significantly reduces costs through avoidance and mitigation of failures, improves safety, and contributes to equipment condition assessment for optimizing operation and maintenance. Insurance company statistics show that - depending on the frequency and intensity of application - DGA can help prevent or mitigate thirty to sixty percent of all transformer failures which would otherwise occur.

The fundamental problem of DGA is to discriminate between normal and abnormal conditions, i.e., to determine reliably whether or not there is a fault which may bring unacceptable risk of short-term failure, based on interpretation of dissolved gases in the transformer oil. In transformers, a fault is made evident by the production of new gas which otherwise would not be present. For subtle or incipient faults, the increase in fault-related gas may be difficult to detect against the background of normal variation in gas concentrations due to changes in load and environmental temperature. In some circumstances, additional uncertainty may be contributed by unavoidable random measurement error. Data quality issues arising from poor sampling technique, exposure of oil samples to air, or mis-labeling of oil samples further complicate the task. As with any decision problem subject to "random" interference, a way must be found to minimize the number of "false alarms" while also minimizing the number of false negatives, i.e., failures to detect real abnormalities.

PROPOSED OUTLINE OF TRANSFORMER DGA GUIDE

J. Dukarm
Delta-X Research Inc
2006-03-21

The transformer DGA guide should be based on the economic and engineering rationale for doing transformer DGA. It must recognize the reality that the most important DGA signs of trouble in a transformer are abnormal increases in combustible gases, particularly when the gases increase in parallel in a pattern suggesting a known fault type. Data quality issues must be taken into consideration. The derivation and maintenance of DGA norms must take into account both the owner's acceptable levels of economic risk and statistical information about DGA data in a particular population of transformers. It will be helpful to provide recommendations for the application of DGA in its various typical applications: Initial assessment, periodic screening, surveillance, and monitoring. Appropriate mathematical methods must be applied for calculation of increments and average rates of change.

DGA
- measurement
- interpretation
  - detection of faults which might lead to eventual failure
  - rough diagnosis
  - rough estimate of severity

PURPOSE OF USING DGA
- manage risk of failure
- improve reliability and safety
- contribute to condition assessment

APPLICATION OF DGA
- Initial assessment
  - high initial values may require verification or investigation
  - establish baseline values
- Periodic screening - identify high-risk equipment
  - detect suspicious changes
  - long-term trend analysis
  - rough diagnosis and risk classification
- Surveillance
  - Newly-energized equipment
    - verify absence of faults
    - establish baseline for future DGA
  - High-risk equipment
    - diagnose fault, if any
    - short-term trend analysis
    - risk classification
- Monitoring

    - - day-by-day condition checking
    - - early detection of faults
    - - detection of transient faults
    - - track response to varying load & environmental conditions

GAS FORMATION IN TRANSFORMERS

- Mineral oil types and properties
- Fault-related gas production
    - Gas production by thermal faults
    - Gas production by electrical discharge faults
    - Gas production by partial discharge faults
    - CO and CO_2 production when cellulose is affected
- Gas production not related to faults
    - Stray gassing
        - H_2, CH_4, C_2H_6 production by oil
        - Catalyzed or electrolytic production of H_2
    - Tapchanger gas
        - C_2H_2 from tapchanger via oil leak or conservator
- Variability of residual gas concentrations
    - Periodic (seasonal and diurnal) variation
    - Losses to atmosphere
- O_2/N_2 ratio as a quality indicator
- H_2 and CO_2 as quality indicators

DATA QUALITY ISSUES

- Data quality problems arising from sampling and sample handling
    - Misidentification of samples
    - Unrepresentative sample
    - Contact with zinc fittings
    - Air exposure
    - Missing or inconsistent H_2, CO, CO_2
    - Residual C_2H_2 in lab instrument
    - Extreme variability between samples
- Random variability of gas concentration measurements
    - Round-robin results on lab accuracy & repeatability
    - Relevance to DGA
        - Detection & diagnosis of incipient faults
        - Gas ratios and diagnostic calculations
        - Estimation of average gas generation rates
- How analysis is affected by estimated random error
- Cost of ignoring data quality and random error

STRATEGY FOR FAULT DETECTION, DIAGNOSIS, AND RISK CLASSIFICATION

- Increments and rates of change as fault indicators
- Required minimum significant concentrations
- Baseline samples and reference samples
    - Increment represents new gas formed since reference sample

Rate is average rate of gas formation since reference sample
Establish caution and warning limits for increments and rates
of combustible gases (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO)
- these are taken seriously only if the respective concentrations exceed the required minimums
- caution and warning represent two different levels of high risk
  caution: maybe more frequent screening, surveillance, investigation
  warning: surveillance, investigation, emergency action

Initial sample
No reference sample
Consider this sample a baseline
Classify combustible gas concentrations vs. mins & increment limits
If any cautions or warnings,
- calculate diagnosis and shorten interval
- consider taking a verification sample and sending to lab

Screening
Reference sample is previous sample
Calculate & classify combustible gas increments and long-term rates
If any positive long-term rates, note for future reference
If any cautions or warnings,
- calculate diagnosis and shorten interval
- consider taking a verification sample and sending to lab

Surveillance
Reference sample is beginning of surveillance or latest baseline
Calculate & classify combustible gas increments and short-term rates
If any cautions or warnings,
- calculate diagnosis and plot on diagnostic chart
- make decision about future operation & testing of transformer

If no cautions or warnings,
- continue surveillance until risk is acceptable or de-energize

Plot trend graphs and look for signs of improvement or worsening.
For transformers which frequently experience screening or surveillance cautions or warnings, consider online monitoring.

Monitoring
Reference sample is latest baseline or N samples back (e.g. a week)
Calculate & classify combustible gas increments and short-term rates
If any cautions or warnings,
- calculate diagnosis and plot on diagnostic chart
- consider taking a verification sample and sending to lab
- make decision about future operation & testing of transformer

Plot trend graphs and look for signs of improvement or worsening.

DEVELOPMENT AND VALIDATION OF NORMS
Determination of recommended screening & surveillance intervals
- based on reliability & expected cost of failure

"Minimum significant value" limits for combustible gases
If all gases are below MSV, the transformer is considered OK

A gas above MSV is not evidence of trouble unless there is a bad increment or rate associated with it

Choosing limits for combustible gas increments and rates
- not strictly based on statistics, but initial values can be
- embody organization's judgment as to appropriate risk levels

Caution and warning limits for combustible gas increments

Caution and warning limits for combustible gas generation rates

Upper and lower limits for CO2/CO
- ratio is calculated only if CO is suspicious

Limits for O2/N2 (may depend on oil preservation type)
- Detection of air leak / plugged breather / sample exposure to air

Caution limit for O2 concentration
- undesirable level of O2 for oil/paper health

DGA DIAGNOSTIC METHODS

Diagnostic methods applied only when presence of fault is suspected

Subtract out residual (baseline or reference) gas if possible to obtain diagnosis based on newly-formed gas

Require at least one gas concentration (or increment) above don't care limit

Including uncertainty in calculations permits estimation of reliability of diagnosis

Duval triangle
- plotting series of points to see fault history
- effect of uncertainty

Rogers ratio
- effect of stray or missing H2

Gas nomograph

Key gas interpretation

Others

APPLICATION OF DGA TO GAS SPACE OR GAS RELAY

Calculation of equivalent TCG from dissolved gas concentrations

Calculation of ETCG from dissolved gas concentrations

Comparison of TCG and ETCG

Conversion of gas percent to equivalent ppm

Application of DGA to equivalent ppm

APPENDIX: Calculations involving uncertainty

Increments, average rates, gas ratios

APPENDIX: Verification of lab accuracy

Periodic submission of pre-calibrated check samples

--- end ---