Integration of Electrical Data and Transformer Gas Analysis for Full Asset Monitoring

Terrence Smith
Commercial Application Director
GE Grid Solutions
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Chris White
Application Engineer
GE Grid Solutions

Abstract – Transformer differential is one of the most often mis-operated protection systems within the power system. When the differential operates, it is often difficult to determine cause because a fault may be buried deep within the transformer. Dissolved Gas Analysis(DGA) can help the trouble-shooter make statements about thermal faults and arcs and faults and help to identify the presence of a legitimate transformer fault. DGA can also help the transformer asset management team make long term statements about the health of the transformer over-time. An on-line DGA system can be added to the transformed to give reliable continuous data about the health of the transformer. Additionally, the on-line DGA can help to trouble-shoot after a transformer fault by giving dissolved gas analysis of the transformer oil. This paper examines a novel technique which uses the electrical fault data from a transformer and the DGA data and incorporates them into a single report to facilitate faster decision making after a transformer fault.

Introduction

Several challenges exist around power transformer maintenance which include: aging transformer fleet with a large replacement cost, long lead time, and optimizing transformer maintenance based on condition. Transformer dissolved gas analysis can aid in these challenges by providing information on the transformer health based on gases inside of the transformer.

Power transformers are made up of cores, windings, and electrical connections. The windings and electrical connections are insulated electrically by layers of paper insulation. The transformer is filled with oil which helps with both heat dissipation and electrical insulation. When the paper and oil is stressed through thermal or electrical faults they breakdown into byproducts and gasses which dissolve into the oil and remain there until the transformer is vented.

These gases can be used to diagnose the specific failure and as such are often referred to as diagnostic gases. For mineral oil and natural ester oils used in transformers, the diagnostic gases are Hydrogen (H_2) Carbon Dioxide (CO_2) Carbon Monoxide (CO), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), and Acetylene (C_2H_2). Analysis of the concentration of these diagnostic gases is called Dissolved Gas Analysis (DGA).

Examples of some of the fault conditions and associated gases:

Gas	Name	Condition resulting in gas production
H_2	Hydrogen	Nearly all fault conditions
CH_4	Methane	Oil overheating between 200 and 500°C
C_2H_6	Ethane	Oil overheating between 300 and 500°C
C_2H_4	Ethylene	Oil overheating over 500°C
C_2H_2	Acetylene	Electrical arcing, Oil >800°C

The gases carbon monoxide and cabon dioxide are generated from the paper insulation of the transformer as the paper either ages over time or begins to break down suddenly.

I. Case Study I: Protective Trips and Speeding Analysis by integrating the two reports.

Transformer protection differential zone of protection often reaches beyond just the transformer itself. In those cases, when the protection trips, the work of determining cause can be sped by integrating a protection report and a DGA report. The best example of this is as shown in figure one below. The transformer differential zone of protection reaches beyond the transformer into the adjacent bus. When the transformer differential trips, there is no way to determine if the fault is on the bus section or inside of the transformer other than visual inspection of the bus. Figure two shows a fault report that integrates electrical data and dissolved gas data into a single report. The electrical data clearly shows a transformer differential. The dissolved gas data shows a dramatic increase in hydrogen after the event. This large change in hydrogen is a strong indicator that the fault occurred inside of the transformer and that the transformer should not be re-energized.

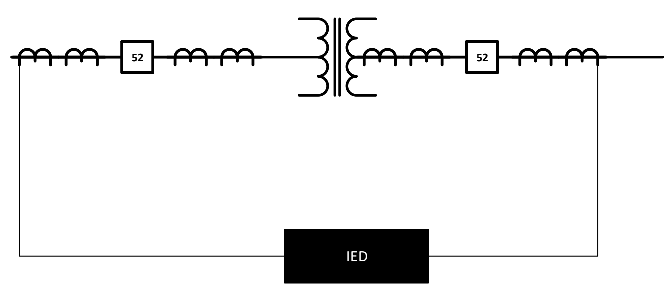

Figure one – Transformer Diff Zone Including Breakers

Digital Fault Records	
Date	08/20/2015,15:21:43.40834
Prefault Trigger Operand	1 : Any PKP
Fault Trigger Operand	1 : Any Trip
Active Setting Group at Prefault	1
Active Setting Group at Fault	1

PostFault Phasors:

Signal	PostFault Magnitude	PostFault Angle
J1 Ia	500.000A	0.0 deg
J1 Ib	500.000A	-119.8 deg
J1 Ic	388.672A	-252.1 deg
J1 Ig	0.000A	0.0 deg
J1 In	146.484A	-25.8 deg
J2 Van	0.00V	0.0 deg
J2 Vbn	0.00V	0.0 deg
J2 Vcn	0.00V	0.0 deg
J2 Vaux	0.00V	0.0 deg
K1 Ia	0.000A	0.0 deg
K1 Ib	0.000A	0.0 deg
K1 Ic	0.000A	0.0 deg
K1 Ig	0.000A	0.0 deg
K1 In	0.000A	0.0 deg
K2 Ia	0.000A	0.0 deg
K2 Ib	0.000A	0.0 deg
K2 Ic	0.000A	0.0 deg
K2 Ig	0.000A	0.0 deg
K2 In	0.000A	0.0 deg

Pre & Post Fault DGA Data:

Parameter	Prefault Value	PostFault Value 1	PostFault Value 2
Date	Aug 20 2015	Aug 20 2015	Aug 20 2015
Timestamp	14:25:00	15:22:00	16:30:00
TDCG(ppm)	48.005	35.791	45.376
Hydrogen H2(ppm)	24.251	17.320	22.698
Carbon Dioxide CO2(ppm)	447.676	449.937	450.536
Carbon Monoxide CO(ppm)	4.703	3.747	4.550
Ethylene C2H4(ppm)	2.789	1.697	2.625
Methane CH4(ppm)	6.859	5.636	6.434
Ethane C2H6(ppm)	6.220	5.020	6.099
Acetylene C2H2(ppm)	3.180	2.368	2.968

Figure Two. -Fault report

II. Case Study II: Protective relay being the complete transformer aggregator of status and alarms.

The protective relay, can also serve as a data concentrator for all the transformer protection and alarms. In this capacity, the relay will likely already be connected to the SCADA or DCS system and will be providing that system with electrical data. The relay can then be the one data concentrator for the entire transformer monitoring system by encapsulating electrical data, DGA data, transformer temperature data, and other transformer alarms into a single device. This makes polling the data easier for a SCADA system because all the transformer data is in a single device and polling can be performed once rather than connecting to multiple devices.

Using the protective relay as an aggregator, the transformer data becomes either a Modbus point in a Modbus user map, a DNP point in a points list, or a generic I/O for MMS. Regardless of the protocol used, the data simply becomes a matter of a relay setting to serve it to a DCS or SCADA system. These types of settings are as shown in figure three below.

Analog Input Point 3	
Analog IP Point 3 Entry	H2O ppm Level
Point 3 Scale Factor	/ 1
Point 3 Deadband	1
Analog Input Point 4	
Analog IP Point 4 Entry	Hydran (H2)
Point 4 Scale Factor	/ 1
Point 4 Deadband	1
Analog Input Point 5	
Analog IP Point 5 Entry	RTD 1
Point 5 Scale Factor	/ 1
Point 5 Deadband	5

Figure Three – DGA DNP settings.

III. Case Study III: Using the protective relay to trend electrical data with M&D data.

If electrical data and DGA data are incorporated into the same device, that device can also trend both electrical data and DGA data over time and produce a combined electrical and DGA model of the transformer. These models provide the ability to correlate electrical, chemical and thermal data, allowing for the creation of individual trending models. Such models help identify correlations between different but inter-related sets of data, such as a record of transformer loads compared to gas concentration data. A correlation model will hot spot, for example, that a gas concentration is occurring every time a transformer is loaded in a particular way. This model can then be used to track transformer load, temperature, and gas concentration changes to identify any relationship between one measure and another. This in turn allows operators to proactively safeguard transformer assets, extending the time before a shut-down for maintenance or decommissioning is required

Figure Four – Integrated Transformer Model

Since the levels of gases produced are dependent on temperature of the oil, the ratios of the gases can give an indication of the type of issue inside of the transformer. Most of these methods require the logging of the ratios over time and then complex analysis of the data. The complex analysis as well as the charting of the data can be off-loaded to the protective relay as seen in figure five below. This figure shows the Duvall's triangle for the transformer DGA and records the ratios of the gases over time. The location inside of the triangle will correspond to the type of fault inside the transformer. In this case we can clearly see that the fault originally started as a thermal fault and migrated into a thermal/electrical fault. This migration over time would lead us to conclude that we shouldn't re-energize the transformer if we have had a fault and to make plans to replace if a fault has not occurred yet.

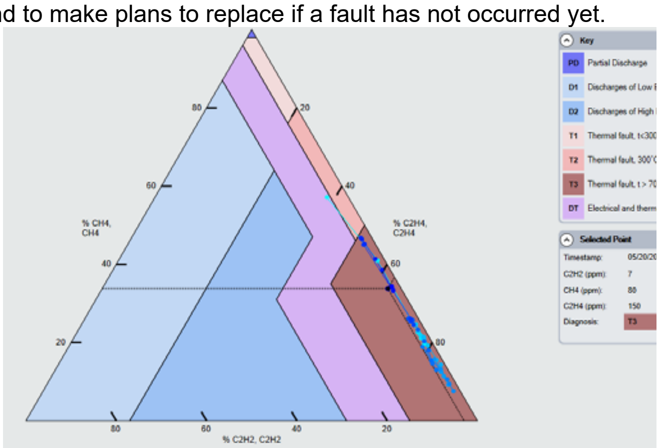

Figure Five – Duval's Triangle

More than half of the installed transformer fleet is over 40 years old with 50% of failures occurring from insulation failure. As the paper in the insulation degrades it produces carbon dioxide. As the paper starts to fail it produces carbon monoxide. The ratios of these two gases can provide a basis for statements about the health of the transformer paper insulation. A normal trend would be for the paper to generate carbon dioxide as the paper degraded. This would cause the CO2/CO ratio to increase over time as shown in figure six below. As the paper starts to fail it produces carbon monoxide which cause the CO2/CO ratio to decrease over time.

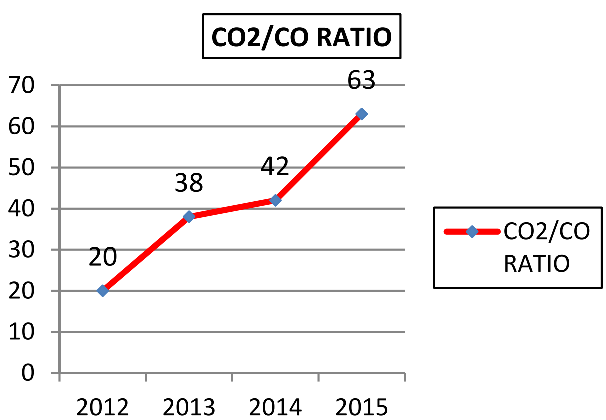

Figure Six – Increasing Normal CO2/CO Ratio

Transformer health report (shown in Figure 7) is a compilation of operational and fault data, allowing benchmarking and identification of deviations from the normal operating conditions. Asset management team can utilize this readily available report for post-event analysis and record archival.

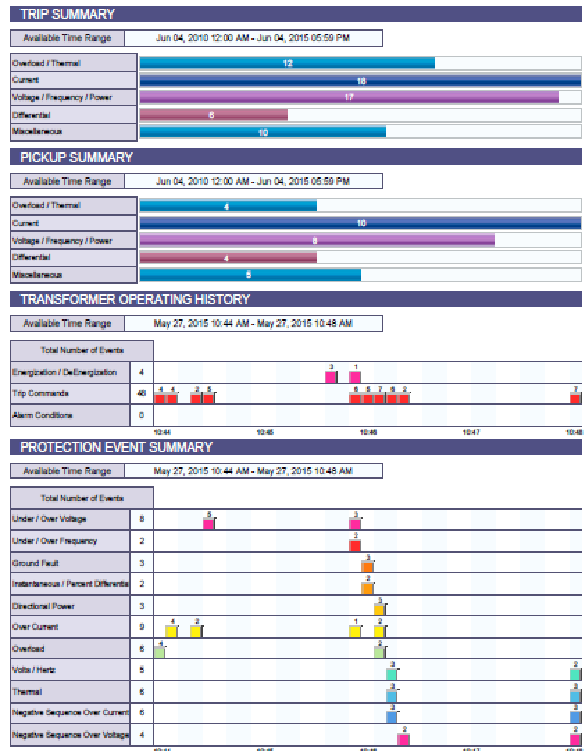

Figure Seven transformer health report.

It provides a snapshot of tripping alarm events on a transformer, including the following:

- Name plate data
- Trend in energization behaviors
- One year learned data
- Historic maximums
- DGA models
- Alarm/trip history

Having all this data in a single device helps eliminate multi-layered monitoring and recording devices, providing one-stop operational, monitoring and fault analytics. The simple and intuitive analytics can be archived for reference and future comparison.

IV. Conclusions

Utility operations continue to evolve, but reduction of maintenance costs will be a constant theme. Transformer condition assessment will help lower maintenance costs by identifying asset condition and enabling condition based maintenance verses time based maintenance. Transformer dissolved gas analysis will continue to be a core requirement for transformer assessment and online dissolved gas analysis gives a better picture of the transformer health because it identifies problems as soon as they develop.

Asset management won't be cost effective unless the large number of data points can be automated in such a way that problems can be easily identified and trends can be automatically recognized. Integration of the protective IED and the online dissolved gas device can ease this analysis by allowing the relay to identify problems and to perform trending analysis.

Biographies

Terrence Smith is the lead P&C Technical Application Engineer for GE Grid Solutions North American Commercial team. He has been with GE since 2008 supporting the Grid Solutions Protection and Control Portfolio. Prior to joining GE, Terrence has been with the Tennessee Valley Authority as a Principal Engineer and MESA Associates as Program Manager. He received his Bachelor of Science in Engineering majoring in Electrical Engineering from the University of Tennessee at Chattanooga in 1993 and is a professional Engineer registered in the state of Tennessee.

Chris White is an M&D Application Engineer for GE Grid Solutions. He has been with GE since 2007 supporting the Monitoring and Diagnostic team. Prior to joining GE Chris worked for Southern Company as a SCADA technician and Distribution Engineer. He received his Associate degree in Nuclear Science Technology from Georgia Military College and is Bachelor of Science in Information Technology from University of Phoenix.

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