ANALYSIS OF DISSOLVED GAS DATA BEFORE AND AFTER A CRITICAL TRANSFORMER REPAIR

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Mirant operates several generating plants in North America, Asia and the Caribbean. In late 2001, routine DGA (Dissolved Gas Analysis) performed on a Mirant Mid-Atlantic 650 MVA GSU built in 1969, lead the electrical maintenance crew to believe an incipient fault was developing in the transformer. Table 1 provides an example of the DGA values obtained at that time.

Routine DGA tests during the 6-month period following the above-mentioned analysis showed no significant changes in fault gas concentrations. However, the decision was made to increase the DGA testing frequency and to install an on-line dissolved hydrogen and water monitor on the suspect transformer. The selected IED (Intelligent Electronic Device), a Calisto monitor from Morgan Schaffer Systems in Montreal, Canada, was installed. Figure 1 describes the main features of the instrument which continuously measures the concentration of dissolved hydrogen in oil in ppm. Dissolved water content is also continuously measured and can be reported in ppm, %RS (Relative Saturation) at 25°C, or %RS at a specific transformer oil temperature if this value is available as an input to the monitor (4-20 mA or Jtype thermocouple input).

As opposed to other sensors of this type, the Calisto monitor features its own oil circulation and conditioning system, i.e. the circulating oil is either cooled or heated to a set point prior to making dissolved hydrogen and water measure-

Table 1: DGA results - Nov. 11, 2001

Dissolved gases	Concentration (ppm)
Hydrogen	392
Methane	594
Carbon monoxide	736
Carbon dioxide	5900
Ethylene	260
Ethane	260
Acetylene	n/d

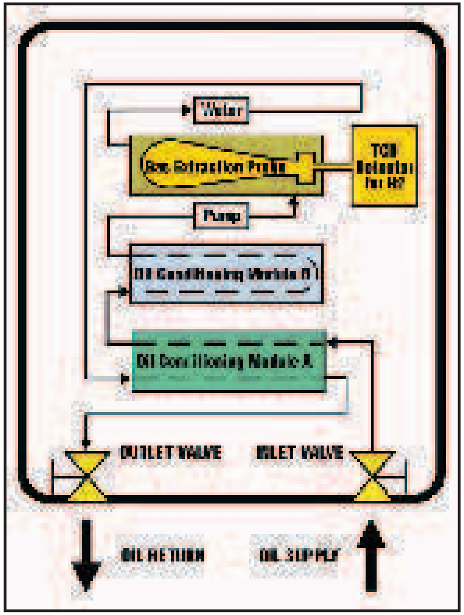

Figure 1: Main features of monitor

Figure 2A: Transformer supply valve

Figure 2B: Transformer return valve

Figure 3: Mounting of enclosure

ments. Dissolved gases are continuously extracted using permeable PTFE fibers, and selective measurement of dissolved hydrogen in the gas sample is achieved using a specially designed thermal conductivity detector (TCD). Continuous dissolved water measurement is performed using an IC (integrated circuit) sensor located directly in the oil flow.

IED INSTALLATION

As the IED continuously circulates oil to get access to representative dielectric fluid from the transformer, connection to independent supply and return valves on the transformer is required. Figures 2A and 2B provide details on the connections of the oil supply and return lines and Figure 3 provides an overview of the enclosure mounting. Standard copper tubing and off-the-shelf fittings are used to make the oil line connections.

Calisto, from Morgan Schaffer Systems, is a highly accurate IED designed to detect incipient faults and to monitor moisture content in critical oil-filled transformers.

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The manufacturer also offers cut-to-length stainless steel flexible hose and fitting kits if added security or protection is required (e.g. use in corrosive environments).

The installation procedure involves (1) mounting of the IED on the side of the transformer control cabinet or on a mounting plate, (2) connection of the AC supply, communication and alarm lines, (3) connection of the oil lines and flushing of the oil circuit and (4) start-up of the instrument. No field calibration or signal adjustments are required once the instrument has been started.

PHASE I - TRANSFORMER DEGASSING AND STEADY HYDROGEN GENERATING RATE

The IED was installed in May 2002 and a decision was made to degas the transformer in order to reset the dissolved gas reference to zero. Laboratory and on-site DGA measurements were performed regularly in the period of June to mid-September 2002. During that period, the IED showed a rate of dissolved hydrogen generation that varied according to Table 2 and Figure 4.

From this data, one can observe that the hydrogen generating rate significantly increased on September 13th, thus indicating a sudden change in the gas generating conditions. Figure 5 shows the dissolved water variation for the same period. As the amount of water in oil is dependent, among other parameters, on the load on the transformer, Figure 5 provides qualitative information on the load variation for the period. Based on this information, it is interesting to observe that the hydrogen generating rate does not significantly vary with load. Moreover, the sudden change in hydrogen generating rate on September 13th was not induced by an increase in load thus indicating a true deterioration of the transformer condition. Onsite DGA tests performed during the period are shown in Table 3. Though large increases in fault gas concentrations are observed, percent changes between tests for both absolute concentrations and key ratios remained more or less constant.

Table 2: H2 generating rates from May 30 to Sept. 26, 2002

Time section (Refer to Fig.4)	Time period	H2 generating rate (ppm/day)
A	May 3 to May 20	<1.0
B1	May 30 to June 15	3.8
B2	June 16 to June 28	5.0
B3	June 29 to Aug. 12	2.8
B4	Aug. 13 to Aug. 25	4.1
B5	Aug. 26 to Sept. 12	1.4
C1	Sept. 13 to Sept. 26	12.1

SUDDEN DETERIORATION IN TRANSFORMER CONDITION

Figure 6 shows the period of September 27th to September 30th where very large amounts of hydrogen were produced under fairly constant load conditions. This graph demonstrates the speed with which a transformer condition can degrade and

Figure 4: Hydrogen generation over 4-month period

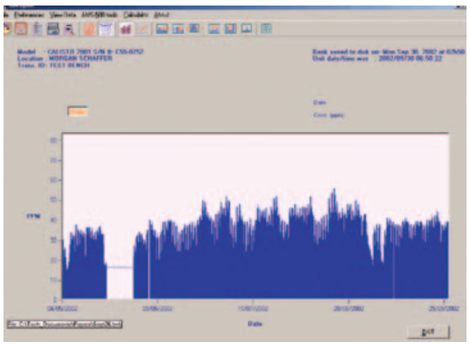

Figure 5: Load-dependent dissolved water variation during same period

Table 3: Typical DGA results from end of May to mid-September 2002

Dissolved gases	May 30, 2002	July 8, 2002	Sept. 17, 2002
Hydrogen	n/d	170	419
Methane	n/d	372	865
Carbon monoxide	4	160	262
Carbon dioxide	25	1360	2726
Ethylene	n/d	179	528
Ethane	n/d	184	505
Acetylene	n/d	n/d	n/d

with which the hydrogen concentration can increase. Table 4 shows the maximum concentration and hydrogen generating rate reached during periods A, B and C.

It should be noted that the ability of the sensor to pick up such increase in hydrogen concentration is very dependent on the oil circulation within the transformer and on the ability of the sensor to have access to this representative oil.

Results from an on-site DGA performed on September 30th, are provided in Table 5.

HYPOTHESES WITH REGARD TO THE CAUSE(S) OF THE INCIPIENT FAULT

The authors analyzed the data contained in Table 3 and Table 5 using the well-known Duval Triangle method [1]. Based on this method, a diagnostic of thermal fault of medium range temperature T2 (300 to 700 °C) was established from July 8 to September 17 (it may be noted that a similar fault T2 was also present prior to November 11, 2001, as indi-

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Table 4: H2 generating rates between Sept. 27 and Sept. 29 2002

Time section (Refer to Fig.4)	Time period H2 concentration (ppm)	Maximum H2 generating rate (ppm/hour)
A	27/09/2002 5:52 to 28/09/2002 5:53 1,367 ppm	100
B	28/09/2002 8:53 to 28/09/2002 23:42 5006 ppm	300
C	29/09/2002 11:43 to 29/09/2002 23:42 9494 ppm	392

cated from Table 6). The September 30th data then led to a high temperature T3 (>700 °C) thermal fault diagnostic.

From these diagnostics, one can suspect that a source of high electrical resistance was initially present in the transformer (e.g. a bad connection).

This high resistance created a resistive hot spot of increasing resistance, thus the observed increase in hydrogen, methane, ethylene and ethane. At some point between September 17 and 30 (possibly on September 27th), additional energy, probably due to circulating currents, significantly increased the temperature of the metal and oil at the fault location. This led to accelerated production of hydrogen, methane, ethylene and a small relative amount of acetylene, an indication of overheating of the oil above 700°C.

SOURCE OF INCIPIENT FAULT

Once the transformer was taken out of service, it was found that a high voltage lead was burned and ready to fail. This finding was consistent with the DGA data, and a technical paper dedicated to providing information on the fault cause and subsequent transformer repair will be published in the coming months.

SCOPE OF APPLICATION OF INCIPIENT FAULT DETECTION IEDS

The above experience demonstrates the value of on-line monitoring of dissolved hydrogen for both life extension and transformer protection purposes. Such value lies in the ability of the IED to provide real time and long term data that is meaningful and truly representa-

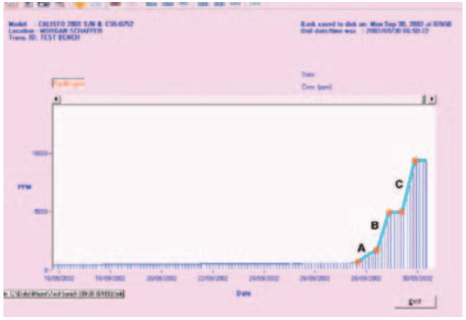

Figure 6: Sudden increase in hydrogen generating rate

tive of the transformer condition. This ability of the IED to provide such information for any type of transformer (new, old, containing contaminants, etc.) and in any type of environment is also of paramount importance.

In order to maximize this value, the following recommendations can be made:

- Understand the nature of the measurement and the parameters that may affect the IED signal.
- Assess the long-term reliability and stability of the IED on normally operating transformers.
- Maximize the IED response time by proper location on the transformer or by using IEDs having their own oil circulation systems.
- Implement a procedure where the IED measurements can be confirmed and validated easily and rapidly in case of an alarm or a change in long-term trend (on-site H2 or DGA measurement).

Table 5: DGA results - September 30, 2002

Dissolved gases	Concentration (ppm)
Hydrogen	8150 (*)
Methane	11000 (*)
Carbon monoxide	351
Carbon dioxide	2620
Ethylene	17960
Ethane	2460
Acetylene	570

(*) Values calculated from inverted peak for hydrogen and out of scale peak for methane. Estimated accuracy: ± 10%.

UPDATE ON MIRANT GSU

The Mirant GSU was repaired and re-energized on October 21, 2002. Since then, dissolved hydrogen concentration has remained constant at approximately 30 ppm.

REFERENCES

[1] M.Duval, "A Review of Faults Detectable in Gas-in-Oil Analysis in Transformers", IEEE Electrical Insulation Magazine, Vol. 18, No. 3, pp. 8-17, 2002.

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