

## Power Transformers:

# Properly Categorizing Developing Faults via Dissolved Gas Analysis

by **Randy Cox**

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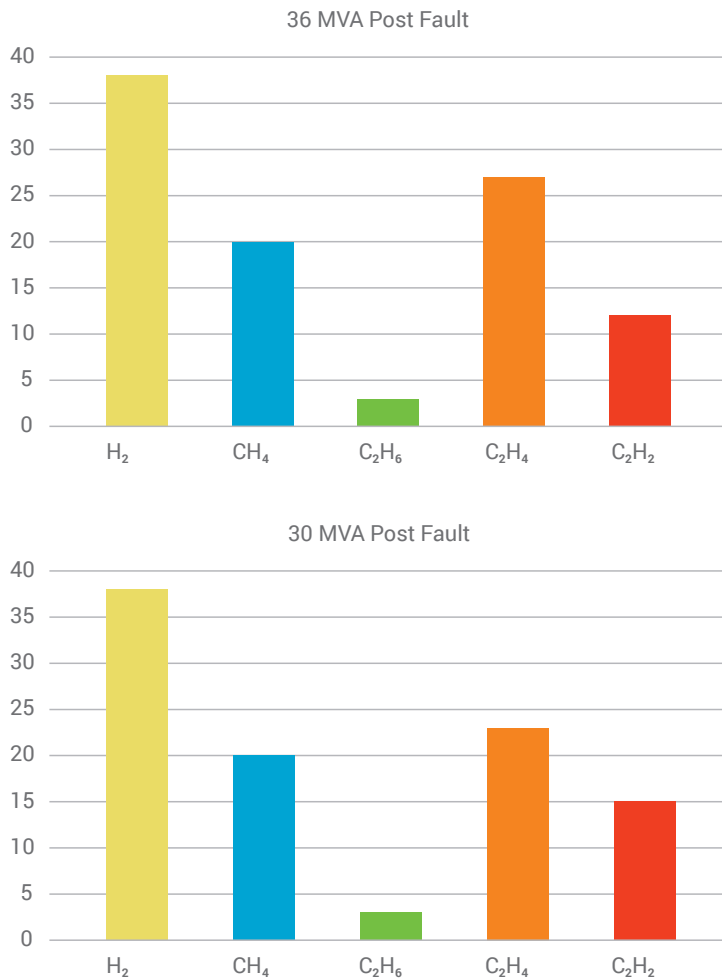
**Randy Cox** is the Domain Expertise Manager for GE Grid Solutions. His current duties include interfacing with the industry, writing and presenting industry related technical papers, committee work and education of customers on the technical advantages of GE M&D technology, products, software and solutions. Prior to being employed by GE Grid Solutions, Randy was employed by SPX Transformer Solutions, Inc. as the Operations Supervisor for the Texas Service Center, which included staffing and implementing a new service center to perform transformer installations, repair and LTC maintenance. Randy has published many industry technical papers related to substation transformer and circuit breaker diagnostics. He is a current member of IEEE & a Fellow at General Electric.

Operating an electric grid has its challenges, not the least of which is finding additional time locating potential problems before they turn into the evening news. Whether you are a District Manager, Engineering Support, Operations Supervisor or Substation Technician, transformer Dissolved Gas Analysis (DGA) is simply one aspect of a busy day for which you are likely responsible. For this reason anything that can be made easier, should be, and under normal circumstances is most welcomed. While much of the chemistry behind DGA is complex and important for our industry chemists to understand, the day to day review of DGA by the utility need not be complex. In cases where we may struggle to make sense of the information, there's a wealth of industry chemists and experts willing to assist, with regards to further, or a deeper interpretation.

In this article we will identify some simple guidelines that may be applied to assist in identifying what is involved in the fault. What we need to know initially is the amount of paper involved in a given fault, if any. These steps of interpretation will most certainly help to simplify the analytics regarding, what many consider to be, a very complicated subject; categorizing (or distinguishing) developing faults within oil filled power transformers. If these answers can be rapidly obtained, it can mean the difference between a less costly onsite repair versus a total replacement of the transformer.



Figure 1. Similar arcing profiles for two transformers that tripped on a transformer differential relay operation



## The Facts

There are “knowns” in DGA. The industry is very proficient at identifying overheating in oil filled power transformers. Measuring the internal oil temperature at 150°C+ temperatures is accomplished by the measurement of what is referred to as the “hot metal gasses.” These gasses are, in order of their initial thermal generation, hydrogen (H<sub>2</sub>), methane (CH<sub>4</sub>), ethane (C<sub>2</sub>H<sub>6</sub>), ethylene (C<sub>2</sub>H<sub>4</sub>) and acetylene (C<sub>2</sub>H<sub>2</sub>). What is not quite as well understood is the diagnosis of paper (the carbon oxide gasses: CO<sub>2</sub> and CO). It can be even more challenging if the issue exists on a paper wrapped lead. To better understand how to arrive at a conclusion regarding an issue, it is important to note that at all working temperatures, CO is less soluble than CO<sub>2</sub> and the higher the temperature, the more CO<sub>2</sub> remains in solution (it will be absorbed from atmosphere if partial pressure of CO<sub>2</sub> in atmosphere is greater than partial pressure in the oil).

This is an important point, since identifying “categorically” where a problem exists, the CO<sub>2</sub>/CO ratio must be trended.

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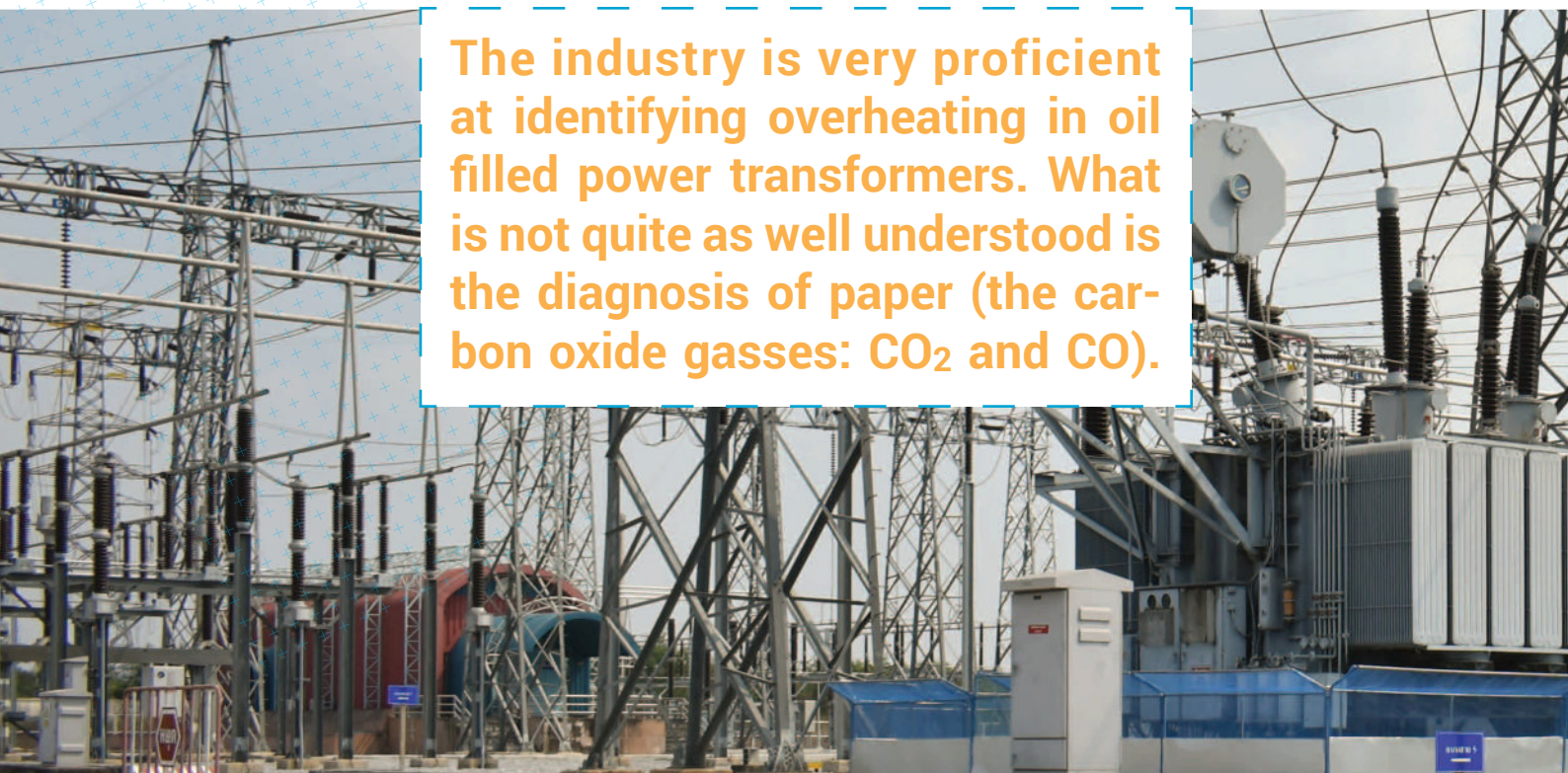


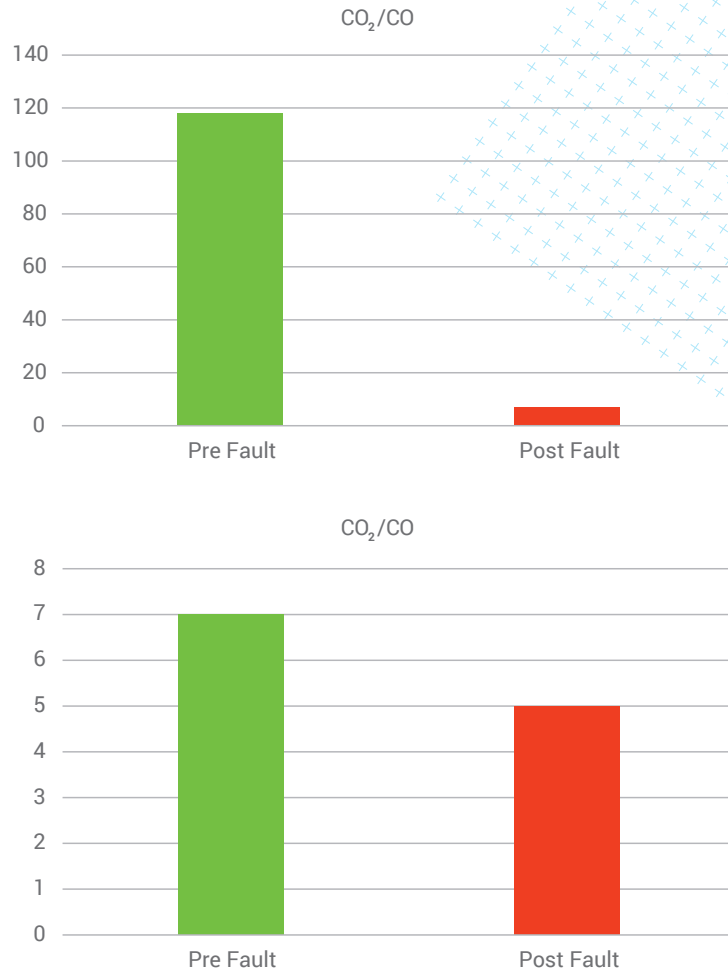
Figure 2. Post event impact on the CO<sub>2</sub>/CO ratio in the 36 MVA transformer (top) and 30 MVA transformer (bottom)

Trending provides critical data for decision making, as opposed to data that is a simple snapshot in time. In other words, what was it prior to the problem, or where is its norm? This thinking is new to our industry, as this ratio is typically referred to in many technical publications and industry guides as a single value for diagnostic purposes. To demonstrate this more fully, the following transformers both tripped on a transformer differential relay operation with a very similar arcing profile. There's no question that a flashover occurred in both transformers as seen in Figure 1 [1].

These transformers had very different problems, evidenced by the post event impact on the CO<sub>2</sub>/CO ratio as seen in Figure 2, maintaining the order of these transformers.

What we now know is that the more paper involved in a fault, the greater the impact on the CO<sub>2</sub>/CO ratio.

Where the ratio dropped significantly, a low side winding failure occurred and where a paper wrapped primary lead flashed over (minimal paper), much less impact.



**The CO<sub>2</sub>/CO ratio trending provides critical data for decision making.**



To further illustrate the value of this ratio, Table 1 presents the data of a 10 MVA transformer that tripped on a transformer differential relay operation, to which there was absolutely no impact on this ratio, verifying that there was no paper involved in the presence of the hot metal gas generated, post fault.

As can be plainly seen in the above example, once the hot metal gas

generated, it did not have a negative impact on the  $\text{CO}_2/\text{CO}$  ratio. An internal inspection revealed a failed de-energized high side tap changer. Even though there was no paper involved in the fault, when the ratio is compared to generation of hot metal gas, the lack of impact actually tells the story. The issue was in an area that did not support any paper being involved, thus bare metal, such as a de-energized tap changer contact.



Table 1. 10 MVA transformer data

Test Date	Hydrogen	Methane	Ethane	Ethylene	Acetylene	$\text{CO}_2$	CO	$\text{CO}_2/\text{CO}$	Nitrogen	Oxygen
9/5/2002	2	0	0	0	0	1820	221	8.235294	68476	9186
8/19/2004	4	0	0	0	0	1875	249	7.53012	80061	7268
6/16/2005	2	1	0	0	0	1951	231	8.445887	79140	7284
8/14/2006	6	3	0	0	0	3450	322	10.71429	82900	7507
8/7/2008	2119	736	44	666	1405	2530	239	10.58577	67189	7881

### Testing the Theory

To better understand the effect that thermal, or lack thereof, has on the  $\text{CO}_2/\text{CO}$  ratio, an experiment was conducted by Memphis Light Gas & Water on a 25 KVA transformer with mineral oil and Kraft paper. A thermal well was installed through the wall of the transformer and inserted to a depth of 5" into the windings. A small heating element was then placed into the well and raised to temperatures ranging from 100°C to 180°C over a period of 22 days. The  $\text{CO}_2/\text{CO}$  ratio started at 55.60:1 at 100°C and as the temperature was increased in 10-degree increments, the ratio displayed a steady increase until 150°C was reached. At this point, the ratio was at 78.51:1, but began to decrease

as the temperature continued to be raised up to 180°C. The ratio had declined to 48.23:1, and at this point the heating element was moved so that it was no longer in contact with the paper insulation and was only directly heating the oil. The temperature of the heating element was maintained at 180°C. After the element was positioned to only be in direct contact with the oil, the  $\text{CO}_2/\text{CO}$  ratio began to steadily rise, apart from the 11/21/2014 sample, until it reached 52.55:1 at the end of the experiment. The 11/21/2014 sample was determined to be erroneous due to all gas levels being approximately half the value of the samples taken immediately before and after that date [1].

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## Why Does It Work?

CO will never remain dissolved in the oil equal to, or more than CO<sub>2</sub>. Because CO seeks to leave solution at all working temperatures relative to CO<sub>2</sub>, the CO<sub>2</sub>/CO ratio cannot drop in the absence of CO creation. Therefore, if both gasses are decreasing relative to prior samples and the ratio drops it must be because CO is being generated more than CO<sub>2</sub>, but both are being generated at lower levels than are leaving the oil. Looking at the design of a transformer, we can better understand why the ratio of CO<sub>2</sub> and CO can be used to identify the general fault location. In other words, does the problem that exists have heavy paper involvement, light paper involvement or no paper involvement. The relative availability of oil to contact the paper determines the available O<sub>2</sub>. The more oil that is available, the more cooling and O<sub>2</sub> available. In the windings, where paper is tightly wrapped, oil has less contact per volume of paper than a lead [2].

## Summary

Transformers have a home as it relates to the CO<sub>2</sub>/CO ratio. Additionally, these ratios are not all the same. In some publications it is noted that they should be between 3:1 and 11:1, while other publications say that it should be above 7:1. The truth is that transformers can, for the most part, be just about any value. The key is not "what value" they display when all is well, but rather what happens to these ratios when issues develop proportional to their norm. What we have learned is that where heavy paper is involved (inner-winding), the ratio drops to a minimum value of 65% or greater. Where less paper is involved, such as a paper wrapped lead or even outer-winding, which has greater access to available O<sub>2</sub>, the value drops to between 25% and 50%. Where no paper is involved, the ratio may actually increase, or it may decrease slightly.

## References

- [1] C. Rutledge, Assistant Manager, Memphis Light Gas & Water
- [2] T. Rhodes, Sr Engineering Technologist, Asset Information & Intelligence, Duke Energy

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