JOHN BRETT

President & CEO at Delta-X Research Inc.

It is very important for us to invest in research and apply first principles science in order to properly understand the early indications of failure in high-voltage equipment

About Delta-X Research

Delta-X Research was founded in 1992 as a consulting company by Dr James (Jim) Dukarm, a mathematician with extensive experience in developing industrial software, including for the electric power industry, employing artificial intelligence and other advanced techniques. Initially, Jim was involved in several projects, including design and development of an insulation power factor testing application for a major electric utility and providing technical support for scientific researchers using a massively parallel computer. Then a large chemical plant asked Jim to develop a software application for managing and interpreting dissolved gas analysis (DGA) data for power transformers. Several additional industrial companies and electric utilities soon volunteered to contribute data and user advice to the project.

The desktop software product that was developed was called Transformer Oil Analyst (TOA). Designed as a decision support tool for asset managers and maintainers, it handled both DGA and oil quality test data and featured a fuzzy logic expert system, user-configurable interpretive criteria, and a simple and intuitive user interface. Over time, hundreds of copies of TOA were sold worldwide. Development, sales, and support of TOA became the entire business of Delta-X Research.

In 2006, TOA version 4 was released as a Software-as-a-Service, also known as a cloud-based solution. Today Delta-X Research is recognized as a technology leader in its field. TOA4 is used by many North American electric utilities, including over half of the largest ones in the United States. We also have TOA4 subscribers in Europe, Australia, Asia, and South America. In early 2015 Delta-X Research reorganized, and I was appointed CEO and tasked to grow the company in order to enhance support for existing customers and to develop new products and services for the expanding market. Jim was freed for full time research and development of new technology for transformer diagnostics and condition assessment.

What is Reliability-based DGA?

For several years Jim has done statistical work and collaborated with other researchers to support and complement the development of IEEE guides for DGA for transformers and tap changers, and for different insulating liquids. Jim worked with Dr Michel Duval of IREQ (Hydro Quebec) on investigating the effect of data variability on DGA interpretation and with Dr Fredi Jakob of the Power Education Institute on the energy represented by gaseous by-products of insulation degradation. All that work eventually led to recent breakthroughs in DGA interpretation.

Fredi Jakob realized that it was possible to calculate a fault energy index, which he called Normalized Energy Intensity (NEI), from thermochemical heats of formation weighted by gas concentrations observed in a sample of transformer oil. Fredi and Jim published a paper in IEEE Transactions on Power Delivery showing that NEI was useful for trending and fault severity assessment in transformer DGA, in effect reducing DGA interpretation from a 5-dimensional problem (interpreting hydrogen and individual hydrocarbon gases) to a one-dimensional problem. This greatly simplified fault detection and fault severity assessment.

Building on pioneering work by Dr Duval on incorporating transformer failure data into DGA, and using large databases of DGA and failure data supplied to Delta-X Research by some of our customers, Jim was able to apply reliability engineering statistics to NEI and develop a statistical model of NEI values just before failure. That, in turn, provides a basis for assessing fault severity in terms of changes in failure probability, eliminating the need for gas concentration and gas rate of change limits for transformer DGA and allowing the ranking of transformers for maintenance. Simply put, we can now identify and assess at-risk power transformers by correlating fault gas production with transformer failures. We call that "Reliability-based DGA," or RDGA, and we have a patent pending related to it.

For clarity, I should point out that RDGA does not compete with triangles, pentagons, IEC ratios, and so on. Those are all methods for identifying the apparent fault type when there is evidence that something may be wrong with the transformer. RDGA provides a better way to determine whether or not there is evidence of an abnormal condition, and if so to assess severity. If RDGA indicates that there may be something wrong, a fault type identification method such as the Duval triangle can be applied to identify the fault type. RDGA is not about identifying fault type; it is only about deciding whether or not there is a fault and, and if there is then assessing severity.

When we showed some RDGA examples to our largest customer, Duke Energy, they asked us to conduct an RDGA assessment of their entire transformer fleet (over 7000 transformers). A team of Duke engineers examined the results and reported that RDGA significantly outperformed conventional DGA, both by eliminating "false alarms" where a transformer is identified as abnormal when there is no active problem, and by detecting a large number of cases where transformers had significant problems (such as cooling system failure) without exceeding any 90th percentile gas concentration limits. In response to this remarkable validation, Duke immediately incorporated RDGA into its transformer health surveillance process.

We can now correlate fault gas production with transformer failures to identify and assess at-risk power transformers

How has RDGA influenced TOA4?

NEI and RDGA were successfully applied in TOA4 for the interpretation of online DGA monitor data. This was very important because it is difficult to get good performance using a conventional limits-based approach on online DGA monitor data, especially when multiple gases are being interpreted at one time. Being able to base trending and fault detection on NEI and having a limits-free method of assessing fault severity is just what is needed for online monitoring.

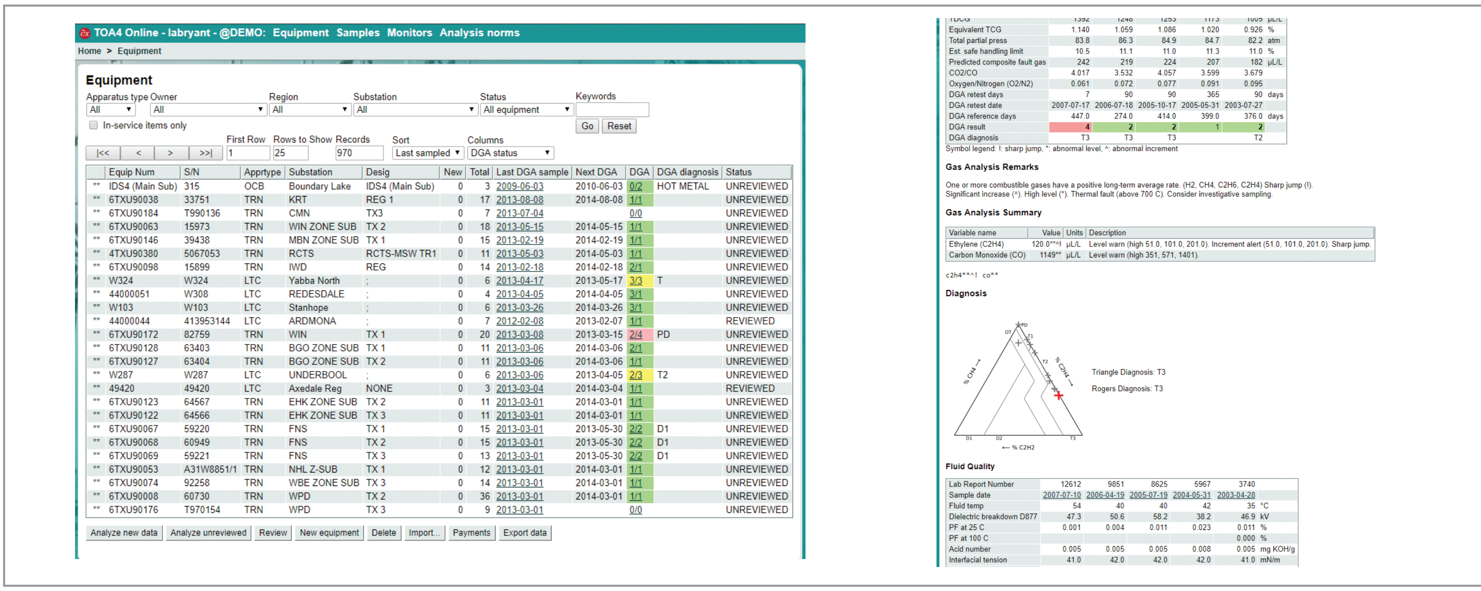
This summer we are adding RDGA for the interpretation of laboratory DGA data to TOA4, with some improvements resulting from our work with Duke Energy. We are expecting that the customers will see a great improvement in performance compared with what conventional DGA has been able to do.

We know that TOA4 users need some time to evaluate RDGA for themselves and adapt their own internal transformer assessment policies. Some utilities may be bound to conventional DGA methods for some time due to regulatory or institutional requirements. In recognition of that, TOA4 will continue to support a very good version of conventional limits-based DGA, both for laboratory data and for online monitoring, as well as built-in reporting tools for comparing the results of conventional DGA with RDGA.

Is the RDGA model applicable for all transformers?

Originally, we developed a statistical model of failure-related NEI for two large utilities that donated data for the project. A formal "log-rank" test showed that the two models were not statistically distinguishable. Based on that, we combined the databases and developed a single model based on all the data. That model is the one that was used for the RDGA validation performed by Duke Energy, even though Duke was not one of the two original data donors. For now, the same model is the basis for all RDGA assessments performed by TOA4.

It is likely that some transformer types may have different enough typical gas production patterns to justify using RDGA mo-



TOA interface providing different kind of asset critical information

Duke Energy has made plans to permanently use RDGA for the evaluation of all oil samples taken on Duke power transformers

dels specialized for the individual types. An example may be transformers that have special physical characteristics and special loading patterns, such as rectifier transformers or transformers that are used for powering subway systems, trains, electric buses, and so on. That is a question we are actively studying, but for now the large database that we have is adequate only for the one generic model. We need to accumulate more data and failure cases for the specialized transformer types to derive the models for them and test whether they are truly distinct. A similar problem arises in conventional DGA, where some transformer types could possibly benefit from their own sets of DGA limits, but the generic limits still perform reasonably well.

At Delta-X Research, it is very important to continue our research and apply first principles science in order to properly understand the early indications of failure in high-voltage equipment. This is the only way we see to ensure our products remain innovative and to support our customers as they make difficult decisions regarding the maintenance, refurbishment or replacement of their critical assets.

Implementing TOA4

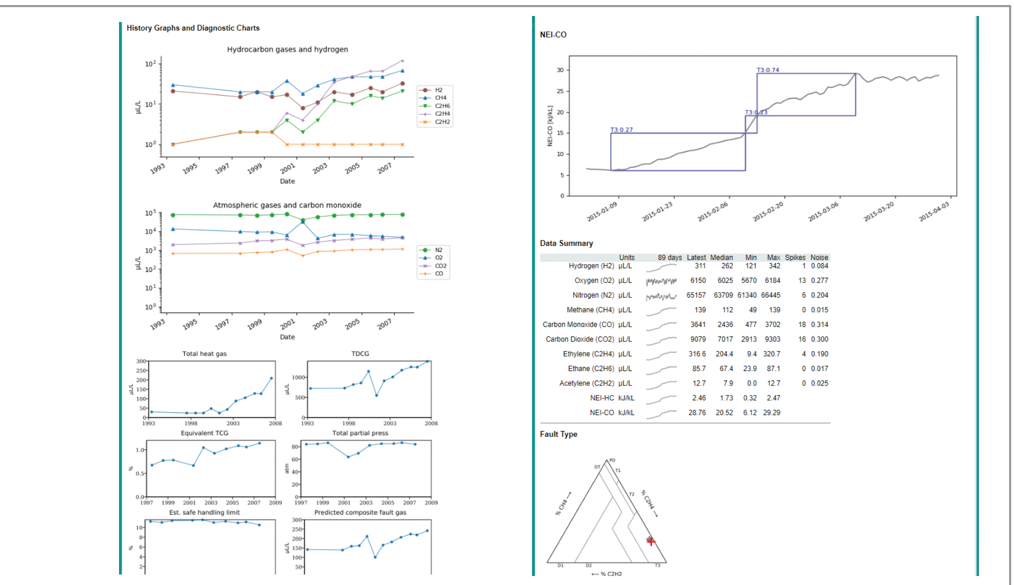
We start by helping you create a database with name plate and location information for transformers and other high-voltage liquid-filled equipment, as well as any previous test data of the equipment. Once that database is set up, you can assign norms which are sets of limits and rules for interpreting the test data. TOA4 will then generate an interpretative analysis of all this data for each individual piece of equipment, and present your fleet in an order that identifies those assets needing attention first.

The applicability of the results to a particular population is partly a matter of experience. Any new user of TOA4 will probably, from an engineering point of view, do some kind of validation check to see whether TOA4 identifies as abnormal the cases where they believe there is something wrong with the transformer. And vice versa, when TOA4 indicates there may be something abnormal about a transformer, you need to check that transformer, look at your records, and see whether TOA4 is right or not. Depending

on what is found, you may change some of your norms or make another kind of adjustment to ensure that TOA4 produces results you agree with, and you become confident that TOA4 is doing a good job of detecting abnormalities.

A new user of TOA4 doesn't have to change their methods of sampling or collecting the data, assuming that they already have good practices in place. TOA4, including RDGA, uses the same dataset and it's simply a matter of applying a consistent automated interpretation method with appropriate criteria. Expert review is always required, since software is never perfect and it may fail to notice some cases or overreact to others, especially when there are data quality problems or special external circumstances.

The RDGA model is generic and does not require customization or a learning period for a particular transformer fleet



John Brett, P. Eng.

Over 30 years, John has held leadership roles in organizations that operated or provided solutions for demanding applications including utility operations, industrial automation, and navy command & control. As an early principal at Tantalus, a leading utility communications company, John helped establish and build a real-time, two-way network to automate utilities all the way to consumers; a model that is now standard for grid modernization projects. In 2015, John joined Delta-X Research as Chief Executive Officer. John received his electrical engineering degree from the Royal Military College of Canada and is a registered Professional Engineer in the Province of British Columbia, Canada.