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Dissolved Gas Analysis: Use Case and Statistics for Advanced HVDC Application

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SUMMARY

The National Grid HVDC Converter Station, located in central Massachusetts, is one of three stations in the Quebec-New England Multiterminal DC Network (MTDCN) that serves to import over 5000 GWh of power into the New England region each year. [1] First commissioned in 1990, the station employs the use of six oil-filled converter transformers alongside three oil-immersed shunt reactors. Having been in service over 20 years, these devices are kept under close monitoring to mitigate risk associated with age degradation. After routine testing discovered evidence of severe deterioration, the station installed nine real-time Dissolved-Gas Analysis (DGA) units to measure the gaseous composition of the devices' internal oil. As a result, National Grid HVDC has since used this chemical analysis to assist in estimating equipment health, detecting incipient faults, and guiding preventative maintenance actions to preserve device integrity. [2] Providing great value, the DGA system has been additionally upgraded for remote data collection, and the system's versatility provides excellent opportunity for further enhancements. Using historical data, this paper will present an active HVDC use case for DGA and describe the observations made through its continued application.

KEYWORDS

HVDC, Dissolved Gas Analysis DGA, Converter Transformer, Reactor, Oil, Total Dissolved Combustible Gas Concentration TDCG, MOXA, Fibre Cable

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THE USE CASE

At the National Grid HVDC Station, there are six converter transformers currently in operation. The station has two poles (hereafter referenced as Pole 1 and Pole 2) that transmit the MTDCN imported power, each of which have three transformers installed for their A, B, and C phases. In addition, the station's AC network contains three shunt reactors in its structure, designated with the denominations R1, R2, and R3.

To maintain safe and reliable operation, the station performs routine diagnostic evaluations on all service equipment, including analyses specific to oil-insulated devices. One of such tests, historically performed by the station every six months, is the method of Dissolved Gas Analysis (DGA). This test requires the manual extraction of an internal oil sample, that is then packaged and shipped to the Doble Laboratory of Massachusetts for examination. Here, the lab analyzes the sample to identify the concentration levels of specific gases that have dissolved in the oil, which are then examined and quantified in a comprehensive report. [3] The gases being measured, also referred to as the "principal gases" for DGA, are predominantly Nitrogen (N_2), Oxygen (O_2), Hydrogen (H_2), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), and Acetylene (C_2H_2). [4] The presence, amounts, and generation rates of these gases are then compared to industry standard typical values (see ANSI IEEE Std. C57-104) to provide research-based interpretations of the device's health The characteristics of these gas levels are said to directly correlate to the presence, type, and approximate location of incipient faults within the device [3] [5] As an example, if DGA results show a sustained increase in acetylene generation, this is said to be indicative of an active, high-energy internal arc suggesting imminent failure. [3] Similarly, increased production of carbon monoxide and carbon dioxide are linked to the deterioration of internal cellulose (paper) insulation, meaning high levels signal the need for proactive measures to mitigate an incipient fault. [3]

Interpreting DGA data is a complex process that does not have a one-size-fits-all approach. Each transformer and reactor are unique, and require individual considerations based on the device's age, usage, and other individual characteristics. The accuracy of DGA testing can be affected by a variety of different factors, especially while taking manual samples, as human error, sampling type, and oil temperature can all influence testing precision. [5] Moreover, the existence of numerous DGA interpretation schemes may result in conflicting and differing diagnoses, occasionally making the DGA test alone insufficient to justify major corrective actions. [4] As such, in addition to the semi-annual Doble DGA analysis, the National

Grid HVDC team made the decision to install a continuous DGA monitoring system, a Multi-Gas DGA Analyzer "CoreSense ™ M10" unit, on each of the nine oil-insulated devices in service. The decision to install the DGA units was the result of a culmination of reasonings, including the aging of the devices (i.e., increased likelihood of faults), rising gas levels observed in previous Doble reports, and the overall desire to acquire the most accurate data available. Other anticipated benefits of the continuous monitoring system were the ability to observe transient faults with faster sample rates, automated trend analysis, hot spot and aging calculations, and insulation moisture monitoring and modeling. [2] Thus, the DGA system's installation would prove to greatly enhance the understanding of each device's health, providing continuous data and instrumental trend reports through out all operating conditions.

INSTALLATION AND PROCEDURE

Figure 2: *Close-up image of the DGA CoreSense Sensor Head installed on the cooler drain valve of the transformer.*

The CoreSense DGA system is comprised of two main components: the sensor head, and the analytical unit. [6] Based on clearance, physical access considerations, and the transformer being energized for installation, the station chose to mount the DGA sensor head to the cooler drain valves on the converter transformers (shown in Figure 1) and the three reactors. The analytical unit of the CoreSense was attached to the sensor via a permanent conduit, which contains all gas, communication, and power lines necessary for the two units to interact. [6] For the transformers, these analytical units were mounted to an adjacent structural wall, while the units for the reactors were placed on nearby housing supports. To retrieve the analytical unit's data, PC connection via an ethernet cable is required, from which a dashboard with all readings, calculations, and graphical data can be

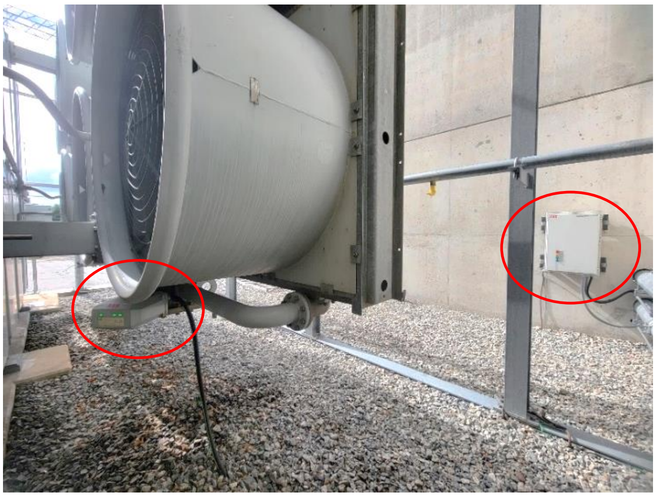

Figure 1: *Image showing the location of the CoreSense Sensor Head (left) and the CoreSense Analytical Unit (right) installed on one of the six converter transformers.*

accessed. From 2017 to 2019, the engineers at the station would travel outside and connect to the analytical units with a laptop, where they could then view and download the needed information. However, safety precautions, weather conditions, and the overall desire to “find a better way” motivated the station to upgrade their DGA system to improve this process. Thus, in 2019, a Moxa 24-port ethernet switch was installed within the station’s interior control room, from which fibre optic cables were routed down through the building to connect with six of the DGA units outside. [7] As their location was closest to the control room, and with their data being of most interest, the six units chosen to trial the system were the converter transformer units. With the distance between the DGA units and the Moxa switch being under 400ft, the station chose 62.5u multimode ST fibre cable as the connection medium for the system. From this, an ethernet cable could then be plugged into the Moxa switch to retrieve the DGA data being sent through the fibres. This setup has proven greatly successful, and has allowed engineers to safely retrieve data with higher efficiency and accuracy than before. Having such an accessible interface has even enabled the station’s operators to collect data in an engineer’s stead, adding an extra layer of system supervision as it becomes part of the control room’s daily routine. Finally, with its modular setup and spare connections, the Moxa/fibre connection system provides opportunities for further future enhancements. These upgrades could include adding the final three DGA units to the Moxa system, the creation of integrated control room DGA alarms, or even the connection of other inaccessible systems around the station network. Undoubtedly, the

__Figure 3:__ Image showing the location of the the CoreSense Analytical Unit (left) and the CoreSense Sensor Head (right) installed on one of the three station reactors.

__Figure 4:__ An image of the Moxa switch enclosure and fiber connections (orange) located in the control room. The blue ethernet cord connects directly from the Moxa switch to an engineering laptop for data exchange.

benefits of this “remote” access feature have made a significant impact in the equipment maintenance process.

DATA PRESENTATION

National Grid HVDC’s continuous DGA monitoring systems have been measuring the levels of Acetylene (C_2H_2), Ethylene (C_2H_4), Ethane (C_2H_6), Methane (CH_4), Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Hydrogen (H_2), along with H_2O moisture levels for the past four years. In addition to performing trend and ratio calculations, the DGA unit also offers the Total Dissolved Combustible Gas (TDCG) method of analysis. This TDCG value is, at its most basic, a summation of dissolved gas concentrations that can provide an “overview” of the device’s internal health. [2]

In 2020, with the decision influenced heavily by concerning DGA results, National Grid’s Pole 1 C-phase converter transformer was decommissioned after more than 20 years in service. In Appendix A Table 1, the TDCG values calculated by its continuous DGA monitor before its retirement are graphically represented. It can be seen that prior to its removal, the TDGC levels were trending above 5020 ppm for the transformer on a daily basis. The ANSI IEEE C57-104’s DGA concentration level limits, seen in Figure 5, suggest this transformer was therefore at the most comprised status of Condition 4. Of additional interest were the individual gas levels: Appendix A Table 2 shows the concentration of ethylene above 1760 ppm, alongside Ethane levels above 615 ppm shown in Table 3. In contrast, Table 4 shows that acetylene levels remained below 0.5 ppm, suggesting that the difference in gas levels could indeed allude to a specific type of fault, rather than all gases simply being elevated. The ANSI IEEE C57-104’s *Key Gases and Fault Type Guide* states that high levels of any of these gases could point to potential arcing, overheated oil, or partial discharge faults depending on the amount and combination of the above gases. [3] As such, the station chose to replace the Pole 1 C Phase transformer as a precaution with an unused spare, purchased alongside the other six back in 1990. After successful installation and reattachment of the DGA monitor, Table 5 shows the new Pole 1 C-phase transformer’s TDCG values, trending at under 20 ppm. With the lowest condition level in IEEE C57-104’s being TDCG values under 720, the DGA results verified that the new transformer was in excellent operational health, opposed to strained and deteriorated previous device. [5] Investigation into the cause of the old transformer’s high gas levels remains ongoing, and its conclusions will provide valuable insight into the accuracy of its DGA test interpretations.

After being in continuous operation since its installation two years ago, the station has observed the new transformer's concentration values rising over time. Shown in Table 6, the TDCG concentration levels have increased from 20 ppm to just under 600 ppm between May 2020 to July 2022. Based on its age and uninterrupted usage, a steady increase in gas levels is expected over the course of time, and is not a concerning situation by in and of itself. Moreover, these levels indicate the transformer remains at the satisfactory level of IEEE C57-104 Condition 1. [5] In comparison, Table 7 presents two years of TDCG data for the Pole 1 A Phase transformer, which has now been in service for over 25 years. The TDCG concentration level is reaching close to 1300 ppm, and is consequently at Condition 2. Not only does this data highlight the satisfactory health of the new transformer, it also illustrates the severity of the old Pole 1 C-phase transformer's condition, as this A-phase unit had also been operating for over two decades. Thus, the station will be continuing to monitor DGA results, and will place special consideration on the rate of change for the Pole 1 C phase transformer in comparison to its counterparts.

CONCLUSION

Despite hesitancy in the industry to acknowledge its credibility, DGA testing has proven to be an invaluable tool for the National Grid HVDC team. The station has used DGA data to direct preventative maintenance, identify potential faults, and examine data trends when needed. After alarming gas levels were identified during a routine semi-annual DGA test, the station responded by installing a continuous DGA monitoring system on each of its nine oil-filled devices. With this readily accessible and highly accurate data, the HVDC team has been able to make preventative decisions to protect the integrity of the station's operation. Having proven its value, the station will continue to utilize and enhance dissolved gas analysis testing as a major diagnostic tool for maintaining safe, reliable, and efficient station operation.

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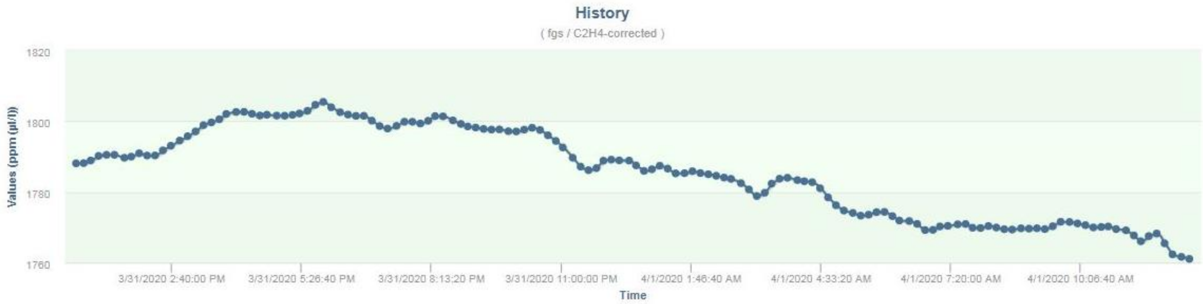
APPENDIX A

<u>Table 1:</u> *A graph showing the TDCG data of the Pole 1 C Phase converter transformer before its decommissioning. Date ranges from 3/31/2020 to 4/1/2020.*



<u>Table 2</u>: *A graph showing the DGA C2H4 (Ethylene) levels on the Pole 1 C Phase transformer before its decommissioning. Date range of 3/31/2020 and 4/1/2020.*

<u>Table 3:</u> *A graph showing the DGA C2H6 (Ethane) levels on the Pole 1 C Phase transformer prior to its decommissioning. Date range of 3/31/2020 to 4/1/2020.*

<u>Table 4</u>*: A graph showing the DGA C2H2 (Acetylene) levels on the Pole 1 C Phase transformer prior to its decommissioning. Date range of 3/31/2020 to 4/1/2020.*

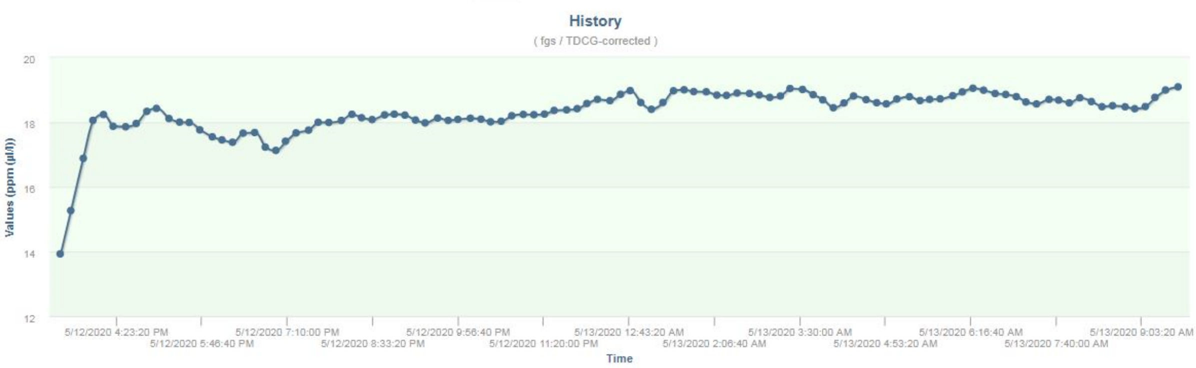


__Table 5__: A graph showing the TDCG data for the new Pole 1 C Phase transformer after replacing its predecessor. Date ranges from 5/12/2020 to 5/13/2020.

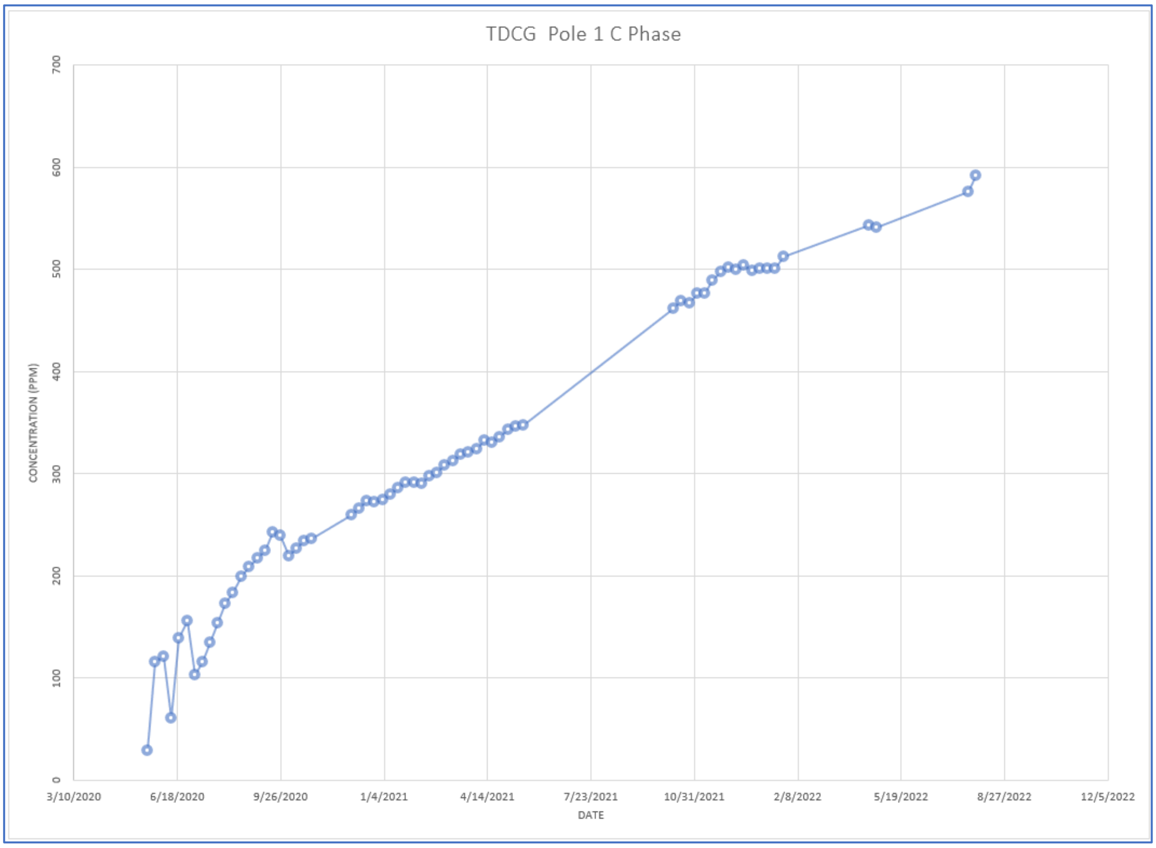


__Table 6:__ A graph showing the TDCG data for new Pole 1 C Phase transformer between 3/10/2020 to 12/5/2022.

Table 7: *A graph showing the TDCG values for the Pole 1 A Phase transformer between 3/10/2020 to 12/5/2022.*