2020 INTERNATIONAL CONFERENCE OF DOBLE CLIENTS

TENTATIVE TECHNICAL SESSION PROGRAM AS OF FEBRUARY 28, 2020

The review of the discussion subjects received at the Doble Client Committee Meetings in Vancouver, British Columbia, Canada as well as additional items raised at the meeting led to the formulation of the following tentative Technical Session Program for the 87th International Conference of Doble Clients. This program is subject to change.

ARRESTERS, CAPACITORS, CABLES AND ACCESSORIES COMMITTEE TECHNICAL SESSION
Grand Ballroom AB | Wednesday, March 11, 2020 | 9:30 AM – 12:00 PM

1. Improvements in Arrester Standard IEEE C62.11-2020 and Harmonization with IEC 60099-4
Jonathan Woodworth, ArresterWorks

For more than 10 years, there has been an informal effort to harmonize the design tests of IEEE C62.11 and the Type Tests of IEC 60099-4. The purpose of the harmonization was to jointly develop practical tests that are more relevant to Metal-oxide arresters than in the past. By March 2020, the latest IEEE C62.11 standard will have been issued. This paper is an overview of changes in this edition and how IEC and IEEE are now harmonized.

2. Polymer 8.4 kV MCOV Low-Side Transformer Arresters and Wildlife Mitigation
Nick Choi, P.E. and Julian Franklin, E.I.T., Lower Colorado River Authority

Lower Colorado River Authority (LCRA) experienced many 8.4kV MCOV arrester failures on power transformers due to animal contact. The porcelain housing of the 8.4kV MCOV low-side arrester is only 3.5 inches tall and is susceptible to failures caused by birds and snakes. LCRA used to install bird covers on the arresters, but the covers became nesting places, depending on the workmanship of the installer.

As an alternative, LCRA has started to use polymer arrester that has the same MCOV rating as the porcelain arrester. The polymer arrester is equipped with smaller top and bottom metal fittings and a taller housing in comparison to the porcelain arrester. These dimensional differences make the polymer arrester advantageous in preventing failures due to contacts by birds and snakes.

Since the polymer arrester application is new for LCRA, Mr. Choi is currently evaluating suitable wildlife mitigation options that would further improve reliability.

3. MV Cable Joint Failure Investigation at a Middle Eastern Petrochemical Facility
Simon Sutton, Doble Engineering Company

A petrochemical plant had suffered two recent medium voltage (MV) cable joint failures in a period of just three to four months. The cables were 34.5 kV, 3x300 mm^2 copper conductor XLPE-insulated, and had been in service for only four years. During the investigation, another joint failure occurred. The client was worried about the reliability of all the joints in the two circuits installed as part of the original project.

Two cables were supplied for examination:

- One which had faulted
- One in good condition

The cables were stripped down at a Doble facility and subjected to various forensic techniques. The root cause of failure in this case was metal wires found in the semiconducting tapes over the conductor connector. The source of the contamination was also identified during the investigation. Only one of the six joints examined had been contaminated with wires. However, a more worrying systematic error in the installation of all the joints was identified. This will be discussed in the paper.

4. Partial Discharge (PD) Alarm Tool for Online Detection of Partial Discharges in Medium Voltage Accessories: Technology and Case Stupolys

Lionel Reynaud, Hydro-Quebec's Research Institute
Michel Trépanier, Hydro-Quebec

In 2009, Hydro-Québec began using a partial discharge automated diagnosis tool developed and designed for use by non-expert workers for their own safety in underground vaults. Called the PD Sniffer. In 2014, scientists at Hydro Québec's research center began developing a new partial discharge detection device called PD Alarm. Like the PD Sniffer, this device must quickly detect and locate partial discharges on accessories, but the goal is to improve its portability while maintaining its efficiency (false negatives still prohibited) and drastically reducing its cost.

PD Alarm is a lightweight device with two antenna sticks held in each hand. It is in detection mode as soon as it is turned on and warns the user promptly when the two antennas pick up a partial discharge between them, for example when they are placed on each side of a straight joint.

A visual indicator on the device and an audible signal warn the non-expert worker of the presence of a partial discharge between the two antennas. Advanced users can also view and save partial discharge signals for further analysis. The antennas are designed to respond to an optimized frequency range that ensures the best results at the lowest sampling frequency.

The article provides a brief overview of Hydro Québec's underground structures and the work processes designed to ensure worker safety. The PD Alarm technology and design is described including the signal processing that give to the PD Alarm ideal speed and accuracy for a device of this size. Finally, some case studies are presented.

5. 115kV Self-Contained-Fluid-Filled Cable Splice Rebuild based on Dissolved Gas Analysis

David Campilii, National Grid

Based on DGA results, National Grid disassembled a cable splice on a 115kV self-contained oil filled cable. Gas concentration on the sample suggested partial discharge activity in oil and thermal conditions in the paper insulation.

High concentrations of almost every combustible gas, was reason enough to take remedial actions. Upon disassembly of the splice, significant discharge activity was found at the shield break and at the stress cones on both ends of the splice. After disassembly, the splice was rebuilt on the existing cable (which appeared undamaged).

The DGA and planned rebuild definitely prevented an in-service splice failure. Details of the case will be reviewed.

ASSET AND MAINTENANCE MANAGEMENT COMMITTEE TECHNICAL SESSION

Panel Session: Recent Experience in LTC Maintenance and the Continued Use of DGA as a CBM Tool
Grand Ballroom AB | Monday, March 9, 2020 | 9:00 AM – 12:00 PM

Panelists:

- Jude Beyerle, Louisville Gas and Electric and Kentucky Utilities
- Tom Rhodes, Duke Energy
- Lyndal Cost, Alabama Power
- Ashley Geigel, Baltimore Gas and Electric
- Steve Larson, Snohomish PUD
- Jon Allen, Avangrid

Panel Session: Insurance Companies Perspectives & Issues
Grand Ballroom AB | Tuesday, March 10, 2020 | 4:15 PM – 6:15 PM

Panelists:

- Gregg Basnight, National Machinery Manager, AEGIS Insurance Services, Inc
- Shuzhen Zhu, Senior Engineering Specialist, FM Global
- John Roach, Assistant Vice President, Hartford Steam Boiler
- Anastasia O'Malley, Project Manager, Consolidated Edison Company of New York

Paper Session
Grand Ballroom AB | Thursday, March 12, 2020 | 8:00 AM – 12:00 PM

1. Maintenance Intervals and Practices
Jackie Brusoe, Western Area Power Administration

The purpose of the proposed paper is to share WAPA's preventative maintenance (PM) practices for power circuit breakers. WAPA uses a time-based PM utilizing Reliability Centered Maintenance (RCM) methods to define maintenance tasks and frequencies.

2. Digitizing Distribution Substations at Tokyo Electric Power Company Power Grid (TEPCo)
Atsushi Eto, Tokyo Electric Power Company Power Grid

At TEPCO, there are approximately 1,600 operating distribution substations, for which, efforts have been made to reduce the manpower for on-site equipment inspections. To strive to reduce transmission costs, TEPCO Power Grid has applied digital technology for these distribution substations. For example, automatic measurement of switching times of switchgear breakers and OLTC has been implemented. Artificial Intelligence (AI) is also being developed to inspect for abnormities by image data processing with network cameras. To realize the digitized distribution substation, the monitoring devices and sensors for each equipment were examined and smart equipment was developed with new designs. Also the IEC61850 protocol has been used to avoid the restriction of interconnection between a telecommunication control system and each device by manufacturer's domestic protocols. The TEPCO Power Grid's perspectives and challenges for digitizing the distribution substations will be described.

3. Snake Fence Material Improvement
Nick Choi, Lower Colorado River Authority

Lower Colorado River Authority (LCRA) experienced repeated snake contacts on low side transformer surge arrester in 2014 and 2018. These events resulted in customer outages. During the failure investigation, heavy rust (corrosion) was observed on the animal deterrent electric fence. Fence charge was tested and was reported to be low and ineffective. Galvanized steel should remain corrosion free for a several decades with proper installation and use of similar metals. After a further assessment, LCRA learned dissimilar metals were used in the assembly of electrical fence; the fence experienced rust due to galvanic corrosions.

LCRA reviewed half a dozen design improvements and different material combinations. Stainless steel and aluminum are excellent choice for fencing that does not rust, but their price did not make an economic sense. Zinc plated bolts are not rated for outdoor use and also came in contact with stainless steel. LCRA had considered galvanized screw and galvanized clip combinations. However, small size galvanized screws are not available due to manufacturing limitations that small screws treads cannot be retained its' shape after a hot deep galvanized process. At the end, LCRA selected stainless steel and galvanized steel while ensuring rubber cushion provides a physical barrier between the dissimilar metals.

The improvement is expected to reduce future repair/maintenance cost, maintain effectiveness of animal deterrent fence, and aid in preventing outages due to animal contact.

4. Condition of Maintenance: Understanding What It Means
Ron Widdup, Shermco Industries

After installation, commissioning, and initial energization of electrical equipment a process of aging and decay begins. How long the equipment provides reliable and safe operation is a direct result of how well it is maintained. The industry realizes this, and there is a trend towards having a better understanding of the "condition of maintenance," especially as it relates to personnel safety. NFPA 70E has a new definition of condition of maintenance and has requirements for electrical workers to understand equipment condition before interacting with it. A significant aspect to electrical workers and management personnel, this presentation will address how condition of maintenance is fast becoming a critical component to electrical safety, equipment reliability, and overall performance. The presentation will identify current and future movements in maintenance and reliability practices and will provide the latest industry codes and standards references, helping the attendees to be knowledgeable of industry trends and rules.

5. On-line Monitoring – More Than A Question of Technology – Strategic Considerations
Shelvin Kumar, Puget Sound Energy
John Skog, Maintenance and Test Engineering LLC

With a much better understanding of asset failure modes and advances in technology, maintenance and business decisions are continually more information driven. On-line monitors are a foundation element of an information centered maintenance strategy and thus selecting monitors that are both technically robust and are complemented by your company's business, operations and maintenance culture are a requirement for success. This paper identifies and addresses the landscape of decisions as well as present lessons PSE has learned, as it has moved from On-line DGA as a novelty to On-line DGA as critical element of our transformer maintenance strategy.

6. Animal Contacts and Wildfire Ignition
Marty Niles & Darren Barnett, Greenjacket Inc.

A correlation has been identified between animal contacts on distribution power systems and the ignition of wildfires. This presentation will identify the five ways in which wildlife can cause fires with specific focus on how animal contacts on distribution power systems ignite wildfires. Supporting data on animal contacts with distribution power systems will show occurrences of at least 8% - 9% of wildfires in PG&E and SCE, respectively.

7. Assessing the Likelihood of Asset Failure
Alan Wilson & Tony McGrail, Doble Engineering Company

In this paper a number of different asset types are analyzed, looking at expected useful asset life, failure modes and timescales, and survival statistics. The result is a high-level view of transformers, breakers and other assets, identifying the determinants of in-service failure and linking the data and information through to an asset health index.

BUSHINGS, INSULATORS AND INSTRUMENT TRANSFORMERS COMMITTEE TECHNICAL SESSION
Grand Ballroom AB | Tuesday, March 10, 2020 | 1:00 PM – 4:00 PM

INSTRUMENT TRANSFORMERS

1. A Successful Internal Arc Fault Test on a Station Service Voltage Transformer: Test Requirements Overview and Lessons Learned
Huan Dinh, ABB Inc.

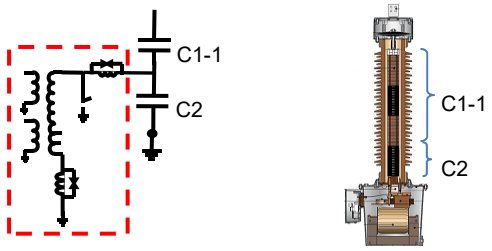
The requirements for an instrument transformer to withstand an internal arc fault are outlined in industry standards IEC 61869-1 and IEEE C57.13.5. Based on successfully performed Internal Arc Fault tests at 40 kA for 300 ms on a station service voltage transformer, in accordance with these standards, this paper will discuss pre-test studies, the actual test experience, and lessons learned during the course of testing.

The lessons learned and insights gleaned as a result of this endeavor include:

- A background of the requirements (proving tank rupture withstand)
- Why this testing is required for instrument transformers but not power transformers
- Tank rupture mitigation methods for power transformers vs. those for instrument transformers
- Ease of test performance, specifically in North America (e.g., lab availability, local safety and environmental regulations, etc.)
- Test success as a performance guarantee
- Validity of test requirements: fault current + duration vs. fault energy
- Alternative means for proving transformer tank strength
- Pros and cons of alternative media (e.g. water, air, TNT) to create sudden pressure and prevent oil fire.

2. Alternate Test and Doble Ratio Detects an Issue in the Metering Circuit of CCVT
Russell Bramlett, Santee Cooper
Long Pong, Doble Engineering Company

C1-1 and C2 tests are well known as the standard test method for assessing the condition of the capacitors in the bottom porcelain of a CCVT. However, the metering circuit, shown in red box of Figure 1, connected to the POT terminal between the two capacitors is not included in the measurement, therefore an issue developed in that circuit can stay undetected. If the Alternate test and Doble Ratio tests are performed, the metering circuit will be stressed by the test voltage drop and will influence the test results when an issue has developed as described in this case study.



a) Typical Electrical Circuit Diagram b) Typical Physical Layout

Overview of Typical One-Porcelain CCVT
Figure 1

BUSHINGS

3. Online Monitoring and Investigation Examples for ABB O+C Bushings
Belinda Di Marco & Colin Clark, AltaLink

Active partial discharge and an increasing power factor trend were detected with online monitors on relatively new bushings. AltaLink investigated further considering that the bushings were only two years old. By analyzing the PD pattern and comparing it with available literature it was speculated that the presence of PD was likely due to floating particles in oil. The presence of particles does not affect the C1 readings but can affect the Power Factor results since generating an additional conductive current. Also, the presence of Partial Discharges can generate abnormal level of gases which were confirmed through DGA. This paper will discuss the monitoring results as well as the subsequent bushing investigation results.

4. PCore 230 kV Bushings with Elevated Power Factors
Lyndal Cost, Alabama Power

Alabama Power has identified several bushings with elevated power factor in the 230 kV class. The six most recent have the following catalog numbers: POC900G1216MS, POC900G0800PS, POC900G0800S and POC750G0800S. They were manufactured between 2009 and 20015. Electrical testing and a teardown were performed at PCORE's facility. Alabama Power has DGA results confirming there is an issue. Hydrogen gas was the highest in concentration. There are trace amounts of Acetylene and heating gases all present. They also have results from paper samples using microscopy that indicate polar contaminates are present.

This paper will explain the testing results and findings from the manufacturer.

5. Benefits of C2 Testing on Bushings and Case Studies
Steve Long, Alliant Energy
Mario Pitre, Aluminerie Alouette
Long Pong, Doble Engineering Company

There have been many questions on the diagnostic significance of the C2 test and its value, so this paper will examine the technical aspect of the C2 insulation system, the test benefits and provide a collection of case studies from field experiences. Two case studies will be described in detail in the paper. The first one was at Alliant Energy involving ABB type O+C bushings rated 69kV manufactured in 2005. The second case was at Aluminum Alouette involving an ABB type O+C bushing rated 46kV manufactured in 2003. A collection of other cases will be summarized in a tabulation in the paper.

6. Results of Simulated C2 Ground Connection with Bushing Monitoring Sensors
Julian Rodriguez, ABB-Micafil

ABB released a service advisory in 2016 that applies to IEEE RIP bushings 115kV and above with a voltage tap. The issue is the soldered grounding connection between the normally grounded condenser foil and the flange may deteriorate after leaving ABB's factory. This could lead to compromised performance while in service. There was a concern that this issue could be exacerbated by the presence of any applied bushing monitor. Doble IDD bushing monitors include test tap adapters which are fail safe, but it was thought prudent to test them at rated voltage and beyond.

ABB Switzerland Ltd. and Doble performed extensive measurements on a 550 kV test bushing (type RTF 550-1800/1000 KSI) in combination with two Doble bushing adapters of the type BTT-A-04 and 03C-1451-04 for Doble's bushing-online monitoring systems. It was found that the tested bushing adapters could maintain the current through the capacitance C1 to ground under nominal voltage and AC test voltages conditions even when the bushing tap internal ground connection is missing. This paper will describe the testing performed to verify bushing tap sensors could be utilized with these bushings.

CIRCUIT BREAKERS COMMITTEE TECHNICAL SESSION
Grand Ballroom AB | Monday, March 9, 2020 | 1:00 PM – 6:00 PM

1. Working in Switchgear Cubicles Just Got a Lot Safer: The Cubicle Inspection and Repair Safety (CIRS) Device
Eric Fell, Consolidated Edison Company of New York

This paper will review the background safety concerns and development of an additional safety device that Consolidated Edison Company of New York (Con Edison) has used for switchgear cubicle maintenance.

The Cubicle Inspection & Repair Safety Device (CIRS Device) provides a safer work environment within switchgear cubicles by eliminating the risk of accidental/incidental contact with energized bus components. The device provides ability to safely perform inspections, preventative maintenance and corrective maintenance without the need for a bus section outage. The device is currently being piloted throughout the Con Edison territory and has already proven to be a safe and reliable solution when deployed for emergency corrective maintenance events.

2. How to Avoid Medium Voltage Circuit Breaker Failures – New Standards Simplified
Samy Faried, PE, ABB

Every medium voltage (MV) circuit breaker (CB) has a maximum interrupting rating at a specified X/R value. A CB may catastrophically fail when called upon to operate if the specified X/R is exceeded. This due to the resulting asymmetrical DC and total current components which may exceed the CB capabilities. This presentation explains the crucial recent changes in IEEE C37.010-2016 and IEC/IEEE 62271-37-013-2015. The X/R value, relay time, and the CB contact opening time play a major role in determining the value of the DC component that is stacked on top of the symmetrical AC current wave. Building upon these new standards, we will clarify and cover the CB selection process to ensure proper CB application.

3. Particles in HV Circuit Breakers
Todd Irwin, GE Renewable Energy

Particle contamination is a major concern in the operation of gas circuit breakers – even tiny particles can cause flashovers in the tight-tolerances within gas circuit breakers. This paper will be a review of an engineering study of the effect on particulate contamination on high voltage circuit breakers and the implementation of particle traps. The presentation will include high speed video of various particle study tests.

4. High Voltage F-gas Free Switchgear Applying CO2/O2 Gas Mixture with a Variable Pressure Scheme
Toshiyuki Uchii, Toshiyuki Saida & Daniel Schiffbauer, Toshiba

Much research regarding SF6 alternatives has been done during the last decade. Some of the major proposed alternative gases still contain artificial fluorinated gases in the mixtures. Despite lower global warming potential (GWP) and quite good dielectric properties, the artificial F-gases exhibit practical limitations. Therefore, it may be beneficial to pursue an F-gas-free “natural gas” based solution with elevated pressure. The present paper describes the key properties of the CO2/O2 gas mixture as a candidate of natural alternative gases to SF6 and the technical achievements.

5. Switch Vacuum Interrupter Component Failure
Nick Choi, Lower Colorado River Authority

This paper will review three case studies of vacuum interrupter failures on transmission disconnect switches. After an investigation, the OEM provider confirmed that the pickup fingers of the interrupters were losing 40% of material in just 10 operations of breaking 2000A load current. After raising concern about this, the manufacturer released improved pickup fingers to improve the life of the interrupter.

6. Online High Voltage Disconnect Maintenance – BC Hydro's Recent Experience
Arthur Carr, BC Hydro

This paper has been deferred to the 2021 Conference

BC Hydro has been working for the past five years to develop new work methods and equipment to eliminate all required planned maintenance outages on several 500kV radial lines. BC Hydro is in the process of implementing the develop solution, which involves a new type of disconnect switch design. The paper will cover the problem and operational need that caused BC Hydro to begin developing the new switch design, the process that was undertaken in the design, and the next steps in the development and deployment of the new switch.

7. 345kV Oil Circuit Breaker Leak Repairs
Dean Oswald, American Transmission Company
Steve Wickman, Transmission & Distribution Services

This paper will review specific oil leak repairs that American Transmission Company (ATC) had on oil circuit breaker bushings. The first two repairs were done on two separate Westinghouse 3450-GW-25000 oil circuit breakers, manufactured in 1970. The leaks were base gasket between the porcelain housing and steel flanges. The third repair was on a Westinghouse 145-GM-20 oil circuit breaker, manufactured in 1972. The leak was found to be at the gasket behind the bushing's potential tap insulator. All three breakers were repaired successfully. The paper will detail the leaks, the repair process, and the long-term outcome of the repairs.

8. Investigation of X-Ray Technology to Assess the Technical Condition of High-Voltage Minimum Oil Circuit Breakers
L.A. Darian, P.V. Golubev, E.P. Grabchak, R.M. Obraztsov, JSC Technical Inspection UES and Ministry of Energy of Russian Federation

This paper presents the results of the studies of non-destructive X-ray testing method capabilities of high-voltage oil-filled equipment based on VMT-110 minimum oil circuit breaker with porcelain external insulation. The main advantage of the examined method is the possibility of efficient non-destructive testing of internal elements of high-voltage oil-filled equipment located at the installation site without dismantling.

The characteristics of four different ionizing radiation sources were analyzed to examine the possibility to use them in testing HV oil-immersed equipment in operation. An instrumentation and analytical system (IAS) based on monoblock X-ray unit with direct-current tube voltage and directed radiation output is suggested. After the analysis of possible reasons for failures of VMT-110 circuit breakers during their operation a list of specific defects and Special Defective Sample (SDS) were created for laboratory studies. The results of SDS examinations showed that this technical solution allows to reveal at least 75% of specific types of defects in internal structural elements of minimum oil circuit breaker.

The assessment of the method informativeness was carried out for inspection of high-voltage equipment technical condition. The resolution of X-ray image of the equipment is not worse than 1 mm of its original size.

Suggested radiographic system and control technology have been tested at four operating 110 kV voltage class substations.

9. Review of Battery Types Found in Substations
John Kim, Enersys

This presentation will review the differences in design, construction, and application of the most common types of batteries found within substations. The presentation will outline the differences between the battery types, where they are best used, why they are used in different applications, and what the pros-and-cons might be for the different battery types.

10. Gas Circuit Breaker Testing and Maintenance
Mike Wolf, Doble Engineering Company

Gas circuit breakers are common sights in most power systems today, but with such long maintenance intervals it is often easy to forget troubleshooting steps to take when test results are not as expected. The focus of this paper will be on troubleshooting and maintenance steps that are taken after routine tests come back with poor results. This paper will also focus on considerations to be made prior, during, and after the decision to perform an internal inspection/maintenance.

INSULATING MATERIALS COMMITTEE TECHNICAL SESSION
Grand Ballroom AB | Wednesday, March 11, 2020 | 1:30 PM – 6:00 PM

1. Introduction to the Doble Oil Survey 112
Eileen Finnan, Doble Engineering Company

Since the early 1950s Doble has been publishing the Oil Survey under the auspices of the Doble Oil Committee. At the end of 2019, the Oil Committee was rolled into the Insulating Materials Committee. As a result, the entire client community now has access to this valuable document and its insights. Each year, refinery samples of transformer mineral oil are tested according to the specifications listed in Doble TOPS (Transformer Oil Purchase Specifications). This presentation will discuss what the Oil Survey encompasses, the products that are involved and how to interpret the data.

2. Keeping a Large GSU Transformer Energized with a Gassing Problem
Brendan Diggin, ESB International

3. Project ULTRA - Scoring the Diagnosis Rather Than the Symptoms
Asim Bashir Bajwa, Mohamed Khalil & John Lapworth, Doble Engineering Company

An updated scoring system for dissolved gas analysis (DGA) results for power transformers is described which attempts to not only differentiate between normal and abnormal results, but also indicate the seriousness of abnormal results in terms of the expected future failure rate. This is a development of an earlier system which was based primarily on simple weighted average of the key diagnostic gases, which while being very successful in differentiating normal and abnormal results and providing a consistent and objective assessment, did not grade the seriousness of abnormal results very well. To correct this, new algorithms have been developed to score the diagnosis rather than the symptoms.

This unique asset health index system shall be based on the interpretation of the DGA score and the assimilation of other condition indications. It is for this reason it has been decided to propose Project ULTRA, it stands for: Unified Logical Transformer Risk Assessment. The integrated technique will be useful for all ratings of oil-immersed power transformers and reactors.

The aim of this guide is to combine the best methodologies into an easy-to-use risk assessment platform. Initially a ‘top-down’ assessment will be implemented to answer the first two questions of a condition-based methodology:

- **Is it normal?** The intention is to filter out those assets which appear to be operating normal, so that resources can be focused on those other assets. This is effectively Detection of faults.
- **Is it serious?** The intention here is for all assets that cannot be reliably assessed as normal, a second stage of assessment is carried out to diagnose the fault and assess its prognosis and the appropriate remedial actions.

Several DGA scoring systems have been proposed which are based on weighting the levels or ratios of important gases, but these tend to exaggerate the score for faults which have unusual levels of certain gases, e.g. stray gassing, arcing/sparking or localized ‘bare-metal’ thermal faults, while potentially more serious faults such as winding faults which often have lower levels of the important gases are overlooked. Therefore, our principle will be to score the diagnosis rather than the symptoms. The paper will illustrate the proposal by discussing a few examples.

4. Review and Comparison of DGA Guides IEEE C57.104-2019 and CIGRE Technical Brochure 771-2019
Lance R Lewand, Doble Engineering Company and Morgan Schaffer Laboratories

Two new DGA guides were released in 2019, one by IEEE and one by CIGRE. This paper will review the new information contained in both the guides and will compare and contrast the two guides. Understanding the information in both guides will help to educate the people involved in managing apparatus from which DGA samples are taken. The DGA interpretation process is becoming more mature but more complicated and these guides area an attempt to help the user to assess the condition of the apparatus in a general sense.

5. Case Study on Transformer Faults Detected Using Online Dissolved Gas Monitors
Melissa Zajac, Doble Engineering Company and Morgan Schaffer Laboratories

Dissolved gas analysis (DGA) is the leading diagnostic tool in our industry for assessing the overall health of a transformer. While DGA has traditionally been performed in a laboratory setting, continuous monitoring of dissolved gasses by online monitoring equipment can lead to earlier detection and diagnosis of incipient fault conditions in transformers. Prompt fault detection is desirable as it can minimize the risk of a catastrophic failure. This case study paper will provide information about fault investigations that were initially launched due to abnormal gassing detected by online DGA monitors.

6. Methanol Formation and Distribution in Power Transformers
L.A. Darian, P.V. Golubev, R.M. Obraztsov, and A.V. Maksimchenko, JSC Technical Inspection UES, Russia

The paper presents the results of a research of the formation of paper insulation's degradation product – methanol – a third generation aging marker. The objects of the research carried out by the authors were cable paper K-120 and transformer oil GK. All investigated materials are of Russian origin. Aging of paper insulation was carried out in specially designed cells placed in a circulation bath. The authors obtained the relationship establishing the correlation between the amount of methanol which was formed and dissolved in the transformer oil during the thermal destruction of paper insulation and its degree of polymerization. The data are compared with the results of similar experiments by other researchers. The results of the analysis of methanol content in oil from several dozens of 35 110 kV power transformers that are in operation at the electrical networks of the Russian Federation are presented. A new parameter – "specific volume of methanol" – is proposed for evaluating the degree of aging of hard (paper) insulation.

This paper was supposed to be presented at the 2019 conference, but the author did not receive his visa in time to attend. He has received his visa and will attend the 2020 International Conference of Doble Clients.

7. Determining Mineral Transformer Oil Compositions and their Aging Characteristics and Effects on Gasket Materials
Clive W. Buttrey, Middle Tennessee Electric Membership Corporation

The Middle Tennessee Electric Membership Corporation (MTEMC) purchases new power transformers directly from the manufacturer. Historically, multiple purchases are made from a single bid specification; with incremental changes made as technology and needs evolve. Until 2019, MTEMC only specified that its transformer oil "shall be inhibited mineral oil. The transformer shall be filled to normal operating level. The oil shall be certified Non-PCB according to the latest EPA regulations and shall be all applicable ANSI standards." This specification has been narrowed as of 2019 to specify specific vendors and specific products.

Over time, three "sister" units, constructed in 2000 and 2001, began to exhibit high CH / CHL / CL power factor values after approximately 15 years in service. MTEMC's typical experience with similar manufacturer's units outside this time period ("cousin" units) has been that water has leached slowly from

the insulation system over time due to subpar factory and field filling procedures and caused the test power factors to increase. A thermal dehydration of the three sister units did not remedy the problem like it had with the “cousin” units. Further investigation showed the main tank oil power factor at 100°C to be 11 and 15 %; and the oil showed significant discoloration – much like reactive LTC oil with arcing contacts. Fuller’s Earth reclamation of the oil restored the power factor at 100°C to less than 1% and the overall power factor tests on the transformer responded as well with values at 0.3% or less. This paper will present analysis of detailed mineral oil testing performed on this set of sister units, as well as units from other time periods from the same vendor, and other vendors used by MTEMC. Of particular interest is the evolution of mostly paraffinic ultra-refined mineral oils and their excellent gasket compatibility. An investigation into the gasket materials being used and their compatibility with naphthenic and aromatic compounds as well as paraffinic compounds in the degraded “sister” units will be conducted this fall and results included in the study.

8. The Impregnation Rate Into Laminated Pressboard for Various Insulation Liquids

Ed Casserly, Juan Acosta & Andy Holden, Ergon Refining Inc.
Brad Greaves & Tom Prevost, Weidmann Electrical Technology Inc.

The ability for the insulating system of an oil filled transformer to perform properly relies on the relationship between the solid and liquid insulation. Neither the solid nor the liquid insulation can be used independently of one another and thus the ability for the liquid insulation to fully penetrate/impregnate the solid insulation is essential. The solid insulation needs to be fully impregnated with the liquid insulation for effective dielectric properties thus the impregnation times are also used after transformer oil filling to estimate required sit times prior to energization. The ability for this impregnation to take place is dependent largely on two factors; the permeability of the solid insulation (based on density) and the viscosity of the liquid insulation (dependent on the temperature). Higher density solid insulation absorbs less liquid and requires longer impregnation times. In addition to the high-density characteristic of laminated pressboard, the adhesive that is used to produce it creates a barrier between the layers of pressboard which oil cannot penetrate. This requires the impregnation to be achieved only through the edges of the material.

Four insulating liquids of varying chemistry and viscosity were tested to determine the rate of penetration/impregnation into laminated pressboard at three temperatures (25, 60, and 90 °C). Three of the liquids were mineral oils (naphthenic, isoparaffinic, and highly isoparaffinic) and the fourth was a natural ester (soybean based). All the liquids were inhibited oils, conforming to either ASTM D3487 or D6871.

The introduction of liquid insulation into transformers is generally performed at about 60 °C, under vacuum. In the experimental setup, the test temperature varied from room temperature to 60°C to 90°C. The laminated pressboard was dried under vacuum and submerged in the liquid at which time the vacuum was released, and the pressure increased to atmospheric pressure. The degree of impregnation was determined by X-ray analysis of the laminated pressboard. The tests were done in duplicate and two measurements (one from each end of the block) were taken so there were four measurements at each time and temperature for each oil.

Laminated pressboard generally has bored holes every 100 mm to facilitate dryout and impregnation, resulting in the longest distance from any hole to be approximately 71 mm. The time required to reach 71 mm at each test temperature can be calculated from the data collected. The relationship between the time to reach 71 mm and the temperature follows a power function. This allows the user to estimate the time for complete impregnation at any temperature or conversely, the temperature required for a given time constraint. These calculations, as well as the relationship to viscosity, will be discussed.

PROTECTION, AUTOMATION, CONTROLS AND COMMUNICATIONS TECHNICAL SESSION
Marina 3 and 4 | Tuesday, March 10, 2020 | 1:00 PM – 2:30 PM

1. **Relay and Automation Upgrade Project at Snohomish County**
   Steve Larson, Snohomish County Public Utility District

2. **Human Performance Errors in the Power Utility Industry: Approaches and Recommendations**
   Morteza Talebi, TRC Companies

Power substation testing and commissioning work critically depends on human performance and coordination. Human dependability is crucial in the power utility workforce due to its contribution to power system reliability. The consequences and effect of human error in this industry are instant, costly, and may even result in serious injury or death.

This presentation aims to share the author's view on current human performance errors in our industry and an analysis of person and systematic approaches. Based on these approaches, a series of recommendations are introduced to help power utilities and companies in reducing or eliminating human error in the power utility industry.

3. **A Brave New World – Substation Networks for Relay Engineer**
   John Bettler, Commonwealth Edison

ROTATING MACHINERY COMMITTEE TECHNICAL SESSION
Lewis | Wednesday, March 11, 2020 | 10:00 AM – 12:00 PM

1. SFRA Test on Stator – Experiences and Development of Guidelines

Long Pong, Doble Engineering Company
Craig Spencer, Calpine Corporation
Hugo Simard, Rio Tinto Alcan
Kent N. Smith, Duke Energy

The sweep frequency response analysis (SFRA) is well known technique for the diagnosis of power transformer windings and the test standard has been developed by different standard organization such as IEEE, IEC and CIGRE. Then the test method has been used successfully on other apparatuses such as harmonic filters [1] and rotors [2], however on the stator windings, the results were mixed, because many factors can influence the results. The stator winding is more complex, typically has multiple parallel circuits, numerous coil slots, different bus ring configuration and multiple ways to perform the tests. This paper will address the latter by examining different test protocols used in the past fifteen years and the test results, then propose an application guideline for a test procedure and data analysis. Examination of the past field test experiences are included for stators in different conditions: new, aged with bypassed coil, and failed units from two type generators (high and low RPM).

2. Root Cause Analysis of Generator Stator Failure and Condition Assessment of 13 Generators at the Kribi Power Plant in Cameroun

Jean-Michel Meunier, Engie (Laborelec)
Andre Landry Nyek, Globeleq
Etienne Dion, Doble Engineering Company

This paper has been deferred to the 2021 Conference

Globeleq, represented by Kribi Power Development Company (KPDC), operate a power plant in Kribi (Cameroon), with a total power rating of 216 MW running on natural gas. The power plant includes 13 Wärtsila 18V50DF engines coupled to ABB generators (AMG 1600SS12 DSE) with individual power ratings of 20.77MVA.

During major maintenance inspections of the generation set, many partial discharge traces have been observed at the stator slot exit. In September 2018, the differential protection relay VAMP265 of generator N°1 trips one hour after returning to operation (commissioning phase) due to phase-to-phase fault.

Globeleq missioned Laborelec company (Engie) to identify the root cause of generator N°1 stator failure and perform condition assessment of the 13 generators at the Kribi Power plant.

This document reports on the various investigations carried out by Laborelec and Doble Engineering Company at the Kribi Power Plant in November 2019.

3. The Relationship Between Vibration, Electrical Signature Analysis and Motion Amplification

Howard W Penrose, Ph.D., CMRP, MotorDoc® LLC

There is a corresponding relationship between vibration, electrical signature analysis and motion amplification in electric motors and generators. The presentation will show real-world comparisons between the technologies, discuss their strengths and weaknesses and how they can be used to provide a comprehensive view of the motor system. Vibration analysis provides a primarily mechanical view of the electric machine and individual rotating components using accelerometers and similar detection devices. Electrical signature analysis uses the electric machine airgap to analyze electrical and mechanical conditions of the incoming power to driven equipment. Motion Amplification provides a visual method using video with

the pixels acting as accelerometers providing a low frequency/low speed method of analysis. Following this presentation, the student will have a basic understanding of the relationship between the technologies; the limitations of each technology; and, how they can provide a full view of different conditions of the machines.

4. Key Stator Coil Specification Elements – A Practical Discussion of What They Mean To You And Your Machine

W. Howard Moudy, National Electric Coil

Some technical specifications are drafted with the intent of including everything in the world that may relate to the product. While this philosophy creates a substantial document, does it really aid in the production of an appropriate product for the application? There are many details that relate to the manufacture of high voltage generator stator coils, but perhaps they are not all equally critical to key coil characteristics to help ensure mechanical strength, electrical performance, maintainability, and long-term reliable operation of the generator. This paper will identify important key elements of a generator high voltage technical specification, through a practical discussion of their importance and value. Key elements such as qualification testing, loss reduction, volts per mil, geometric confirmation, outer corona protection, and manufacturing test protocol will be addressed.

TRANSFORMERS COMMITTEE TECHNICAL SESSION
Grand Ballroom AB | Thursday, March 12, 2020 | 3:30 PM – 6:00 PM

DIAGNOSTIC METHODS

1. Port Richey West Distribution Bank Failure
David Clark & Frank Santo, Duke Energy

This presentation will describe the events of a distribution transformer internal failure in which little to no physical damaged was detected. It will examine how the lack of evidence of damage and other circumstances may have led to a biased perception, thus influencing diagnostic methodology. Furthermore, it will highlight which diagnostic tools and tests were effective in confirming and pinpointing the internal damage as well as those that weren't.

After the initial event, many diagnostic tools, general observations, forensic data and inspections, as well as lessons learned from past events were utilized to make a definitive determination as to the status of this unit. Subject Matter Experts with varying backgrounds were called upon to assist with the analysis and evaluation process.

One major outcome of this process has been the understanding that it is essential not to rely on limited tools for a definitive assessment and evaluation of high priority power delivery assets. It is, however, an absolute necessity to employ all tools at one's disposal when questions remain as to the integrity, reliability and safety of such assets.

2. Influence of Core/Coil Configuration on Single-Phase Exciting Current/Loss Measurement
Part II: HV Delta Winding and 4-Loop Wound Core
Mark F. Lachman & Yuri N. Shafir, Doble Engineering Company
Fernando Leal, Carlos Gaytan & Israel Barrientos, GE Prolec

3. Influence of Core/Coil Configuration on Single-Phase Exciting Current/Loss Measurement
Part III: HV Wye Winding and 4-Loop Wound Core
Mark F. Lachman & Yuri N. Shafir, Doble Engineering Company
Fernando Leal, Carlos Gaytan & Israel Barrientos, GE Prolec

These papers are a continuation of work presented in 2019. They will include formalized theoretical derivations and discussion of the physics of single-phase exciting current phase patterns for high-voltage delta and wye windings for wound cores units. All derivations will be compared with empirical data.

4. Importance of Comprehensive Acceptance Testing of New Transformers
Vernon Matthews, Chelan County PUD

Our company had purchased an 115KV to 12.47KV DYN1 Distribution transformer with LTC. The transformer arrived and a contractor for the manufacture dressed out and tested the transformer. We followed up their testing with our own testing. While performing SFRA we saw some anomalies on X1-X0 with the low side open circuit test. We also found a higher winding resistance on X1 than the other two phases with very sporadic resistances on different taps. After it was tested, we reviewed the factory test results and realized that the factory tested the winding resistance on the low side as though it was a Delta (X1-X2, X2-X3, X3-X1). We decided to retest the same way that the factory did to make a more accurate comparison. What we found was that the resistances were higher on X1-X2 and X3-X1 compared to X2-X3 which was different than the factory test results. With X1 being common with both tests it validated our concerns with X1.

The contractor for the manufacture came back to make an internal inspection. They concluded their inspection without finding anything. It was our decision to sectionalize the transformer to eliminate different components to focus our search using the winding resistance tester. The LTC was opened to gain better access to internal connections. On the first test we connected the winding resistance leads on X1 and the first point of entry into the LTC. That test came back with resistances closer to the other phases. This proved that the problem wasn't in the winding. The next test we performed was from X1 to the last connection leaving the LTC. This test did not change the test results from the first test proving that the problem was isolated from the LTC to the X0 bushing. The final test we performed was connecting from the last connection leaving the LTC to the X0 bushing. The resistance was substantially higher. The contractor then focused their search in this area. What they found was a loose bus connection. There was ¼" gap between each piece of bus, with the only electrical connection being mild steel bolts that only had a few threads holding the nuts on. The connections were tightened and the transformer was retested. The test results concluded that the problem had been fixed.

5. Effects of Grounded Tap Winding and Resistors on the Overall Tests of Transformers
Carl Pankratz, Doble Engineering Company

A presentation will be given to explain how resistors, that are included in the design of the load tap changer, effect the overall test results of transformers.

Grand Ballroom AB | Friday, March 13, 2020 | 7:30 AM – 12:00 PM

OPERATING USE

6. HVDC Transformer Site Repair & High Voltage Testing Experience
David Garon, Hydro-Québec
Ed teNyenhuis, ABB

The repair of a large convertor transformer at site is described including the installation of new windings and full HV AC & DC testing.

The HVDC transformer is 132 MVA, 345 – 55 – 55 kV and originally manufactured by Canadian General Electric in 1983 in Guelph, Ontario. The transformer failed in service requiring a full rewind.

The principle concerns for performing an HVDC site repair were the strict high level of cleanliness required and the complicated AC & DC high voltage testing. Complete testing at site was done including losses, impedance, induce voltage, applied voltage, impulse voltage, DC applied voltage and DC polarity reversal. This required 3 separate sets of large mobile test equipment.

New windings were manufactured to the original GE design in a transformer factory, processed by vapor phase and shipped to site in steel shipping containers.

The successful completion and energization demonstrate that site repair with full testing is a possible option for even a complicated convertor transformer.

FAILURES AND TROUBLES

7. Progress Report on Historical Power Transformer Failure Rates
Ronald D. Hernandez & Mark Rivers; Doble Engineering Company

The paper is a progress report on the last activities performed by the Doble Client Transformer Failure Statistics Subcommittee. It includes breaking down the total annual failure rates into transmission and

distribution categories, creating the statistical distribution of the annual failure rates, comparison of North America and South America failure rates, among others.

8. Power Transformer Tank Cover Overheating - Analysis, Mitigation and Case Studies
Luke Wang, Bob Stewart, Muhammad Arshad, BC Hydro

For decades, signs of overheating on power transformer tank cover have been observed leading to components failure or even catastrophic failure of the transformer.

International standards, e.g., CSA C88 and IEEE C57.12.00, have different design criteria to define the tank cover overheating. In addition, transformer users and suppliers may interpret those criteria in different way, tending to controversial debating. Lack of temperature criteria of accessory equipment and devices installed on the transformer tank cover can jeopardize their function with safety issues, if the temperature of different parts is not collaborating properly. IEEE C57.116 explicitly identified IPB and its shorting plate connection, which typically has very high LV terminal current, for the potential overheating issues, but it did not provide technical mitigation solution details. However, it is realized in recent years that even for non-IPB application not identified in IEEE C57.116, the effect of high current through Low Voltage terminal of the transformer has big impact on transformer tank cover overheating, particularly on LV Bushing turret or area near LV terminals; Conduits running on cover, and the Bushing.

FAT (Factor Acceptance Test) heat run has been used as a useful tool to verify the overall transformer thermal characteristics and performance. However, it may not fully simulate the actual in-service conditions due to its technical constraints on core loss. Further, due to the difficulties in test setup, FAT heat run test cannot include and / or simulate the effect of high current through Low Voltage terminal of the transformer, which generally results in big difference between the test results and actual in service operational conditions, especially in tank cover areas.

In recent years, 3-D FEM simulation has become an essential tool to validate and identify potential transformer design issues. However, the criticality of the high current through Low Voltage terminal of the transformer may not be realized by some designers, therefore is often ignored during FEM simulation. With the electromagnetic analysis of current and its thermal impact being missed, the 3-D FEM simulation results cannot accurately simulate the thermal performance of the transformer, particularly the tank cover area.

To elaborate the above theory and findings in FAT heat run test and 3-D simulation, various case studies in recent projects are introduced to demonstrate the tank cover over heating effects caused by high current through Low Voltage terminal of the transformer. Both IPB and non-IPB application tank cover over heating issues are analyzed in theory as well as real application.

Based on the lessons learned in these projects, a group of mitigation solutions are proposed and recommended for different stages of the project during design, FAT, commissioning and service. Relevant critical design review items are highlighted with real application examples on Cooling scheme design; Material selection for tank cover; bushing selection; Accessory device selection and location; Gaskets; Conduit routine; Leakage and Stray flux control for Magnetic design by 3-D simulation with LV terminal connection included.

Supplementary to IEEE C57.116 regarding transformer overheating caused by IPB, it is concluded and recommended in this paper that

- Overheating criteria shall be agreed upon by supplier and user with clear and common international standards with temperature of different parts of the transformer (e.g. bushing, relays, gaskets, cables, etc.) collaborating properly
- Tank cover overheating can be mitigated in early stage by thorough design review as highlighted above, followed by 3-D FEM simulation for validation
- LV lead connection, both with IPB and non-IPB, shall be considered in the design and be fully simulated in above 3-D FEM simulation with the electromagnetic effect of the high current being incorporated. It plays an important role for tank cover overheating, for both IPB and non-IPB application

- FAT heat run shall focus more on tank cover when required
- Commissioning heat run test with final in-service condition shall be performed

LIFE CYCLE MANAGEMENT

9. Field Dryout of 3 Single Phase Transformers Simultaneously with Low Frequency Heating Method

Dinu Amarasinghe, Bruce Power L.P
Ed teNyenhuis, ABB

Aged transformers can require the removal of moisture from cellulose to reduce the risk of dielectric failure and to extend transformer cellulose life. Moisture levels in cellulose can increase over time due to ingress from the atmosphere and as a by-product of cellulose aging.

Conventional field processes of vacuum and hot oil circulation are efficient for removal of surface moisture such as during transformer installation or routine maintenance however they have limited effectiveness for major moisture removal in cellulose. The Low Frequency Heating (LFH) technology can achieve large moisture reductions in cellulose for transformers.

Bruce Power had the requirement to perform dryouts of 3 large single-phase generator transformers (each 275 MVA OFAF, 500 – 22.8 kV, 75,000 liters of oil) during a 2-week outage. It was decided to perform the dryout of all 3 transformers at the same time by using a novel concept of electrically connecting the units together and powering them simultaneously by the LFH technology.

The HV neutral terminals of the 3 transformers were connected and power from the LFH was applied to the HV terminals. The LV terminals of each transformer were shorted. Current was thus achieved on the HV windings and transformed to the LV windings. Cycles of LFH current followed by vacuum were done with winding temperatures up to 110°C.

The LFH principle is that electronic power conversion provides low frequency power to the high voltage windings of a transformer while the secondary windings are shorted. In this manner, high current can be applied to all windings in a controlled manner with near negligible leakage flux due to the low applied frequency (low mHz values). High uniform temperatures in the winding can be achieved.

Dielectric Frequency Response (DFR) measurements were done before and after the dryout. The average winding moisture in cellulose values dropped from 1.6 – 1.4% to 1.0 – 0.9%.

This novel dryout of doing 3 units together had time and resource savings and has provided life extension for the transformers.

NEW CONCEPTS

10. Evaluating Overhead Line Reclosing Sequences Based on Transformer Through-Fault Exposure

Ed Atienza & Chris Kelley, Schweitzer Engineering Laboratories

Overhead line reclosing schemes are commonly used to minimize outage durations and maximize reliability on distribution feeders. While reclosing has shown reliability improvements (especially during temporary faults), reclosing into faults to test line segments subjects upstream power transformer windings to mechanical damage due to through-fault exposure.

This paper demonstrates using the transformer through-fault capability curves of IEEE C57.109 to evaluate the through-fault damage of various reclosing sequences on an example distribution transformer.

Reclosing sequences evaluated include fuse-saving schemes, trip-saving schemes, overcurrent curve enhancements to traditional schemes, and hybrid schemes using high-speed wireless fault sensors. These sequences are evaluated for both temporary and permanent fault conditions. The coordination of multiple reclosers and sectionalizers in series on a distribution feeder is also considered in the sequences that are evaluated.

The method described in this paper provides distribution owners and operators with a tool to consider the reliability benefits of reclosing versus the loss of life of power transformers. Readers can apply their own distributions of fault currents, locations, durations, and frequencies to this method and quantify the benefits of enhancements to traditional reclosing schemes.

11. A New Role of SFRA for Reliable Performance in Wireless Power Transfer Systems

Dowon Kim, Global Testing Services
Ahmed Abu-Siada, Curtin University

Since the Sweep Frequency Response Analyzer (SFRA) was introduced in the power industry during the last few decades, the reliability of high voltage (HV) winding apparatus (i.e., power transformers and rotating machines) could be objectively examined by analyzing the transformation of electrical components. The principle of the inductively-coupled wireless power transfer (WPT) system is based on Faraday's Law and Tesla's idea of alternative current like a traditional power transformer. As the demand for wireless battery charging devices increases significantly, and the power of the WPT device reaches to the mega-Watt ranges, the cost-effective condition monitoring method for reliable WPT system is necessary.

Hence, SFRA can conduct vital roles in WPT devices. First, SFRA provides accurate measurements of electrical parameters: winding resistance (R), self and mutual inductance (L) and compensating capacitance (C) with respect to frequency. Second, single or multiple resonant points over the transfer distance are observed precisely. Third, the changing values of RLC components are detected due to the deterioration, misalignment of windings and characteristic variation of magnetic coupling over time since the WPT is installed on-site. This study introduces circuit analysis of a two-coil WPT system and the design process with simulation and SFRA. Furthermore, three critical roles of SFRA mentioned above are investigated in a practical demonstration.

12. PD Measurement on Refurbished Transformers Liquid Immersed Distribution and Class I Power Transformers

Thang Hochanh, Surplec

When a repair facility proceeds to refurbish a transformer, the bushings and windings must be considered when dielectrics tests and partial discharge measurements are performed. If one of the components above have been kept with the transformer, it will be necessary to lower the test levels in order to take in account the condition of the insulation.

In our facility the following modified test procedure has been applied to many transformers:

Induced voltage tests at minimal dielectric test level:

- Apply 75% of the original test levels
- The sequence is as follow:
    - Raise the voltage to 130% for 7200 cycles
    - Lower the voltage to 110% and record the PD measurements at every 2 minutes for 10 minutes
    - The transformer passes the test, when during the 10 minutes test:
        Partial Discharge level is 500 pC or less.
        No Spikes are visible on the phase resolved partial discharges (PRPD) screen.

This modified induced voltage test is referred to as the: Induced Voltage Test S1. According to feed-back from our customers the refurbished units, that passed the Induced Voltage Test S1, are not gassing in the field.

DESIGN

13. Operational Reliability of Air-Core Dry-Type Reactors Design-, Installation-, Maintenance- and Assessment-Considerations

Alex Grisenti, Alexander Gaun, Coil Innovation GMBH
Thomas Falkenburg, Coil Innovation USA

Air-core dry-type reactors are key components in electric power transmission and distribution systems and in power supply systems of industrial plants. Besides the classic reactor applications, such as short-circuit current limiting, filtering or shunt compensation, air-core dry-type reactors play essential roles in the operation of many SVC and STATCOM installations, as well as in HVDC schemes. The proliferation of air-core dry-type reactors used over the last few decades may be attributed to such factors as the economic advantages of air-core reactor technology when compared to that of iron-core oil-insulated reactors, the benefits of the linear characteristics of air-core dry-type reactors as opposed to iron-core reactors, and the new high-performance insulation materials and advanced manufacturing technologies which have facilitated the use of air-core dry-type reactors at much higher voltage and power levels.

Air-core dry-type reactors are subject to extensive multiple stressing, which can hardly be compared with any other equipment employed in electric power systems. In other equipment, as for instance transformers or capacitors, the active part of the apparatus is not directly exposed to the environment, as it is built within oil-filled tanks or containers (cans). Thus, the environmental impact on the apparatus is essentially confined to the electrical connections, i.e. the electrical bushings for transmitting the power in and out of these tanks or containers. Air-core dry-type reactors installed outdoors are subject to dielectric, thermal, mechanical and environmental stresses as discussed below. These stresses, however, cannot be considered isolated from each other as some of them occur simultaneously and their interaction may create combined stresses, which could accelerate the aging mechanism of the apparatus.

In order to minimize aging effects and to achieve the highest level of operational reliability, several aspects need to be considered in the design stage, in the installation phase and in certain preventive maintenance efforts. These aspects will be addressed and discussed in this paper. The paper includes practical recommendations regarding high-performance materials to be employed in the reactor's insulation system, magnetic field effects, optimum connection of air-core reactors, and the need for protective coatings or covers depending on the site conditions as well as preventive maintenance efforts. Furthermore, comments will be made regarding the assessment of the aging status of installed reactors which have been in service for many years. The aim of this paper is to provide a guide for substation engineers and designers as well as equipment purchasers in order to contribute to the highest possible operational reliability of air-core dry-type reactor installations.