The review of the discussion subjects received at the September Doble Client Committee Meetings in Miami, Florida as well as additional items raised at the meeting led to the formulation of the following tentative program for the 81st International Conference of Doble Clients. This program is subject to change.

ARREUTERS, CAPACITORS, CABLES AND ACCESSORIES COMMITTEE

1. Commissioning Testing 161kV Harmonic Filters
   Francis Thibault; Rio Tinto – Alcan
   Dennis M Boyd; Nucor Steel Berkeley
   Long Pong; Doble Engineering Company

Harmonic filters and capacitor banks are secondary apparatus in a substation and in the past often received very little testing or condition monitoring. Today, because of a great augmentation of electronic loads in recent decades, they play an important role in stabilizing the network, improving the power quality and increasing the capacity of transmitting the electricity. Energy intensive industrial customers such as aluminum smelters and steel producers may be idled if the filter yards of their static var systems are out of service. Therefore, a run-to-failure program becomes the costlier option and the electrical utility is interested in a more rigorous quality control and preventive maintenance program. To this end, this paper will provide the test techniques available that provide valuable information on the condition of the harmonic filter. Three harmonic filters are used in case studies and are subjected to the SFRA, capacitor bank, inductor, resistor and overall insulation tests. The first two filters are new and are tested during commissioning to check the design parameters, to control quality and to establish the baseline for the future maintenance program or troubleshooting. The third filter is a 2007 vintage system and is used to study if the SFRA test is effective in detecting a capacitor failure in the bank and in checking the overall system condition.

2. Lowering Losses on Transmission Lines Using Arresters
   Jonathan Woodworth; Arrester Works

Power systems experience losses in many forms and a great deal of effort is put forth to reduce these losses in many areas. However the losses related to overhead ground wires (OHGW) of transmission lines is rarely mitigated on systems below 345kV. The losses relating to OHGWs are due to inductive currents from the phase conductors onto the OHGW or sometimes called shield wires. This paper will show how arresters can be used in place of OHGWs on transmission lines to 100% eliminate these induced losses and at the same time increase the reliability of the system.

3. Installation and Commissioning of Oil Filled Cable under the Cape Fear River
   Dan Chapoton; Duke Energy

This paper will focus on the 230 kV transmission cables that were recently installed under the Cape Fear River. This paper will review the process for this installation by a utility that did not have a history for this type of installation.

4. Safety Concerning the use of Hot Sticks during Live Line Work
   David Grant; Manitoba Hydro

This paper will show how particles falling into the vicinity of a high voltage conductor, during live line work, can endanger the workers, by compromising their hot sticks and other safeguards. Included in the presentation will be videos of experiments completed a year and 11 years ago, which explored this phenomenon. It will move on to explain the way that Manitoba Hydro’s operating rules were adjusted as soon as this problem was discovered. This work was undertaken during the investigation of a pair of 550KV flashover incidents.
5. Hot Stick Refinishing at Manitoba Hydro
   David Grant; Manitoba Hydro

The history of hot stick refinishing at Manitoba Hydro will be summarized in this paper. In the 1990s, during the investigation of a flashover incident, the condition of working sticks was questioned. Considering the number of sticks in use in Manitoba by all users, a refinish shop was commissioned. Procedures were developed in-house, to re-work used sticks, and to refinish them in an existing large building, summer and winter. Standard tests were developed to confirm everything from the efficacy of the heating system to the new finish drying time. This will all be explained to the Client audience.
ASSET AND MAINTENANCE MANAGEMENT COMMITTEE

1. Tactical and Strategic Plans for National Grid’s Metal-Clad Switchgear Fleet
   Eileen Duarte; National Grid

National Grid has embarked upon the need to perform a thorough evaluation of its metalclad switchgear fleet and to determine the proper approach in addressing the associated issues and concerns.

Based on inquiries from executive leadership, concerns from operations related to safety and reliability, asset condition issues associated with deterioration and age, arc flash guidelines, and changes in technology, the state of National Grid’s metalclad switchgear fleet has become a priority. Over the past few years, the utility has experienced several safety related incidents with metalclad switchgear and components involving personnel. Additionally field personnel in pockets of the company have requested reviews of alternatives to metalclad switchgear replacement and installations such as open air designs. Lastly, as National Grid approaches regulatory agencies for capital dollars to replace aging and deteriorated equipment, the utility was requested to produce a cost-benefit analysis and justification of the proposed replacement program.

This paper will describe issues and concerns with National Grid’s metalclad switchgear fleet and the steps the utility’s Asset Managers took to address them. The paper will include a discussion of both short-term tactical approaches and long-term strategic plans. The paper will review National Grid’s substation design standards and the decision-matrix tool it developed to assist the Planner with the decision to install or replace with metalclad switchgear or air-insulated equipment at new or existing sites. The paper will also touch on National Grid’s maintenance practices and our maintenance challenges. The results of a recent survey, conducted collaboratively with Doble Engineering Company and CEATI (LCMSEA Group), will be imbedded in the paper. To assist with prioritization, criticality ranking of our fleet was conducted with focus on four categories – Asset Health, Safety, Performance and Customer Impact. The inputs associated with each category and the scoring system used will be discussed. Lastly, an example of a cost-utility tool used to determine the correct mitigation solution for a particular metalclad switchgear, such as replacement, rebuild, refurbishment, conversion, retirement, or simply continue to maintain, will be provided and discussed.

2. EMP An Overview of Threats and Mitigation Solutions for Operations Centers and Substations
   Michael A. Caruso, ETS-Lindgren Inc.

The concern over the effects of High-altitude Electromagnetic Pulse (HEMP), Electromagnetic Pulse (EMP), and Intentional Electromagnetic Interference (IEMI) has largely been regarded as an issue for Military and Government Facilities. To most, it is very clear that Military and Government facilities utilized for Command, Control, Communications, Computer and Intelligence (C4I) purposes would need to be protected from such phenomena. However, with Government, Private and Public facilities and services becoming interdependent and an increasingly significant component of the Critical Infrastructure, the concern over the effects of HEMP/IEMI has grown exponentially.

HEMP is an electromagnetic wave of energy (>50,000 volts/meter) emitted from a nuclear detonation at 18 miles (30 km) or more above the earth’s surface rendering electronic devices inoperable without having blast or radiation effects.

IEMI is an electromagnetic wave of energy emitted from the deliberate and malicious use of an electromagnetic weapon or device (non-detonation in origin) that can be damaging, disruptive and data altering to all unprotected electronic devices.

This presentation will explore the threat; examine the extent of the threat and present mitigation solutions that should be incorporated in Operations Facility Design as part of a Disaster Planning/Recovery program to address the growing concern over EMP.

The Program is subject to change.
3. Taking Substation Maintenance to the Next Level  
Elizabeth Bray; Southern Company

In the age of “smart” technology the majority of substation maintenance activities are still a manual process. With the rise in technology within substations it could be used to better manage the overall health of the substation assets. With the decrease in available O&M budgets the ability to carry out all planned maintenance activities are getting more difficult every year. Technology could be the solution due to the rise of substation monitoring technology by allowing monitoring technology to determine when to perform maintenance activities. The benefits of this transition could have a positive impact on reliability and other positive impacts to the business. This paper proposes transforming this idea into reality by leveraging available technology and taking substation maintenance to the next level.

4. Effective Mitigation of Wildlife-Caused Interruptions at National Grid  
Travis Egy; National Grid

The purpose of this paper is to discuss the evolution of substation animal deterrent applications at National Grid and their effectiveness in the reductions of animal intrusions resulting in service interruptions or equipment damage.

5. Round Table Discussion on Equipment Replacement Strategies  
Greg Bennett; Xcel Energy  
Josh Srp; Lower Colorado River Authority  
Ken Weaver; Dominion Power

This roundtable discussion will involve representatives from four North American utilities that will describe their formal substation equipment replacement programs. The presentations will include discussion of the following key points:

1. Description of formal equipment replacement programs.
2. Criteria which the utilities employ to identify equipment that is included as part of a system-wide replacement program.
3. Description of prioritization criteria (the order in which specific equipment is replaced).
4. The size of the equipment population that is being replaced.
5. The expected duration of the program.

6. Round Table Discussion on Substation Storm Hardening Techniques  
Tony Picagli; United Illuminating  
Anastasia O’Malley; Consolidated Edison Company of New York  
Steve Rhoads; National Grid

Electrical utilities in several Northeastern states experienced significant damage to their substations as a result of Hurricane Sandy which struck in October, 2012. The panel participants will share each utility’s experiences with flood mitigation and recovery. Subsequent to the storm, these utilities have implemented a multi-stage hardening approach to their substation facilities. These modifications and new substation designs and construction procedures will be presented and discussed as part of the roundtable discussion.

The Program is subject to change.
BUSHINGS, INSULATORS AND INSTRUMENT TRANSFORMERS COMMITTEE

1. Utility Experience with Acceptance Tests of Insulation on High Voltage Bushings, Insulators and Instrument Transformers
   N. D. Jacob, W. M. McDermid & J. Lambert; Manitoba Hydro

For nearly 40-years, Manitoba Hydro has implemented a program for performing in-house high voltage insulation acceptance tests on new insulators, instrument transformers and bushings. These tests are performed after delivery from the manufacturer and are done in addition to the factory acceptance tests. In general, in-house high-voltage tests have consisted of capacitance/dissipation factor and partial discharge measurements performed at voltage levels between 70-80 percent of the full factory test levels.

Data collected by Manitoba Hydro over the history of this program has consistently identified numerous pieces of apparatus which fail to meet Manitoba Hydro acceptance criteria and/or performance criteria specified in industry standard. In some cases single pieces of equipment which may have been damaged internally during shipment have been identified and returned to the manufacturer. In other cases entire shipments containing multiple units have been found faulty due to poor manufacturing and/or poor factory testing practices. It is believed that Manitoba Hydro’s testing program has prevented numerous potential in-service failures.

Historically, much of this testing program has been applied to equipment 115kV and below due to test equipment voltage limitations and space constraints. In 2011 Manitoba Hydro completed construction of a High Voltage Test Facility for in-house high-voltage insulation acceptance testing on equipment rated up to 500kV AC and DC. A major component in the justification for building this facility is attributed to the success of the program for in-house high-voltage insulation acceptance tests and the benefits it has for equipment reliability in Manitoba Hydro’s transmission system.

This paper will provide an overview of Manitoba Hydro’s new High Voltage Test Facility, our new test capabilities as well as examples of faulty equipment identified with this testing.

2. Bushing Application and Life Expectancy
   Abel Pereira; Bonneville Power Administration

Bushings of similar design can perform differently and have a life difference based on its application, i.e. installed in breakers, transformers, and reactors. Different designs may also produce different behaviors. This paper will discuss bushing application and life expectancy based upon experiences at Bonneville Power Administration.

3. Duke Energy Bushing Replacement Program
   Catherine Brady; Duke Energy

Bushings are being replaced on approximately 1000 individual pieces of equipment over the next 5 years. The utility is replacing GE type U, Lapp PRC and Trench COTA bushings. The paper will discuss the safety, operational, reliability and business case justification that the utility considered in implementing its replacement program.

4. Assessing the Risk of Bushing Failure due to High Hydrogen Levels
   David Olan, Priya Raina & Robert Middleton; BC Hydro
   Mike Lau; Weidmann Diagnostic Solutions

BC Hydro recently had a catastrophic failure of an oil-filled 500 kV bushing on one of its shunt reactor banks (bank consisted of 3 single phase 45 MVAR units) resulting in a fire and total loss of the three-phase bank. This failure initiated a subsequent GIO analysis of a number of in-service 500 kV bushings. The analysis of a number of these bushings revealed alarmingly high hydrogen levels but relatively low levels of other hydrocarbon gases in the oil. To gain a better understanding of the cause and risks of high hydrogen levels in bushings, BC Hydro has undertaken a test program to study the behavior of a 500 kV bushing under drastic temperature changes. The study confirmed that partial discharge (PD) activities would have developed under an internal vacuum condition, which would then cause Hydrogen generation.

The Program is subject to change.
The test program monitored such key parameters as DGA, PD, tan delta and capacitance under a heating-cooling cycle used to simulate in-service conditions. The heating-cooling cycle tests were followed by a period of energizing at rated voltage with a gradual increase in voltage. The listed parameters were also monitored during the voltage test. Finally, the subject bushing was dismantled in search for bushing insulation degradation and the risks of developing a high hydrogen concentration in oil will be evaluated.

It is hoped this study will provide:
1. Information on key parameters under service conditions.
2. Through the use of on-line monitoring or maintenance testing of these parameters, imminent or future bushing failures can be predicted.
3. Data on the relationship between vacuum and partial discharge levels.

5. The Future of Condenser Bushing Technology and Materials
   Randy Williams; ABB Alamo Tennessee

The basic concept of a condenser bushing has remained the same for the last 60 plus years. The changes have been mostly manufacturing practices and processes. Due to field issues and concerns with safety, security, field maintenance, and the environment, regulations within the United States on condenser bushings is about to change. This paper will briefly address the history of Resin Bonded Porcelain Insulator Bushings, Oil Impregnated Porcelain Insulated Bushings, and the future with Dry Type Bushings utilizing Polymer Insulators. Focus will be on basic design, materials, and the pros and cons of Dry Type Condenser Polymer Insulator Bushings.

   Bernhard Heil; HSP Hochspannungsgeraete GmbH

Resin Impregnated Paper (RIP) Bushings are a reliable well established solution for many applications. Although such bushings are maintenance-free, some parameters might be controlled on a regular basis or prior to bringing into service. For any reasonable evaluation of the reliability a founded understanding of the physical aspects is essential. Since the condenser core is a solid material the parameters for any evaluation are different compared with oil impregnated paper (OIP) bushings. This paper presents the physical background in regard of relevant parameters for any evaluation. Examples from the field are given to demonstrate how a reasonable evaluation of the reliability can be carried out.

7. Investigation on the Failure of a 25KV Solid-Core ECI Bushing
   Catherine Brady & Gary Harrison; Duke Energy
   Jacques Vanier & Sebastien Riopel; Electro Composites
   Daniel Huenge & Shibao Zhang; PCORE Electric

This paper will describe the forensic analysis of a 25KV Solid-Core ECI bushing installed in a 25KV Oil Circuit Breaker. The failure was due to a lightning strike to the bushing.

8. Partial Discharge Assessment of 34.5kV Potential Transformers
   Falk Werner; Doble Engineering Company

This paper will contain the results and findings of a partial discharge (PD) assessment of a substation. The initial reason for the PD assessment was a series of failures of 34.5kV potential transformers (PTs). Experiments in the lab have exhibited elevated partial discharge levels within individual PTs. The goal of the assessment was to identify PD in PTs in service without disconnection. A High Frequency Current Transformer (HFCT), connected to the ground leads of individual PTs or groups of PTs was used as a measurement sensor. This paper describes the PD mechanism within the PT, the method that was applied in the test lab as well as within the substation to identify PD within specific apparatuses, and the derived conclusions.
9. Potential Transformer Saturation Test and Induced Voltages
Long Pong; Doble Engineering Company

This paper has been deferred to the 2015 Doble Client Conference.

New test procedures have been developed to perform high voltage tests for inductive Potential Transformers (PT). By using a Doble M4110 Leakage Reactance module with the M4100 test set, it is possible to induce the primary side to the rated voltage or beyond through the secondary winding. This allows the performance of the HV tests in the field to ensure the integrity of the PT.

The HV tests consist of:
1. Rated Voltage Exciting Current Test
2. Saturation Curve Test
3. Induced Voltage Test and PD monitored by portable PD-Smart
4. High Voltage Ratio Test

This paper will include the test procedure, two case studies and the data analysis.
CIRCUIT BREAKERS COMMITTEE

1. ABB 550PM Refurbishment Program: Improved Reliability Through Interrupter Design Enhancements
   Ken Edwards; Bonneville Power Administration
   Mike Lane; ABB

This paper has been deferred to the 2015 Doble Client Conference.

According to CIGRE documents, high voltage interrupters have, in general, a fairly low major failure rate. Bonneville Power Administration has, since 2009, experienced an abnormally high number of major failures on 550 kV interrupters. Specifically, failures were comprised of dielectric break-down of line-to-ground insulators of the interrupters. This paper describes the investigation to determine the root cause of such failures, including best means to determine at-risk installed breakers, field evaluations of installed breakers, and tests conducted to determine root cause. Further discussed are past and present interrupter improvements, including confirmation testing of recent improvements, made to minimize the potential for such dielectric break-downs in the future.

2. Failure Frequencies for High-Voltage Circuit Breakers, Disconnectors, Earthing Switches, Instrument Transformers, and Gas-Insulated Switchgear
   John Skog; Maintenance and Test Engineering, LLC

Failure frequencies for circuit breakers (CBs) (only single pressure), disconnectors and earthing switches, instrument transformers, and gas-insulated switchgear (GIS) have been determined through a comprehensive worldwide utility survey. For CBs and GIS, where comparable results from earlier surveys exist, significant reductions in failure frequencies are observed.

This paper presents a few key results from the survey, namely, the failure frequencies for the different types of equipment as a function of the equipment’s year of manufacture.

3. Predicting the Remaining Life of Vacuum Interrupters in the Field
   John Cadick; Cadick Corporation
   Finley Ledbetter; Group CBS

A very large percentage of the vacuum interrupters (VI) that are in service today, have reached or exceeded the manufacturer specified life-span. As might be expected, VI failures have risen rapidly in the last ten years, and virtually all of them have been caused by or related to loss of vacuum. Unfortunately, none of the existing field tests have the ability to determine the pressure inside a VI, nor can they predict the rate of vacuum loss. Fortunately newly researched and developed hardware along with modern condition based maintenance algorithms offer a solution to this problem.

This presentation introduces a new, tested field technique to measure the vacuum level and predict the remaining life of the VI utilizing the Penning Discharge Principle. It provides information about the new field test, and explains how implementation of this test will allow equipment owners and testing companies to measure and predict future changes in vacuum levels thus failure.

4. DC Arc Flash 2013: Regulatory Updates and Recommended Battery Risk Assessment Guidelines
   William Cantor; Test Products Inc. (TPI)

There continues to be confusion in the stationary battery community about how to protect battery maintenance personal from chemical, electrical and arc-flash hazards. If strictly interpreting the current standards published by NFPA and IEEE, the Personnel Protective Equipment (PPE) required would make it impossible, or at best, unsafe to work around batteries. The IEEE Stationary Battery Committee Codes Task Force has spent considerable time working on proposals to NFPA 70E with the intention of providing practical guidance for PPE required for battery
maintenance. This task force has also worked with the NFPA 70E DC Task Group. NFPA 70E recently has taken a special interest in separating the hazard from the risk, something it has not done previously.

This paper proposes a thought process that can be used to, first, evaluate if and where a hazard may exist in workplaces where DC voltage sources are present, then to determine the degree of risk, and ultimately to determine the PPE that would be appropriate for any given battery activity. A flow chart was presented with guidance for how to use it. This paper will also update the committee on the status of codes and standards relating to DC arc flash.

5. Battery Eliminators, Power Supplies, and Safety Standards
   David Barnes; C&D Technologies

What is a ‘Battery Eliminator’ unit and why do I need one?” is a question many users ask. Charger manufacturers describe chargers with options as filtered, unfiltered, and battery eliminator but do not explain the differences. Users are further confused by products being referred to as a ‘charger’ and ‘rectifier’ without anything distinguishing the difference between them. This paper will help explain manufacturer terminology and options in order to choose the correct charger.

6. New Use for the TR 3171 Linear Transducer for Motion Measurement
   Lee Morgan; Bonneville Power Administration
   Jozef Levi; Doble Engineering Company

High voltage circuit breakers are mechanical devices and monitoring the motion of the breaker’s arcing contacts can give valuable information about the condition of the breaker being tested. High voltage SF₆ circuit breakers have a much shorter arcing contact displacement compared to bulk oil circuit breakers with the same voltage rating. A linear transducer can be adapted for use with these circuit breaker designs that have shorter contact movement. This paper will present and explain a new use for the TR3171 linear transducer specifically developed for use with the AHMA operating mechanism.

7. Determining Circuit Breaker Health Using a Novel Circuit Breaker Vibration Analysis Approach
   John Cadick; Cadick Corp
   Finley Ledbetter; Group CBS

All objects can be characterized by their response to physical stimuli. When struck by its clapper, a bell will ring with a certain fundamental frequency and numerous overtones (harmonics). The frequencies of the fundamental and the overtones are determined by the size and geometry of the bell as well as the material from which it is made.

Imperfections such as cracks will cause the bell to respond at different frequencies and/or different amplitudes. If the normal frequencies and amplitudes are known, it is theoretically possible to determine the type, size, and location of an imperfection.

These basic physical facts have led to the well proven scientific method of vibration analysis, which is used extensively for determining existing or impending problems in rotating equipment such as motors or generators. Past attempts to use vibration analysis for circuit breakers have met with only limited acceptance, primarily because of the size and complexity of the test equipment, added expense, and the lack of good vibration signatures for comparison purposes.

This paper discusses a new vibration analysis method that is being used successfully for determining the mechanical condition (and thus the electrical performance) of circuit breakers. Using a marriage of compact and modern communications equipment, internet data transfer and sophisticated Condition Base Maintenance Algorithms (CBMA), this new method offers a number of valuable features.
INSULATING MATERIALS COMMITTEE

1. Case Study of McGraw Edison 996 LTC
   Wayne Hagman; NStar
   Lance Lewand; Doble Engineering Company

   Laboratory oil testing was used to determine a poor condition being present in a transfer switch compartment of an LTC that eventually led a problem also being found in the selector compartment. This paper will explore the laboratory tests being performed and what they showed, the problems found and how they manifested.

2. Stray Gassing of Refinery Streams and Transformer Oil Produced From Them
   Jimmy Rasco & Edward Casserly; Ergon Refining, Inc. USA

   Dissolved gas analysis (DGA) is an important analytical tool in diagnosing the health of a transformer. The amounts and ratios of various gases, produced in the transformer, have been correlated with possible problems within the transformer. Since the early 1990’s the phenomenon of new transformer oils releasing high concentrations of gases at low temperatures (90°C to 200°C) has been noticed. This process of generating gases, primarily hydrogen, at low temperatures was termed “Stray Gassing” by CIGRE. Many of the instances of stray gassing have been noticed during transformer factory acceptance tests before they are put into service. After the year 2000 this phenomenon increased to the point that both Doble and CIGRE started investigations to find the cause. They studied oils types, transformers, building materials and transformer operating conditions.

3. Use of Dew Point Probes during Field Dry Out of Transformers
   Bruce Rockwell, Tony Rosato; American Electrical Testing
   Lance Lewand; Doble Engineering Company

   Three cases studies will be presented to show the value of taking dewpoint measurements during vacuum dryouts and other oil processing activities. Also, placement of the dewpoint sensor will be discussed in detail as it has been found that placement of the sensor can influence the measurement and also enable personnel to determine if leaks are present.

4. A New Technique to Estimate Furan Concentration through Spectral Response of Transformer Oil
   A. Abu-Siada & S. Islam; Curtin University, Australia

   Furans are the major degradation of insulating paper in transformer oil. Hence the concentration of furans in oil can be used as a good indicator of paper deterioration. Furan concentration in transformer oil is currently measured using High-Performance Liquid Chromatography (HPLC) or Gas Chromatography-Mass Spectrometry (GC/MS). Both methods provide accurate and reliable results in detecting furan concentration. However, the two methods need very expensive equipment and take a long time to perform the test on oil samples which should be chemically treated before conducting the test. Moreover, both methods require an expert to perform the test and to interpret its results. This paper introduces a novel technique for detecting furan concentration in transformer oil through measuring oil spectral response. The Ultraviolet-to-Visible (UV-Vis) spectral response of transformer oil can be measured directly and does not need an expert person to conduct the test. Results show that there is a good correlation between oil spectral response and its furan contents. Effect of ambient temperature and conducting materials dissolved in transformer oil on its spectral response is also investigated. A fuzzy logic model to estimate the relationship between furan concentration and spectral response parameters of transformer oil is presented. The technique is proved to be reliable, fast, cost effective and can be implemented online.

5. A History of Gasket Testing and Research, Our Experience at Manitoba Hydro
   David Grant, Manitoba Hydro, Canada

   Gaskets leak. When a transformer gasket leaks oil, the owner is in trouble. The public and their government do not like to see oil on the ground. Changing these gaskets is very costly. Predicting which materials will fail quickly in service can save a lot of money. Manitoba Hydro has been researching and testing soft gasket
materials for over 20 years. In this paper will be insights into the factors that lead to early gasket failure. It will also explain the tests most likely to predict early failure, in service. It will also describe the research done at Manitoba Hydro in soft gasket properties, and how they are degraded in service.

6. SF6 Analysis of HVCB Gas Mixture
Alexandre Brassard, Steve Laberge, Mathieu Lalonde & Jonathan Poirier; Hydro-Québec–TransEnergie
Marie-Claude Lessard; Hydro-Québec–IREQ

This paper has been deferred to the 2015 Doble Client Conference.

SF6 has become an indispensable insulation material for electric power transmission and distribution equipment. Hydro-Québec has a fleet of more than 550 SF6 high voltage circuit breaker rated between 69kV and 800kV. Due to the cold climate, most breakers are either filled with a SF6-N2 or SF6-CF4 gaseous mixture. To ensure the quality of the gas mixture, maintenance crews are actually using SF6 portable field testing instruments. Those apparatus allow the determination of the insulating gases concentration and also permit the detection of potential external contamination which can be introduced during maintenance, gas handling or leakage. Furthermore, this operation allows detection of SO2 which is related to the decomposition of SF6 by electrical discharges and reaction with contact materials and contaminants.

Since 2012, Hydro-Quebec began to combine portable field testing with laboratory measurements using a gas chromatography technique. In this regard, Hydro-Québec's Research Institute developed a new method using a flame photometric detector combined with a thermal conductivity detector. Cases studies and findings will be presented.
1. NERC Requirements for Setting Load Dependent Power Plant Protection --- PRC–025"  
Charles J. Mozina; Consultant–Beckwith Electric Company  

During the 2003 blackout, 290 bulk power generators tripped off-line. These trippings resulted in the loss of 52,000 MWs of generation. Investigation of these trippings indicated that many were due to improperly set generator relays or lack of coordination with transmission line protection. A major area that contributed to the loss of generation was the inability of power plant protection to “ride through” survivable system low-voltage events. Transmission line protection loadability has been addressed in NERC Standard PRC-023. NERC PRC-025 addresses loadability of power plant protection and is much more complicated to apply than the transmission loadability requirements outlined in PRC-023. PRC-025 has successfully passed NERC balloting and is planned for Fall 2013 submittal to FERC for final approval. It will require every generator owner (GO) and operator (GOP) to set load responsive power plant protective relays to meet required stress points as outlined in the standard. These new requirements will limit transmission system backup protection. The standard requires documentation of setting calculations and evidence that the settings were installed.

The proposed paper will outline PRC-025 requirements. The standard has a number of calculation options and addresses load dependent generator unit protection (21 and 51V), generator step-up transformer (GSU) relays (51), auxiliary transformer relays (51) that supply plant load when the generator is on-line, and backup transmission line protection (21) for specific one-line configurations for lines exiting the power plant. Transmission line requirement can involve transmission owners (TO) and operators (TOP) depending on ownership. The stress points in the case of generators, GSU and transmission lines are based on the effects of generator excitation system field-forcing. These effects will be discussed in detail in the paper in addition to the calculation options.

2. Mastering the Use of Symmetrical Components by Multifunction Numerical Protection Relays  
Steve Turner; Beckwith Electric Company  

It is important that novice engineers starting a career in system protection learn how to master the use of symmetrical components for fault calculations. The paper presents several detailed technical examples that illustrate how multi-function protection relays calculate and use symmetrical components to enhance their performance during system faults. Protection engineers must understand the central tenants of symmetrical components in order to understand the design principles of modern multi-function numerical protection relays. Three examples are presented:

- Zero-sequence current elimination for transformer differential protection
- Positive-sequence voltage polarization for mho phase distance elements
- Negative-sequence current detection to inhibit out-of-step blocking

3. The Benefits and Pitfalls of Commissioning an IEC61850 Integrated Substation  
Chad Dwelley & Michael Cone; Electric Power Systems  

Electric Power Systems is the Owner’s Commissioning Agent on a large project with Central Maine Power. This project is utilizing IEC61850 protocols for its integration and protection systems, which, prior to this work, was new to our engineers. We are in process of completing this project successfully and in the process have learned much about how to handle systems with IEC61850 capabilities. There are numerous factors to consider when commissioning an IEC61850 substation that may not be present in a traditional design, especially once part of the system has already been placed into service. There are a number of methods that were employed to properly and safely complete commissioning of the system, including the use of Doble IEC61850 GSE Configurator software, multiple networking tools, vendor specific applications, and much more. Using these tools, we were able to develop efficient procedures to test all aspects of the integration and protections systems and most importantly, do so while portions of these systems were in service. This presentation will discuss the benefits and pitfalls of commissioning an IEC61850 system compared with those of traditional protection schemes.

The Program is subject to change.
4. Distinguishing Between an Out of Step Condition (ANSI Device 78) and Stable Power Swing
John Kweku Amoo-Otoo; Consultant-ABB Power Transformer
ROTATING MACHINERY COMMITTEE
TESTING, MONITORING AND INSPECTION

1. Review of EMI Diagnostics on some Air Cooled Generators
   James E. Timperley; Doble Engineering Company

Since 1980 EMI (electromagnetic interference) Diagnostics has provided information on the electrical and mechanical condition of several hundred electric generators.

This on-line technique has been applied to many sizes and designs of 2-pole and 4-pole steam and combustion turbines, air cooled and hydrogen cooled generators.

This paper provides several case studies of electrical and mechanical deterioration identified with EMI Diagnostics for air cooled machines. Several methods that enhance analysis of EMI Diagnostics are presented, such as trending, data comparison at different loads as well as data comparison of on-line and off-line are discussed.

2. Diagnostic Method for Rotating Machinery Rotors – Applying Sweep Frequency Response Analysis (SFRA)
   Alberto Ottilio Quintero Nieves & Angel J. Aranda Carmona;
   Comision Federal de Electricidad – Mexico

The results of the SFRA on salient-pole rotors and cylindrical rotors are analyzed and discussed.

3. A Quality Assurance Test Program of Stator Bars/Coils
   Hugh Zhu; Doble Engineering Company

This paper presents a test program used to evaluate the quality of new generator and motor bars/coils. The program includes diagnostic tests, voltage endurance test, thermal cycling test and dissection of coils/bars. The diagnostic tests can be used to detect defects and assess the insulation condition of stator bars/coils. Accelerated aging tests attempt to simulate the insulation aging process within a much shorter time frame than the machine lifetime. Voltage endurance test and thermal cycling test are typical accelerated aging tests used to check the quality of stator bars/coils. Dissection of the coils/bars can discover internal defects which may not be revealed by the electrical tests. The paper describes the test methods, test requirements, and associated IEEE standards. Incorporating the test program into a generator rewind specification is also discussed.

4. 100% Generator Stator Ground Fault Protection – What Works, and What’s New
   Charles J. Mozina; Consultant–Beckwith Electric Company

This paper responds to a paper given at the 2013 Doble Client Conference presented by Clyde Maughan [1]. The paper asserted that ground faults near the stator neutral are not as rare as many in the relaying community had thought and discusses the mechanism of how these failures occur. His discussion centered on his experience with analyzing failures on cylindrical rotor large steam generators. The last four major stator ground fault cases he investigated were faults near the generator neutral. These generators were not equipped with any type of 100% stator ground fault protection. The resulting damage was extensive in all four cases.

This paper also updates an earlier paper by the author [2] that discusses the application of three different 100% stator ground fault protection schemes used to detect faults near the stator neutral. It discusses recent changes that are occurring within the industry to speed stator ground fault tripping and to detect ground faults that self-extinguished and then reestablished. Many generator owners have upgraded the protection on older generators by implementing one of the methods to detect stator ground faults near the neutral. However, there are still a number of older generators within North America that have not been upgraded.

Two third-harmonic methods and a low frequency-injection method are discussed in this paper that can detect stator ground faults near the generator neutral. Third-harmonic schemes have been widely applied on generators

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within the U.S. to provide stator ground fault protection over the entire stator winding. In a number of cases, however, these schemes have been found not to be applicable. In many cases, these shortcomings were discovered during commissioning or when they operated improperly resulting in a false tripping of the generator. This paper discusses situations in which third-harmonic schemes will work and outlines the limitations of such schemes. It also discusses the use of low frequency injection subharmonic schemes which are gaining wide acceptance in the U.S.

5. Air Gap Monitoring – Key Element to Avoid Unnecessary and Costly Repairs
Marc R. Bissonnette; VibroSyst M
John Linn; Portland General Electric

In the summer of 2010, Portland General Electric decided to install an on-line monitoring system on a 95 megawatts hydro-electric generator, in order to closely monitor the air gap with the help of four (4) air gap sensors, which were installed at the upper part of the stator core a few years previously. The utility suspected rotor structural integrity problems, namely floating rotor rim issues because of an existing condition on other units at the plant. The utility wanted to verify if this was the case, prior to a planned outage in the fall of 2011 where significant repair work was scheduled for the rotor.

Dynamic behavior tests were performed in June of 2010, in order to produce a comprehensive analysis report. Tests were performed while the unit was under most operating conditions, and it was possible to determine the rotor and stator shapes, as well as their relative position.

This paper will show how this type of technology is very valuable when verifying the rotor and stator integrity under all operating conditions.

In this particular case, the monitoring system, more specifically the air gap data, prevented major unnecessary repairs on the rotor.

FAILURES, TROUBLES AND NON-CONFORMANCES

6. Problems Experience with Modern Generators
Clyde V. Maughan; Maughan Generator Consultants

Making generators at lower cost has had a significant negative impact on the current fleet of newer generators, units less than about 30 years old. A number of factors have come into play, e.g., pressures to manufacture new machines more quickly and with less costly materials and processes, designs that push duties into higher and uncharted levels, "reinventing of old problems".

Couple these competitive market realities with reduction in number of engineers in OEM organizations and the loss of institutional knowledge as elders have retired, it is not surprising that some machines are failing much sooner than historically expected. This paper will present examples of some of the more critical missteps on various high-speed power generators and propose compensatory maintenance approaches for power plant engineers.

SPECIFICATIONS

7. Selection of Insulating Materials in Stator Coils
Leah Simmons; Doble Engineering Company

This paper will review the process utilized to select the materials used in construction of stator coils. It will look at how the characteristics of these materials, whether desirable or undesirable, affect the coils performance. This paper will also review the tests that are available to evaluate specific characteristics.

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OPERATION

8. Generator Breaker Failure Applications
   Dennis Tierney & Chris Dall; Calpine Corporation

This paper presents several real-world case studies which prompt further consideration when determining the schemes and corresponding current detector settings on circuit breakers directly connected to generator terminals or on the high side of their respective step-up transformers.

IEEE Std. C37.119-2005 Guide for Breaker Failure Protection of Power Circuit Breakers states that it is important for breaker failure current detectors to pick-up for minimum “fault current” conditions. The guide recognizes that for generators and other high-impedance power system devices there may be practically no currents for some internal fault scenarios. In these cases IEEE Std. C37.119 recommends that the breaker failure scheme be augmented with breaker position auxiliary contacts to determine correct breaker opening.

IEEE Std. C37.102-2006 Guide for AC Generator Protection section on generator breaker failure protection builds upon the schemes discussed in IEEE Std. C37.119 with the use of the breaker 52a contact to augment the current detectors in the various schemes. Furthermore IEEE Std. C37.102 discusses a modified scheme for detection of a flashover in the generator circuit breaker.

The performance of different generator breaker failure schemes and their applied settings under four different real-world scenarios is discussed in detail. The scenarios presented in this paper include:

1) A fault between the generator terminals and the generator low side breaker
2) When the generator breaker opens and the 52a contact confirms this, however, the breaker fails to extinguish the arc
3) If one or more of the generator breaker's main contacts flashover during a normal shutdown
4) If one of the generator breaker's poles on a low side generator breaker fails to open.

The calculation of appropriate current detector settings to identify these scenarios and minimize damage is explained in detail.

9. The Effects of Cycling on Hydro Generators
   William Moore; National Electric Coil

This paper will discuss the effects of cycling on hydrogenerators. Each major component of the hydrogenerator, and how it reacts to cycling operation, will be covered. The effects on the rotating parts, especially on higher speed turbogenerators, are quite obvious.

Fatigue cracking in rotor shafts, tooth tops, blower hubs, pole crossovers and copper field windings are quite obvious and well documented for high speed turbogenerators. The effects on slower rotating hydrogenerator rotors are less obvious but are still present. Particular areas of concern include the field pole dovetails and pole to pole connectors. Case histories of failed parts in these areas due to cyclic operation will be presented and discussed. In the stator winding and core components, the effects of cycling are more obscure. Since these parts are stationary and don’t see rotational forces, fatigue is less of an issue.

Other effects from cycling, due come in to play. These include primarily temperature differentials, between the coil insulation, coil copper and the stator core iron. Each of these components has different rates of thermal coefficients of expansion and cycling and the associated temperature changes can have an effect. These issues will also be discussed.
TRANSFORMERS COMMITTEE

TRANSFORMER FAILURES AND TROUBLES

1. 325MVA GSU Failure Investigation and Corrective Action on Remaining In-Service GSUs
   Robert Schwabe; New York Power Authority
   Lance Lewand, Dom Corsi & Bill Griesacker; Doble Engineering Company

On August 26, 2012, The New York Power Authority’s Blenheim Gilboa’s Pump Storage Power Project GSU #2 failed catastrophically after only five (5) years and two (2) months in operation. The transformer was manufactured by Hyundai and place in service in 2007. The initial assessment attributed the failure to a fault in the high voltage A phase winding. Since the plant has three identical Hyundai GSU’s remaining in service, The Authority decided to perform a detailed teardown and analysis to identify the root cause for the failure.

Hyundai participated in the teardown and failure analysis by providing technical experts to witness the process and support the analysis. NYPA also contracted with Doble Engineering Company to support The Authority during the teardown process and laboratory analysis on samples removed from the transformer winding. The initial findings indicated that the failure emanated in the De-energized tap changer caused by a fault between the A phase and B phase High Voltage tap position 1 stationary contacts. Since additional analysis was required to ascertain the failure mechanism, the tap changer was shipped to the Hyundai manufacturing facility in Sofia, Bulgaria to perform additional tests and measurements. The analysis indicated that residual stress from the cables connected to stationary contacts caused the stationary contact support beam to bow over time leading to contact separation between the B phase moveable and stationary contacts. The separation caused contact arcing and gas generation that eventually caused an arc to bridge the gap between the A and B phase high voltage contacts leading to a phase to phase fault and in-turn causing the transformer failure.

Based on the findings, Hyundai and The Power Authority discussed tap changer improvements to the design that would prevent contact movement when a force is applied to the contact support beams by the leads. Two modifications were proposed and the second accepted by The Authority based on the design structure and laboratory test results. Hyundai agreed to provide three new tap changers and installation support for the three remaining GSUs at no cost to The Authority. Contractors along with Hyundai and NYPA staff replaced all three tap changers and returned the units to service.

Follow-up examination on the removed tap changers revealed significant contact movement towards the stationary contact edge associated with tap position 1 on GSU #1 at approximately 1.5 mm from the edge where the normal tolerance is between 10.5 and 12.5 mm. GSU #3 indicated less movement with approximately 5 mm from the edge. The most alarming analysis was associated with GSU #4 having - been installed last - where the contacts were at the edge and there were indications that micro arcing was at the onset. GSU most likely would have failed in the near future. The failure analysis, new tap changer design and replacement in the existing units potentially saved The Authority significant costs associated with replacing the three units as a precautionary measure or having another failure that could have a substantial impact on generation and revenues at the plant.

This paper will document the teardown process, sample collection throughout all the windings, root cause failure analysis, tap changer modifications to the original design, tap changer replacement in the remaining in-service GSUs and analysis on the removed tap changer and potential impact on additional failures.

2. Removal of Flammable Levels of Gas from a Power Transformer
   Larry Christodoulou & Tom Zampell; Electric Power Systems

This paper describes how to safely reduce the TCG (Total Combustible Gas) level of a power transformer, which is considered to be flammable, to a non-flammable level.

An 115kV/13.8kV power transformer located in a substation in an urban location was in service when the gas detector relay targeted. The customer tested the gas in the headspace and from the main tank bottom sample valve. The TCG in the headspace was 85.22% and 59.27% from the bottom of the main tank. The transformer was removed from service and a means of degassing the transformer was needed.
The levels of combustible gas exceeded the flammable parameters as identified by using Doble Calculator: “Determination of a Combustible Gas Atmosphere.” The transformer could not be inspected or tested until the levels of combustible gas were reduced. The utility enlisted the services of Electric Power Systems (EPS) to create a safe environment for the utility to perform testing and inspection.

OPERATING USE

3. Effects of Loaded Tertiary Windings on Transformer Life
   Ruth Hooton & Paul Jarman; National Grid, UK
   Hongzhi Ding & Simon Ryder; Doble Engineering Company, UK

Many large transmission transformers are fitted with tertiary windings, for a variety of purposes. Some transformer users choose to load transformer tertiary windings, often to provide reactive compensation. This paper examines more than 40 years of experience using loaded transformer tertiary windings to provide reactive compensation in Great Britain. There is a high prevalence of problems related to leakage flux with such transformers, e.g. core bolt overheating, core/frame/tank circulating currents, and winding circulating currents. Tertiary loading also seems to accelerate solid insulation ageing, as might have been expected.

4. Emerging Technology: The ABB VRLTC Load Tap Changer
   Steve Leath; Duke Energy
   Jon Brasher; ABB

The Type VRLTC tap changer was piloted as a function of the Duke Energy retrofit program. The VRLTC is an emerging technology vacuum LTC incorporating specialized features which include a variable speed servo motor, with a multi turn absolute encoder to ensure position of the LTC at all times. The advanced monitoring system is continuously monitoring the health and performance of the LTC and will alert the user if conditions are trending toward failure. It features a 1,000,000 operation maintenance cycle with all parts that may ever need replacing on the front side of the diverter compartment for easy access. The VRLTC is designed for OEM application or as a retrofit LTC replacement.

5. Power Transformer Magnetic Core Issues
   Bill Griesacker; Doble Engineering Company

General experience shows that power transformer magnetic cores can provide years of reliable service when they are manufactured well and sustain no damage during transportation and installation. However, core problems do occur and one of the first indications is gas generation patterns that are commonly associated with low to moderate temperature overheating of the oil. Core issues are not usually associated with fast acting failure modes of transformers but can deteriorate over time and their gas generation can mask other possible problem activity in the transformer. In core form transformers some areas of the core are accessible, in shell form transformers access to the core is very limited, making location and repair of core problems difficult. This paper will present problems encountered in manufacturing, transportation and operation of power transformers, review methods used to detect the problems and discuss solutions that have been used to resolve them.

5A. PHI Online Monitoring and Asset Risk Initiative
   Carl Kapes; PHI (Pepco Holdings)
   Rick Cantrell, Ken Elkinson, Tony McGrail; Doble Engineering Company

In an effort to maximize reliability by proactively monitoring critical substation assets, Pepco Holdings, Inc. is implementing an automated system that will facilitate the collection and management of all online asset data collected within the substation, including information from Pepco’s vast number of online multi-gas transformer DGA monitors and a set of pilot online transformer bushing monitors utilizing the Doble Intelligent Diagnostic Device (IDD). The automated system will also incorporate oil lab test data and other hand-written data into a central database that can interface with SCADA and PI Historian data.
Pepco, by partnering with Doble on this pilot project, wants to be able to proactively visualize strategic, short and long-term overviews of asset health and performance, be able to better prioritize capital expenditures, operating and maintenance budgets and increase overall reliability.

This pilot project includes online monitoring and data collection and management for six (6) 500/230kV Autotransformers at Keeney Substation, six (6) 500/230kV Autotransformers at Red Lion Substation, and three (3) 500/230kV Autotransformers at Orchard Substation. dobleARMS will provide the ability to interface with Pepco’s offline DGA, multi-gas online monitors, online bushing power factor monitors, and PI Historian data.

The dobleARMS system will enable Pepco to manage their critical transformer online and offline data in a centralized software suite through one user interface. The output will consolidate the available transformer intelligent electronic device data into system, substation, asset and device views, through dobleARMS, and allow Pepco to easily analyze the information necessary to make critical operational, safety and financial decisions, which benefits not only the utility and their customer base, but also in the interest of continued reliability of their electric systems.

**DIAGNOSTIC METHODS**

6. **Capacitive Exciting Currents: A Driver for Improved Transformer Modeling**  
   John Lapworth, Asim Bajwa and Rafal Zaleski; Doble Engineering Company, UK

The measurement of exciting currents, also known as magnetizing currents, is one of the fundamental diagnostic tests for transformers, in particular for detecting shorted turns. Usually such currents are inductive, as expected from the basic transformer requirement to set up magnetic fluxes in the core, to enable voltage transformations between windings. However, on a few occasions capacitive exciting currents are measured, usually for modern transformers with very low core losses and magnetizing currents.

In this paper the reason for capacitive exciting currents is reviewed. It is confirmed that such currents are real, rather than a measurement anomaly, and it is shown that far from being an unusual curiosity, such currents are the commonplace, and occur to a greater or lesser extent for all transformers, irrespective of vintage, even though they are not usually apparent, apart from being responsible for the ubiquitous low frequency minima in SFRA measurements. The different voltage and frequency dependencies of inductive and capacitive components of exciting current are discussed, and the relationship between them is investigated for various types of transformers and windings. Lastly, some important consequences of capacitive exciting currents are discussed with case examples, including possible errors in turns ratio measurements at high voltage using an insulation analyzer and Transformer Turns Ratio (TTR) capacitor.

7. **Single-Phase Exciting Current Harmonic Content and Transformer Diagnostics**  
   Mark Lachman; Doble Engineering Company  
   Vadim Fomichev, AbdulMajid Shaikh & Alexander David; Delta Star, Inc.

Doble Engineering Company is studying the harmonic content of the single-phase exciting current to develop some practical rules that will enhance the analysis of the exciting current. A short presentation will be shown to highlight the initial progress with this work.

8. **Example of Transformer Short Circuited Winding**  
   Keith Burgess; Magna Electric Corporation

MEC has an example of the discovery of a short circuited winding inside of a transformer. The discovery was before the transformer had a failure in service. The presentation will show all results of the transformer including:

- DGA
- Insulation Power Factor
- Exciting Current
- Ratio
- DC Resistance
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- Leakage Reactance
- SFRA

The paper will describe which test results shows the failure and why. The paper will describe teardown of transformer and indicate that our conclusions of the test results were correct. This example will show the benefit of putting together a package of all test results to get full picture of what is happening.

9. Experience with DFR-based Moisture Estimation in Transformers
   Ronald Hernandez, Paul Griffin, Lance Lewand & Mark F. Lachman;
   Doble Engineering Company

The offered paper is a progress report on the dielectric frequency response (DFR) activities taking place at Doble. Specifically, the paper will discuss further steps towards refining estimation of moisture in the solid insulation of transformers under a variety of conditions. This would include the effects of acidity in the oil and paper on the estimation of moisture. Doble has developed a technique to separate and measure acids that have an influence on the estimation of moisture in paper from those that do not have an effect. The paper will include results of field case studies, showing the influence of these acids on the moisture estimation in the solid insulation of power transformers using the DFR measurements. Experience with DFR testing of new transformers will be included. This work is part of an on-going effort in evaluating the DFR technique as additional tool for special applications.

10. Use of Online Frequency Response Analysis Systems in the Evaluation of Substation Transformers and Associated Devices
    Jim McBride; JMX Services, Inc.
    Jody Benefield; Georgia Power Company
    Larry Coffeen; LTCoffeen Engineering, LLC

This presentation will describe new techniques of using online frequency response analysis (FRA) to assess the condition of transformers and associated devices. Online FRA allows for the assessment of transformer windings, bushings, and associated devices without requiring a transformer outage. Using the normal operating system transients on the power system, online FRA techniques evaluate the frequency response of the transformer while connected to the power system. This technique permits the analysis of these transformer systems from low frequencies to 2 MHz. System transient information obtained from online FRA recorded waveforms can also allow for the high frequency analysis of the interactions inside transformers and between substation equipment. Field data will be presented displaying online FRA analysis techniques and the use of online transient data to access transmission equipment condition.

11. Turns Ratio Test on Rectifier Transformer Connected to Rectifier
    Long Pong; Doble Engineering Company
    Pierre Leblanc & Rodney Wade; Alcoa Mt Holly

This Paper will be published but not presented.

Field testing a rectifier transformer is always a challenge because of its complex winding configuration, secondary bus connection to the rectifier and time constraints. Therefore, no one wants to disconnect the transformer from the rectifier for testing. This motivates the testers to find alternate test methods for preventive maintenance or condition assessment, as described in [1] below which first proposed the Doble Ratio Test on a transformer connected to the rectifier, but the paper did not complete the study. This paper will be the continuity of the study and focus only on the Doble Ratio Test method including one case study, a modified test procedure and test results from the following rectifier transformer at Alcoa in Mt. Holly, South Carolina.
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Circuit Diagram of Rectifier Transformer connected to Rectifier
Figure 1

REFERENCE

12. Examples of Problems Found during Testing of Transformers
James Reed, Richard Von Gemmingen; Dominion Virginia Power

- An improperly coupled LTC drive shaft on a new transformer received from the factory. The LTC contacts would make up in one direction of travel, but not the other. This was a fairly unique problem that could have slipped through the cracks.
- A broken lug internal to the transformer going from the tapped winding to the selector switch
- An in service transformer that had suffered significant winding movement and deformation, probably from an earlier through fault. DGA sampling initially indicated the problem, then SFRA and LR confirmed the problem. A “controlled” teardown was performed at a salvage facility for root cause analysis. We had a failure of a similar constructed unit and still have several such units on the system.

13. Image Processing-Based Technique for the Identification of Transformer Winding Deformation in Real Time
A. Abu-Siada, S. Islam; Curtin University, Australia

Frequency Response Analysis (FRA) has been growing in popularity in recent times as a tool to detect mechanical deformation within power transformers. To conduct the test, the transformer has to be taken out of service which may cause interruption to the electricity grid. Moreover, because FRA relies on graphical analysis, it calls for an expert person to analyze the results as so far, there is no standard code for FRA interpretation worldwide. In this paper an online technique is introduced to detect the internal faults within a power transformer by considering the voltage-current (V-I) locus diagram as a transformer fingerprint that can be measured every cycle to provide a current state of the transformer. The technique does not call for any special equipment as it uses the existing metering devices attached to any power transformer to monitor the input voltage, output voltage and the input current at the power frequency and hence online monitoring can be realized. Various types of faults have been simulated to assess its impact on the proposed locus. A Matlab code based on digital image processing is developed to calculate any deviation of the V-I locus with respect to the reference one for fault identification and quantification. Effect of other operating conditions such as load level, load power factor, power systems harmonics on the proposed locus is also investigated. The proposed technique is easy to implement and automated so that the dependency on expert personnel can be reduced.

14. Identifying Contact Troubles within Transformers
John Earle; Ontario Power Generation

Dissolved Gas Analysis of Generator Step Up Transformers is one of the most discussed and most useful means of predicting potential faults in transformers. This presentation summarizes how dissolved gas analysis predicted a faulted transformer, and permitted remedial actions to take place saving the asset. Highlighted are key steps from discovery of the fault through dissolved gas analysis, repair, and post repair monitoring.

ACTIVITIES IN THE ELECTRICAL POWER INDUSTRY

15. EPRI Research in Transformers
Luke van der Zel; EPRI

EPRI (Electric Power Research Institute) is a non-for-profit collaborative research organization, supported by utilities and energy companies both in the USA and abroad. Within EPRI there is a strong research focus in the area of Transformers. This paper will share a high-level overview of the areas of research EPRI is engaged in. The research efforts cover a wide spectrum including novel sensors, analytics for diagnostics and fleet management, tools for life assessment, life extension technologies, bushings forensics and GMD (Geomagnetic Disturbances). Highlights from the research will be presented and the paper will conclude with an overview of EPRI’s future research plans.

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