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International Conference on Condition Monitoring, Diagnosis and Maintenance

CMDM 2011

Bucharest, Romania

September 19 – 23, 2011

Organized by:

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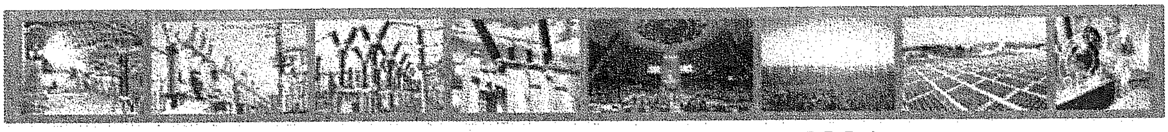

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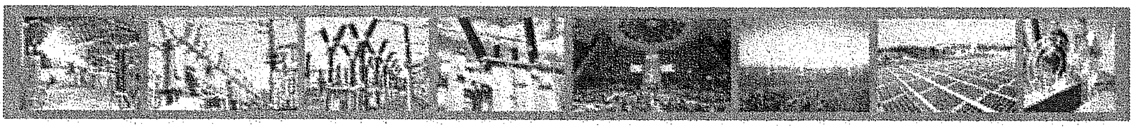

International Conference on Condition Monitoring, Diagnosis and Maintenance 2011

CMDM 2011

- Modern Management Technology -

September 19 - 23, 2011, Radisson Blu Hotel, Bucharest, Romania

FOREWORD

On behalf of Romanian National Committee of CIGRÉ, it is our great pleasure to welcome our distinguished guests of the first International Conference on Condition Monitoring, Diagnosis and Maintenance (CMDM 2011) taking place in Bucharest, Romania, on September 19th-23rd, at the Radisson Hotel.

CMDM 2011 is organized by the Romanian National Committee of CIGRÉ and the Romanian Power Grid Company "Transelectrica" as co-organizer, under the patronage of the Ministry of Economy, Commerce and Business Environment of Romania.

The conference brings together expert engineers, scientists, researches, decision makers, academics and others with interest in the domain and provides an excellent opportunity to share state-of-art information on condition monitoring, diagnosis, maintenance and asset management techniques in the electric power system. The main topics include: (1) Smart Grids, (2) Condition monitoring and diagnosis for power equipment and high voltage lines, (3) Condition monitoring and diagnosis in power plant, (4) Failure phenomena based on electrical, mechanical, chemical and thermal causes, (5) Degradation assessment for power equipment, (6) Modern maintenance tools and technologies, (7) Advanced sensing techniques for condition monitoring and diagnosis, (8) Applications of artificial intelligence for data mining and condition assessment, (9) Substation automation and automated metering, (10) Asset management tools for power equipment, (11) Distributed resources and renewables.

We would like to extend our warm welcome to all the participants at CMDM 2011 conference and to wish a successful and enjoyable meeting. We hope that everyone will find the CMDM 2011, both technically interesting and stimulating, and that your staying in Bucharest will be an unforgettable and pleasant time.

The Romanian National Committee of CIGRÉ,

Dr. Ciprian Diaconu	Dr. Constantin Moldoveanu	Dr. Dorin Ioan Haţegan
Chairman	Vice-Chairman	Secretary

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#122

THE IMPORTANCE OF CORRELATING DYNAMICS WHEN PERFORMING PARTIAL DISCHARGE MEASUREMENTS

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SUMMARY

Online measurement and assessment of partial discharges has proven to be an effective tool in evaluating the condition of insulation and thereby limiting unscheduled outages. Yet, dynamic factors such as humidity, load, and temperature have a significant effect on PD levels. In the past, this data has not been collected simultaneously with PD measurements-something best done on a continuous basis such that correlation and trends can be revealed. This paper will show that the best assessment of insulation condition is based on correlating dynamic environmental and load conditions with PD levels and then trending this information over time. This process will result in superior diagnostics and thereby improved maintenance and outage decisions. Actual data collected from rotating equipment and switchgear will be presented and discussed.

KEYWORDS

Partial Discharge, Humidity, Temperature Load Current, Correlation, Operating Characteristics.

1. INTRODUCTION

In today's competitive environment, increasing demands are being placed on the management of physical assets. It has become imperative to capitalize on advances in technology that allow new approaches to the maintenance of these physical assets. These include reliability-centered maintenance, predictive diagnostics, condition monitoring and expert systems. Concerned customers and suppliers are taking advantage of the convergence of these new technologies to implement proactive maintenance programs to improve the performance and extend the life of their installed base of equipment.

The electrical industry has a very limited number of "predictive tools" and those available are generally labor intensive and require some level of expertise. One tool is the continuous monitoring of medium and high voltage equipment for partial discharges. This includes motors, generators, switchgear, bus duct, cables and transformers.

Measurement and analysis of Partial Discharges (PD) in electrical equipment has become a very popular tool in online assessment of insulation condition in medium voltage (MV) and high voltage (HV) apparatus. Both PD level and PD trend are diagnostic parameters in condition assessment. Traditionally the online technology has been applied to motors and generators, but is now being expanded to other equipment such as switchgear, bus duct, cables and transformers. Traditionally, PD tests have been performed on a periodic basis, approximately every 6 to 12 months. Most standards related to the online assessment of insulation systems recommend trending of data in order to provide the best assessment. Setting alarms or basing judgments based on magnitudes (Qm) alone is not sufficient. Basis for this statement are is fold.

1) No standard exists as to what magnitude is considered "good" or "bad". [1] Some suppliers of PD technology have published data in an attempt to get to this point, but the data is controversial.

a) Lack of calibration - No calibration of the system has been performed. Many less than ideal installations of coupling capacitors at the line terminals of motors and generators have been observed. The high frequency signals produced by a PD event attenuate quickly as the traveling wave moves through a winding. In order for the PD signal to properly propagate, a low inductive circuit is required. Unless calibration has been performed on each and every machine, comparison of absolute values of Qm is not valid.

b) In many cases, pulse count is much more important than magnitude. In order to choose the proper parameters to monitor, it is recommended following any of the key standards related to making PD measurements found within IEEE and IEC. It is recommended that PD power or PD Intensity be the key factor to monitor since it takes into account both magnitude and pulse count.

c) Trending is the key factor in determining the condition of an insulation system. A low level of PD increasing quickly will signify a major defect, while a high level of PD that is stable will indicate there is a major defect, but it is not getting worse. A general "rule of thumb" has been established that a doubling of PD levels in six months will indicate insulation in poor condition and is quickly deteriorating.

2) There are several external factors that may significantly affect partial discharge. The most important are voltage, temperature, humidity or absolute moisture in the air or isolating fluid, load current and hydrogen pressure. Neglecting these factors may produce incorrect diagnostic conclusions resulting in missing a problem or producing a false alarm. In addition, correlating PD characteristics to these factors frequently provides valuable information that allows one to further discriminate the type of PD failure mechanism and to plan more appropriate corrective action.

OPERATING CONDITIONS

Voltage

Applied voltage can have a significant impact on PD activity. The higher the voltage on the system, the more likely PD will occur. Also, the higher the voltage, the more destructive the PD activity. Experience has shown in North America that voltage levels are fairly stable and this is a secondary factor to monitor.

Temperature

In rotating equipment it is recommended that winding temperature be monitored. In other types of air insulated equipment such as switchgear and bus duct, ambient temperature should be monitored.

In rotating equipment two types of common defects behave differently with winding temperature. Both slot discharges and slot exit discharges have very similar phase resolved patterns as shown in Figure 1. The horizontal axis of each chart is the magnitude of the pulses in millivolts and the vertical axis is the phase angle of the power frequency AC waveform (0 - 360 degrees). The dots represent the number of pulses per cycle. Both types of defect have a positive pulse preference (PD occurring on the negative half cycle).

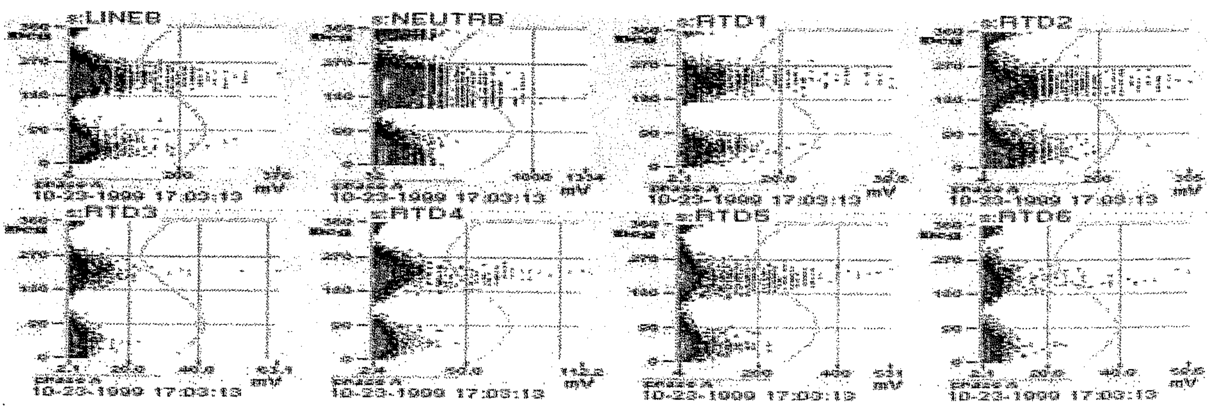
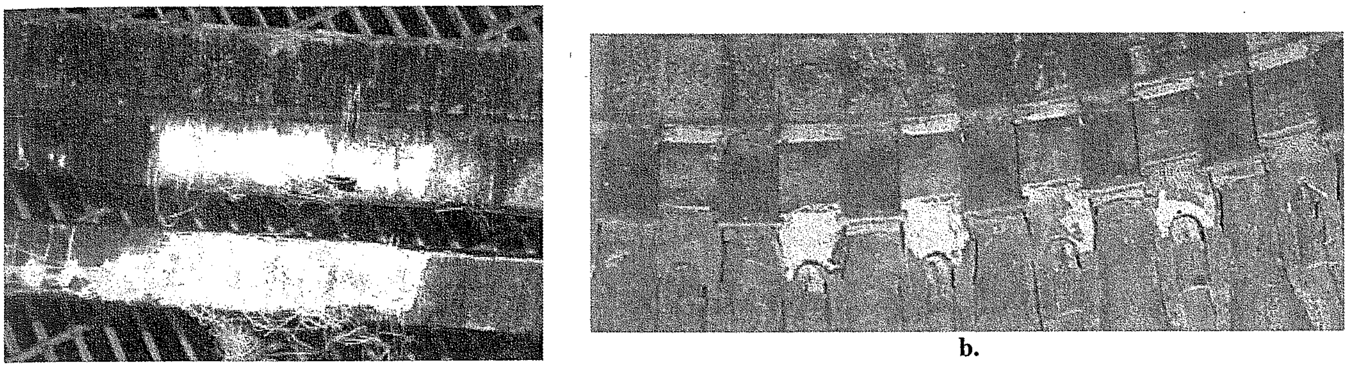


Fig. 1. Phase resolved data showing positive pulse predominance (negative half cycle). Both slot and slot exit discharges have similar patterns or fingerprints.

The only way to identify which defect is occurring with the equipment in service is by analyzing the effects of the winding temperature. Figure 2 shows pictures of both types of defects. A slot discharge in

Figure 2a will have a negative correlation to temperature. As temperature increases, PD activity will decrease. This is attributable to the fact the copper winding and insulation both have significantly different coefficients of expansion. As the winding heats up, the number and size of the voids decrease.

Slot exit discharges are shown in Figure 2b. Slot exit discharges occur when the semi-conductive grading coating at the slot exit has improper conductivity or has worn away. The semi-conductive coating is designed to reduce the stress at this point. This type of defect has a positive correlation with temperature (As temperature increases, PD activity will increase.)



a. b.

Fig. 2. Both types of defects have same fingerprints (Fig. 1) but behave differently with winding temperature

Load

If the winding is tight in the stator slot there will be no significant effect with load on the machine. If it is loose, as load increases additional mechanical forces will be placed on the coils and they will vibrate or move in the slot. This will have a tendency to increase PD activity. Of course, load will affect winding temperature, but it will lag in time. One needs to discern the timing of the events in correlation with PD activity.

Humidity and Moisture in the Air (Gas)

The ambient water content of the air in medium voltage air-cooled apparatus can have a significant effect on PD. It may be so significant that if not accounted for, trending is quite difficult. This is especially true for outdoor installations. In environmentally controlled indoor applications, the effect of moisture may be not be that pronounced.

Initially relative humidity was monitored. After additional testing and analysis it has been determined the actual moisture content in the gas has a better correlation to PD activity than humidity. It still remains difficult to clearly disseminate absolute moisture effect from temperature effect since these two quantities have a strong relationship. There are cases where absolute moisture content correlates better than humidity, examples, which are shown in this paper. The authors have observed about 50% of the air-cooled rotating equipment currently under continuous monitoring shows variations in PD activity with moisture content or humidity. Normally a negative correlation is observed - as humidity or moisture increases, PD activity decreases.

In switchgear correlation of ambient moisture effect is more frequently positive, but a negative effect has also been observed.

At least two processes may attribute to the moisture effect on PD. Water molecules have an excellent ability to capture free electrons in a discharge and therefore increase breakdown voltage of the air. The more water concentration in the air the more voltage is required to break the same gap. Some of insulating materials used in MV equipment are relatively hydroscopic and may absorb significant amounts of water. Surface contamination may work in a similar way. Water changes the surface conductivity and consequently the electrical field distribution, which will cause overstressing some areas and creating additional PD.

Additional fundamental research is needed to establish the physical mechanisms of moisture influence on partial discharge behavior in operating equipment.

Pressure

This is not a real factor on air-cooled apparatus, but can have a significant affect on hydrogen cooled machines. Paschen's Law governs the breakdown point of gas. As pressure increases, PD activity will decrease. Gas type and the gas breakdown properties are also factors to consider.

CONTINUOUS MONITORING

It has become evident that if one is performing periodic PD tests on equipment and trending is a true indicator of insulation deterioration progress, then one must make sure these dynamics (temperature, humidity, load current, etc.) are as close as possible for each and every measurement. Most of these dynamics are beyond user control; therefore proper trending most likely is not possible.

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With an appropriate continuous monitor that not only monitors PD activity, but also monitors key operating condition parameters will assist in the proper diagnostics and prognosis of equipment condition. With hundreds of thousands of measurements in our database it has become evident that in about 50% of the cases, there is a significant variation with operating dynamics.

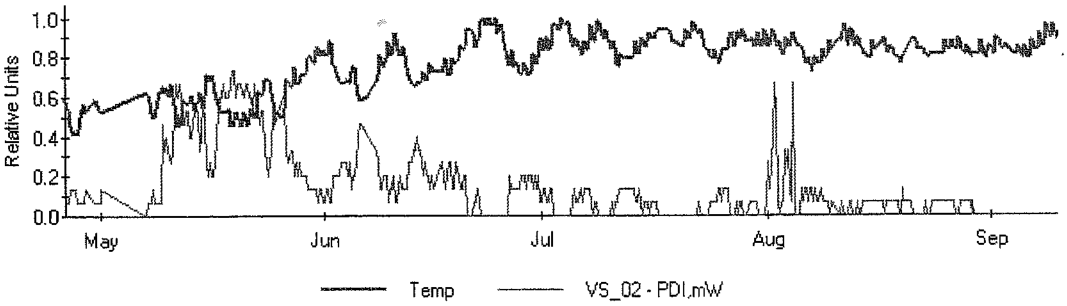
On rotating equipment it is recommended that winding temperature, load current and humidity or hydrogen pressure be monitored in conjunction with PD activity. On switchgear and other stationary air insulated equipment, temperature and humidity should be monitored.

CASE STUDIES

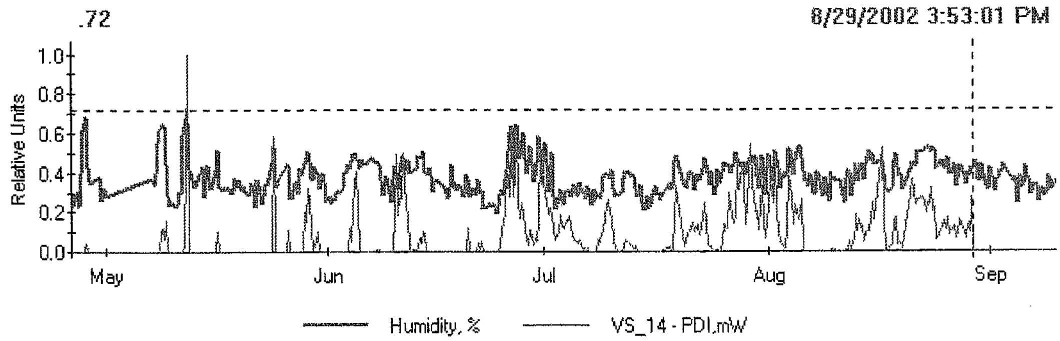
The following four case studies show the effect of these dynamics on operating equipment.
Data were obtained with the InsulGardTM 15-channel partial discharge monitor that records dynamic parameters in conjunction with partial discharge phase-resolved data.

Case 1

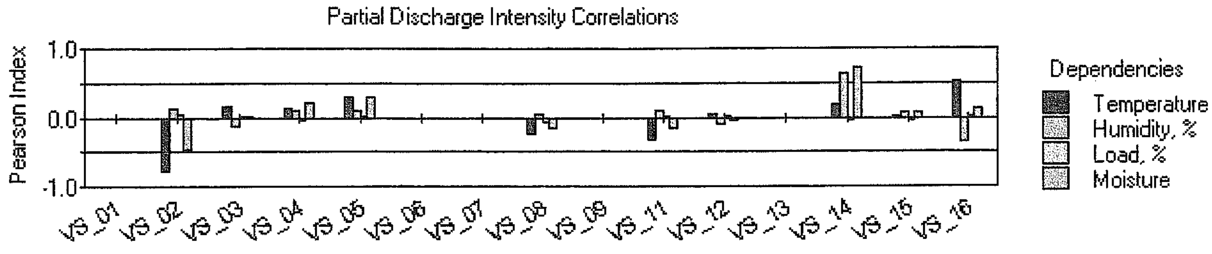
Figure 3a shows cubicle 2 - Partial Discharge Intensity (PDI) trend data and ambient air temperature on 16 cubicles of 13.8 kV switchgear. In April 2002 an event occurred that caused damage to the insulation system. As the temperature increased during the summer, the PDI activity decreased. Online diagnostics determined that the problem was with a potential transformer (PT). In August 2002, the PT was replaced and now there is no PD.
Figure 3b shows the same line up of switchgear, except cubicle 14 PDI and humidity. This was also diagnosed as a problem with a PT. It was replaced and the PD disappeared.
Figure 3c shows the correlation charts for each channel based on the Pearson Index, a well-accepted statistical correlation index. Cubicle 2 PD negatively correlates to temperature and cubicle 14 PD positively correlates to air moisture.



a.



b.



c.

Fig. 3. Effects of Dynamics on PD activity in a lineup of 13.8 kV switchgear. a. - Cubicle 2 - PDI and Temperature (75% Negative correlation); b. - Cubicle 14 and Humidity (70% positive correlation); c. - Correlation Charts

As can seen in Figure 3, if periodic PD testing were performed it would be quite easy to miss detection of the defect and impending failure.

Case 2

This case presents data from a 16,000 HP, 13.8 kV machine from a large petrochemical plant. Several tests were done online with temporary sensors including Radio Frequency Current Transformers (RFCTs) on cable shields and 12 RTD-sensors. Signals from the RFCTs were in the range of 150 – 250mV and were not a cause of significant concern. Significant PD activity was noticed on most of the RTDs with four RTDs with very high PD levels. RTDs 01, 03, 09 (A-phase) and 05 (middle phase, phase rotation A-C-B) show the highest levels. Figure 4a shows the phase-resolved data from these RTDs taken online under normal operating conditions with a temperature of 110°C.

During a subsequent outage, offline PD tests were performed in a motor repair facility. The results of both tests correlated. The 80pF coupling capacitors installed at the line terminals were below 200mV and the same RTDs show the highest PD activity (RTD 01, 03 09 while energizing A-phase and RTD05 while energizing the middle phase). The observed PD magnitudes were 10 to 20 times lower than during the online test. Figure 5b shows offline data from the same sensors at a temperature of 21°C.

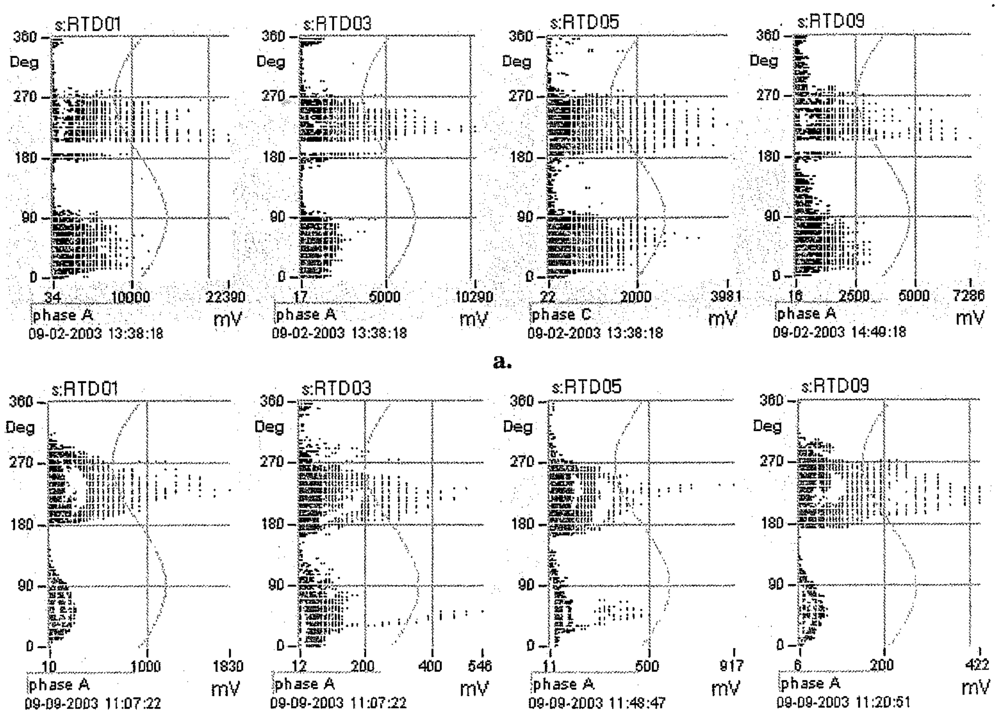


Fig. 4. Phase resolved data from a 16,000 HP, 13.8 kV machine.
a. - Under normal operating conditions @ 110°C.
b. - during off line test @ 21°C.