CONTINUOUS ON-LINE SYSTEM FOR PARTIAL DISCHARGE MONITORING FOR HA1 AT CHE ROBEŞTI

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A proper evaluation of the state of the electrical insulation in motors and generators rated 3.3 kV and above using Partial Discharge (PD) measurements, along with the correct interpretation of the results, represents the key for long term use of the machine based on positive data related to insulation condition. This paper presents the results of experimental research upon partial discharge for HA1 hydro-generator at CHE ROBESTI, equipped with a Kaplan turbine and technologies behind a continuous on-line PD monitoring system for hydro-generators provided by Iris Power from Canada. Using proper tools and advanced software for data analysis, the PD measurements provide a valid status of the machine insulation status, based on information unaltered by electrical-interference signals from poor electrical connections, sub-systems operation or corona effect etc. Proper PD measurements and analysis can indicate the need of a future or immediate maintenance. Taking into consideration that over years companies with experience in PD monitoring have stored information and PD tests in databases for internal use, one can easily compare and provide an objective solution or interpretation of PD levels measured for the stator insulation condition under surveillance, relative to other similar machines. This article provides an objective and practical overview of system components, multiple installation and configuration issues, together with benefits of on-line monitoring of the insulation system for HA1, CHE Robe□ti over a period of few months, taking into consideration that the insulation age in no more than 2 years old.

Keywords: high voltage equipment, partial discharge monitoring, PD online measurements, electrical insulation, stator winding

1. Introduction

PARTIAL discharges (PDs), sometimes called corona, represents incomplete electrical sparks taken place in deteriorated, damaged or poorly made stator-winding insulation systems in motors and generators rated 3.3 kV and above. Over the past 25 years, online PD monitoring has become the most widely applied method to determine the condition of the electrical insulation in such machines [l]-[3]. PD testing and data analysis can detect most of the common manufacturing and deterioration problems in form-wound stator windings, including the following:

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1) poor impregnation with epoxy;
2) poorly made semi conductive coatings;
3) insufficient spacing between coils in the end winding area;
4) loose coils in the slot;
5) overheating (long-term thermal deterioration);
6) winding contamination by moisture, oil, dirt, etc.;
7) load cycling problems;
8) poor electrical connections (although this is not strictly an insulation problem) [2].

Reliable manufacturing operations will always be concerned with process production motors. Comprehensive programs to maintain electrical equipment for peak performance have been recommended and implemented at various plants [3]. PD detection in operating motors and generators can be achieved using multiple methods [2]. The electrical techniques rely on current and voltage pulse variation that is created whenever a partial discharge occurs. One of the methods used before any modern monitoring system was measuring the current pulses with a high-frequency current transformer at the neutral point [4]. Some companies used RTD sensors (Resistance Temperature Detectors RTD are temperature sensors that contain a resistor that changes resistance value as its temperature changes) as an antenna [5][6]. High-voltage capacitive couplers are used for most rotating machines for PD periodic tests or continuous monitoring as PD sensors.

PD measurements for motors and generators taken during normal operation condition are subject of electrical signal interference. The sources of this perturbation signal called **noise,** include corona signals from the power system, slip ring/commutator sparking, poor electrical connections, arc welder operation, and/or power tool operation [1]. PD pulses and noise signals have almost the same characteristics and improper analysis of the test results could give mislead information about the insulation condition.

Analysis of failure statistics has shown that a high percentage of failures can be attributed to breakdown of solid insulation. This insulation breakdown is often preceded by partial discharge activity and therefore non-intrusive detection of this activity is an effective tool for the detection of deterioration in the insulation [8].

Located on Olt River, CHE Robe□ti has an installed power of 27.1 MW and is designed to annually produce 74.64 GWh. CHE Robe□ti has two units commissioned in late 2011, so having a history of PD data from the beginning of operation is more than relevant for machine insulation system condition. The Olt River at this point is the most exploited hydropower source in the country.

The HA1 unit is a vertical synchronous generator “HVS 800/95-60” with the following main technical characteristics:

Table 1

CHE Robesti main technical data

Apparent Nominal Power	P_a = 24000 kVA
Active Nominal Power	P_n = 21780 kW
Planning power	Pea = 18900 KVA
Rated voltage	U_N=10500±5% V
Rated stator current	I_N=1330,6 A
Planning stator current	I_{Na} = 1309 A
Rated power factor	cos Φ_N = 0,9
Rated frequency	f_N =50 Hz
Rated speed	n_N = 83,3 rot/min.
Efficiency at rated load	η = 97,2 %
Phase connection	star (wye)
Phase number	3

The main objectives of this research paper is to provide technical and relevant information directly from CHE Robe□ti HA1 unit, regarding PD data (insulation system condition - machine status) and afferent sub-systems responsible for data acquisition and processing.

2. System structure for PD monitoring

CHE Robesti HA1 is modernized and equipped with an advanced PD monitoring system, named HydroTrac, produced by Iris Power Company from Canada. The PD sensors used are HV capacitors, directly connected to system bus and end-winding area of the stator. Below is the as built architecture of the communication system and data analysis.

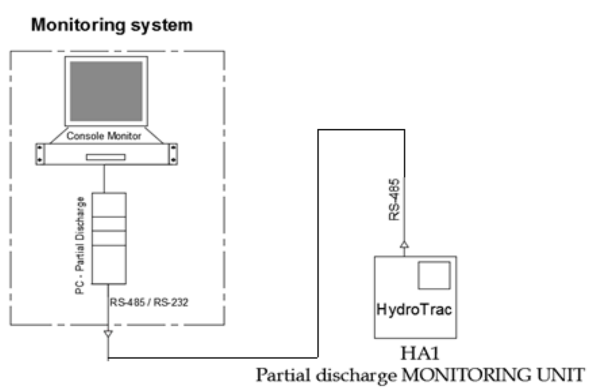

Fig. 1 CHE Robesti HA1 - PD Monitoring System

The Iris Power HydroTrac system at HA1 consists of permanently installed high-voltage capacitive couplers, two couplers per phase, a dedicated Iris Power HydroTrac monitor (HydroTrac), plus digital communications for configuring the monitor and downloading the stored PD data into a specialized workstation. The system is an economical means of providing automated, continuous partial discharge (PD) measurement and trending [6].

For each phase, a C1 sensor is located as close as possible to stator end winding to ensure low attenuation of the fast rising PD pulse; a C2 sensor is mounted ~2m away from the C1, to ensure proper signal separation. A total of six PD sensors provide full machine PD pulse caption and transmission to the HydroTrac unit through coaxial cable. Fig. 2 shows the approximate location for a pair of couplers for a given phase.

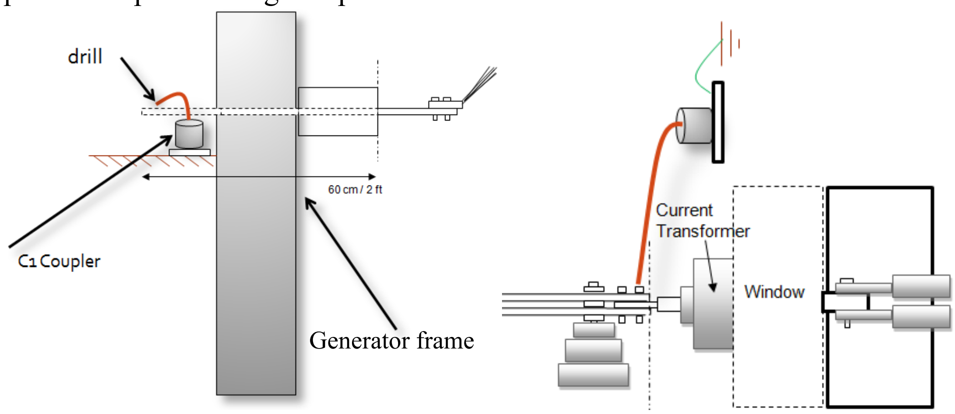

Fig. 2 Capacitive couplers location

The accuracy of the collected and stored data in HydroTrac monitor depends on the quality and efficiency of the noise separation algorithm implemented into the monitor unit. There are several consecrated methods for distinguishing between purely stator PD data and not any data consisted from PD and noise or just noise. Having the same overall electric characteristics, both PD and noise pulses must be separated and properly stored or ignored (noise interference from the system). The most widely used methods for data separation are:

1) frequency domain filtering; 2) surge-impedance mismatch;

3) pulse-shape analysis; 4) time of arrival.

Practically, to reduce the risk of false indications to less than a few percent's, at least three of the four methods are implemented simultaneously. In high noise environments, all four are implemented [1]. The first there methods are designed to operate more at software level, electronically embedded into the monitor.

In this paper, the time of arrival method is described and taken into consideration due to calibration procedure of the sensors, using pulse injection into the system as a simulation of PD and noise signals. HA1 unit uses the above mentioned method for signal separation. This method is used when the software cannot distinguish between PD and noise, due to almost identically pulse shape, so an additional method for signal separation is required, using 2 sensors on the same phase.

The theory states that if the distance between the sensors is at least 2 meters, an injected PD like pulse from the power system will arrive first at the “C2” sensor and few nanoseconds later at “C1” sensor (in copper bus bar the pulse speed is 1ns/30cm). An injected pulse from the generator or machine arrives firs at "C1" and later to "C2 sensor". Digital logic embedded into the monitor, can store real PD pulses and ignore system noise interference, taking into consideration the sensor that detect the measured signal first.

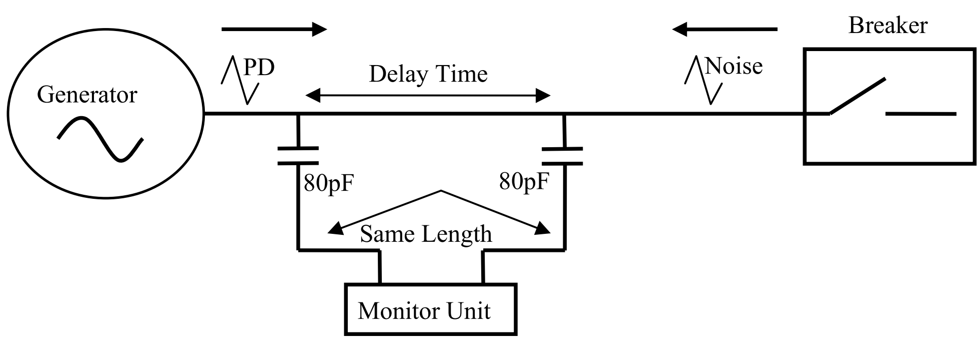

Fig. 3 Time of arrival method for noise separation using two coupling capacitors per phase

IEEE 927 (IEEE Guide for the Measurement of Partial Discharges in AC Electric Machinery) states that a capacitor that is to be used in on-line monitoring applications should meet the following requirements:

- Withstand the impulse and 50 Hz or 60 Hz over potential test voltages of the machine winding over the range of possible operating temperatures.
- Have a PDEV, for pulses >2pC, higher than the phase-to-phase operating voltage of the machine over the range of possible operating temperatures. PDEV - The highest voltage at which partial discharges (PDs) above some stated magnitude (which may define the limit of permissible background noise) no longer occur as the applied voltage is gradually decreased from above the inception voltage. PDEV, is expressed as 1/√ 2 of the peak of the alternating voltage.

- Have a sufficiently low dielectric loss to ensure that it will be free of signs of thermal runaway over the range of possible operating temperatures.
- Show no signs of deterioration of the above properties after thermal cycling and mechanical vibration representative of operating conditions.
- Have dimensions and mass such that in the installed position, it will not exhibit mechanical resonance, for example, at 100 Hz or 120 Hz.
- Meet the physical constraints and electrical clearance requirements of the location in which it is to be installed [9].

CHE Robesti HA1 unit operates for 2 years, with a class B insulation system (thermal classification). PD activity is expected to indicate higher values due to remaining voids from impregnation process. In time, PD levels are subject of lower values. The testing procedure is conducted during real operating conditions, under typical temperature, voltage stresses, and vibration levels [7].

The HydroTrac PD monitor installed for HA1 respects international standards for PD testing of inductive apparatus (IEEE 1434 and IEC 60270), where the pulse amplitude is measured in the absolute units of millivolts (mV). For a given test, all the PD activity is translated into the value of 2 parameters.

The monitor process the PD pulses, by storing the number, the amplitude and the phase position (50 or 60 Hz power cycle).

Fig. 4 shows a typical plot PD data from one phase of a motor stator winding. The peak positive and negative PD pulse magnitudes (+Qm and -Qm) represent the highest PD pulses measured in mV with a minimum PD repetition rate of ten pulses per second. Qm is a reasonable predictor of insulation condition at the most deteriorated location in the winding. A high Qm measured in a winding compared to a lower Qm in another winding, usually implies that the former winding is more deteriorated [1].

HA1 Trend Report - Qm, from CHE Robe□ti facility is displayed below, containing data from the beginning of commissioning in 2012 till the end of 2013.

Fig. 5,6,7 show PD activity from all three pairs of capacitive couplers in a trend plot for each phase. The monitor compute the quantities Qm and NQN parameter based on the pulse amplitude and frequency, for both negative and positive PD counters embedded into monitor. Trending of the ±Qm and ±NQN values represents the *progression* of the aging mechanism. A doubling of PD activity (Qm values twice that of the previous test) every six months is a strong indication of a rapidly developing failure mechanism [10].

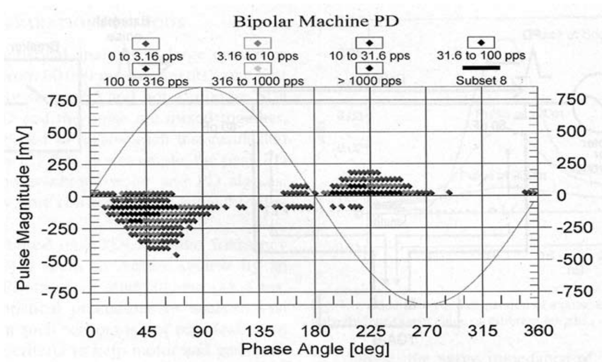

Fig. 4 Typical PD data. The vertical scale is the positive and negative PD magnitude in millivolts. The color represents how many discharges are occurring per second at this amplitude and phase position. The higher the PD, the larger is the defect within the insulation. The peak PD amplitude (Qm) for this phase is —400 mV and +200 mV [1]

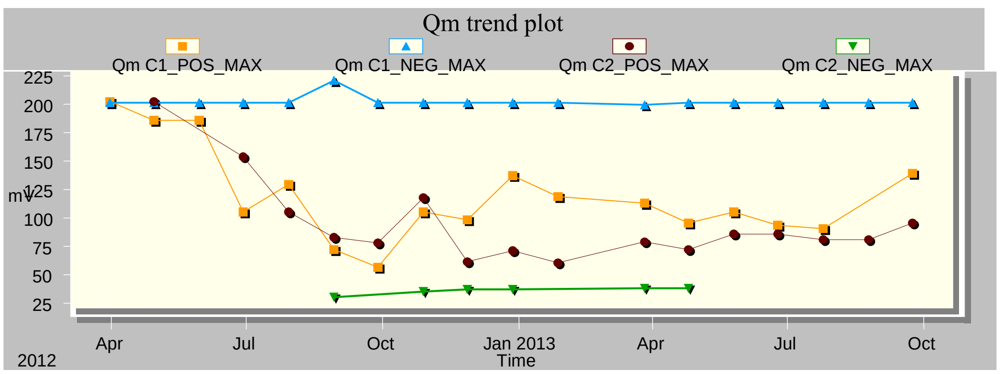

Fig. 5 Phase – R

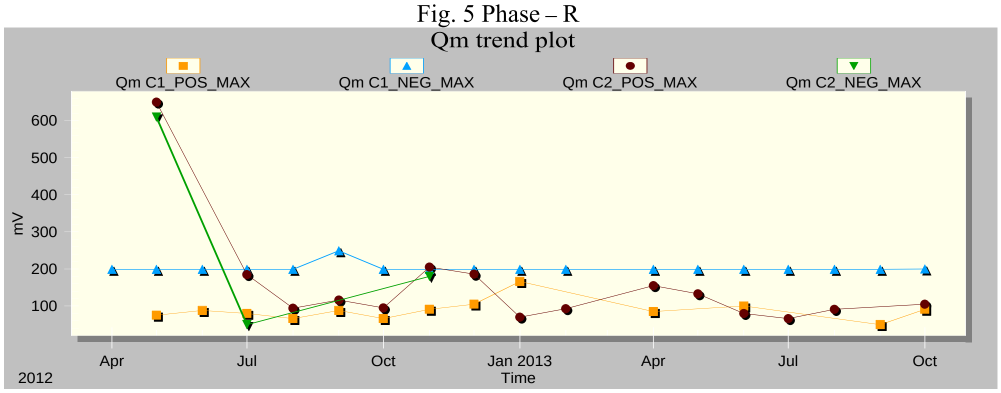

Fig. 6 Phase - S

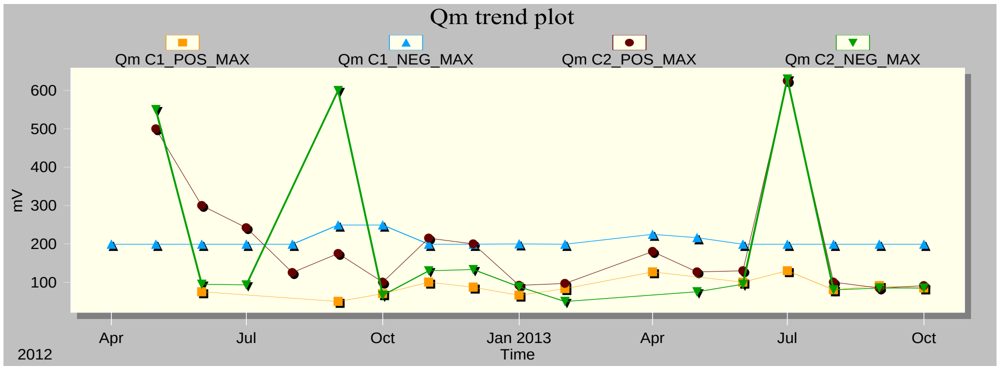

Fig. 7 Phase – T

Phase R (Fig.5) data analysis shows a severe negative PD activity, captured by C1 sensor, indicating PD originating near conductor surface inside insulation system or incomplete bond between the insulation material and the copper strands. A relative high value of positive PD activity from C1 sensor, over a period of few months could indicate that PD originates on the surface of the insulation system, possibly caused by improper installation of the coil, looseness or even degradation of the voltage stress coatings.

Phase S (Fig.6) data analysis shows higher values of the pulses coming from the C2 sensor, indicating system noise interference captured by the sensor. C1 sensor indicates values that are stable in time and with acceptable variations.

Phase T (Fig.7) data analysis shows some peak magnitude of pulses captured by C2 coupler and acceptable values for pulses from the machine side.

NQN - Normalized Quantity Number, is a partial discharge quantity that is proportional to the total partial discharge measured by a PD sensor. *NQN is an indicator of the average condition of the stator winding insulation*.

Qm - Peak Amplitude is the amplitude of the pulses for one fundamental (directly measured) pulse category that has a frequency of 10Hz, and corresponds to the peak PD activity. *Qm is an indicator of how severe the PD is at the most deteriorated part of the winding*.

Due to a large number of motors and generators that have installed 80pF capacitors, an online monitoring system can provide a continuous data acquisition, together with an extended and full phase analysis of the processed data, thus machine condition (insulation status) in time, translated into an effective predictive maintenance tool.

3. Conclusions

Based on the site information, the Iris Power advanced PD online monitoring system provided an overview of the machine condition for insulation system, regarding PD occurred in stator winding. The maintenance engineers from CHE Robesti were informed and instructed to keep storing data captured by the sensors. CHE Robesti HA1 unit show an expected PD activity, due to short operating period, but because of online monitoring, most maintenance can be planned well in advance and that catastrophic failure is greatly reduced.

In the case of new or newly refurbished units, like CHE Robesti HA1 unit, the information provided by an integrated monitoring system is very important to show a complete history of the PD activity. With proper and valid information the facility can greatly reduce downtime by inspecting only the most susceptible PD occurring areas in insulation system, thus preventing major faults is possible in short time.

The partial discharge monitoring activities within the insulation systems of rotating machines provide early indication of the occurrence of detrimental factors, which if not corrected by preventive maintenance, could result in costly unplanned outages.

R E F E R E N C E S

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