10125 Session 2022
SC A1 − ROTATING ELECTRICAL MACHINES
PS2 − ASSET MANAGEMENT OF ELECTRICAL MACHINES

Construction of the Partial Discharge Measurement History According to IEC 60034-27-2

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SUMMARY

Regarding the monitoring of the stator insulation condition, the established technique is the monitoring of partial discharges (PD). This technique has been used effectively within Eletrobras Eletronorte and several case studies have been presented. However, one of the pillars of predictive maintenance is the construction of the measurement history with the monitoring of the measurement trend curve. This history was built over five years (with the measurement systems that provide the PRPD graph "Phase Resolved Partial Discharge") in generators with more than thirty years of operation (HPPs Tucuruí, Coaracy Nunes, Samuel and Balbina), stators with natural aging of the insulation, when taking into account the typical curve of the behavior of PD during the life cycle of a machine.
Currently, Eletronorte is responsible for the operation and maintenance (O&M) contract for the Belo Monte Complex formed by two HPP Pimental and HPP Belo Monte plants. With this, it was possible to carry out PD measurements since the beginning of the operation of new windings.
The IEC 60034-27-2 [1] standard describes online monitoring of partial discharges taking into account the operating factors of the machines. In this work, PD measurements were performed under very specific conditions for commissioning tests of a new generator. For this, the tests were performed in the commissioning of a generator from Belo Monte Hydroelectric Power Plant with Francis turbine and nominal power equal to 611.1 MW. For conducting PD measurements, 1000 pF capacitive couplers and the IMA-DP measurement system developed by Cepel [2] were used.
This work presents the behavior of partial discharges of a new generator considering the main requirements described in IEC 60034-27-2. PD measurements on the generating unit were carried out since the first excitation test, synchronism, operating range test, generator heating test and PD measurements after release for commercial operation.

KEYWORDS

Partial discharges, hydrogenerators, commissioning tests, generator heating test, operating range test.

1. GENERAL

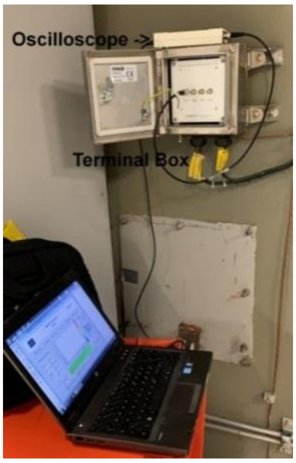
In general, interpretation of online PD results should be performed in two steps. First, it is critical for any maintenance planning to consider if there are isolation problems, indicated by significant PD activity. If checked, then the specific source of PD activity needs to be determined for a more detailed assessment. Since the degree of deterioration and the eventual risk of insulation failure depends greatly on the specific type of partial discharges, it is crucial to have good information about the source of any significant PD activity, such as the type and possible location within the machine's stator winding.

An important objective of interpreting PD data online is to evaluate the trend of specific PD parameters in time. For a reliable trend assessment in new machines, it is essential to hold an initial record of PD activity to be used for comparison with subsequent regular or continuous PD measurements. In old machines, the comparison parameters should be the first measurements taken. In this sense, IEC 60034-27-2 describes various discharge patterns present in rotary machines. For the stator winding condition evaluation, the "Phase Resolved Partial Discharge" (PRPD) or ϕ-q-n pattern recorded during periodic measurements or during continuous monitoring should be used to determine the specific type of any PD activity inside the machine stator winding [1, 3].

IEC 60034-27-2 also describes PDs online monitoring considering the machines operating factors such as operating temperature, bar vibrations and degree of contamination. In this work, the PD measurements were performed under specific conditions. The tests were carried out on the commissioning of a Francis turbine and 611.1 MW nominal power generator from Belo Monte Hydroelectric Power Plant (HPP). Belo Monte HPP was built on the Xingu River, 65km outside of Altamira, Pará State, Brazil. Its first generating unit commercial operation started in April 2016.

For PDs measurements, capacitive couplers of 1000 pF (Figure 1 - a) and measurement system IMA-DP (Figure 1 - b), developed by Cepel (Electric Energy Research Center) [2], were used.

(a)



(b)

Figure 1 – (a)1000 pF capacitive couplers installed, phases A, B and V; (b) Measurement monitoring system IMA-DP.

2. OPERATING CURVE TEST

Figure 2 shows the active power, average PD persistent amplitude and relative vibration when the unit is running on unexcited, excited and synchronized, with a load ramp from 0 to 611MW.

After the machine reached excitation, the first PD measurement was performed. From the moment the unit was synchronized, the measurements were performed according to the 10% load increase.

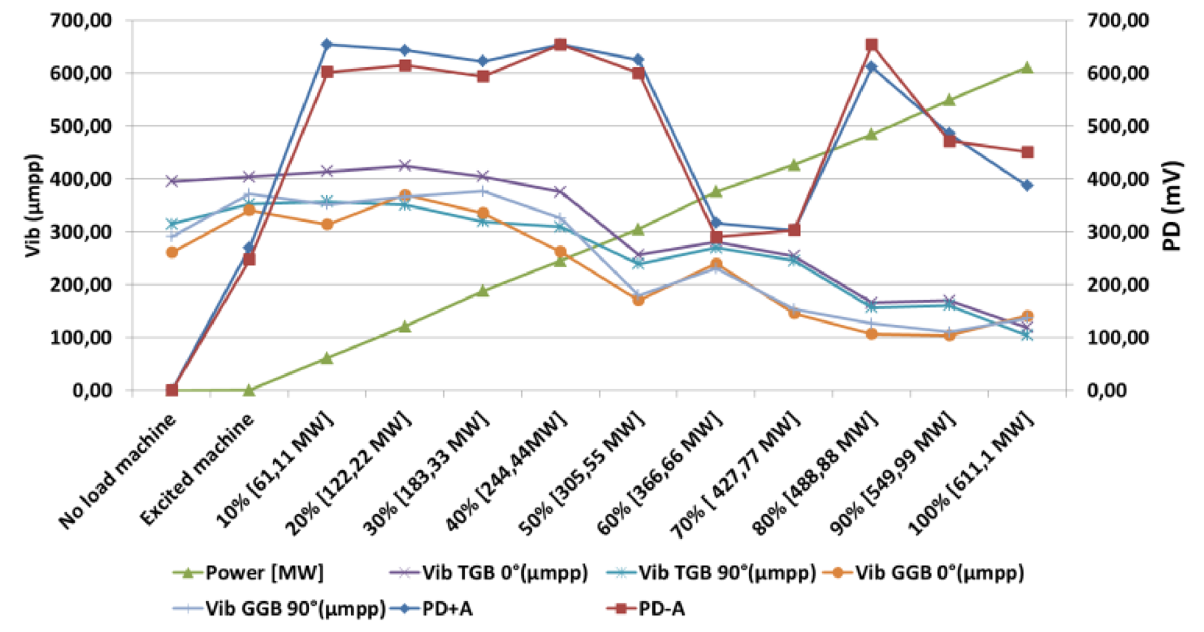


Figure 2 – PD A (mV) vs Vib TGB and Vib GGB (µm).

The operating curve test shows mechanical effects related to the generating unit operation. The relative vibration was analyzed for each operating point of the generating unit with 10% power increases from 0% to 100%, with an average stabilization time of 20 min at each level. The ratio of the PDs to the unit oscillation in the unit load ramp was clear from 0 to 100% of the nominal power (Figure 2). After the test started, the relative vibration increased about 40% of the nominal power. Even with power values between 10 and 40% of the nominal power, the levels of PD measurements were higher than the measurements with the machine nominal power. The nominal power and the highest value of armature current showed lower relative vibration values and PDs stabilization at values lower than the maximum values of other points. This showed the influence of the relative vibration in the PD levels. This can be observed in three phases (Figures 2-4). For the operational range test, the strong relationship between the magnitude of PD and the relative vibration measured in GGB (generator guide bearing) and TGB (turbine guide bearing) is evident.

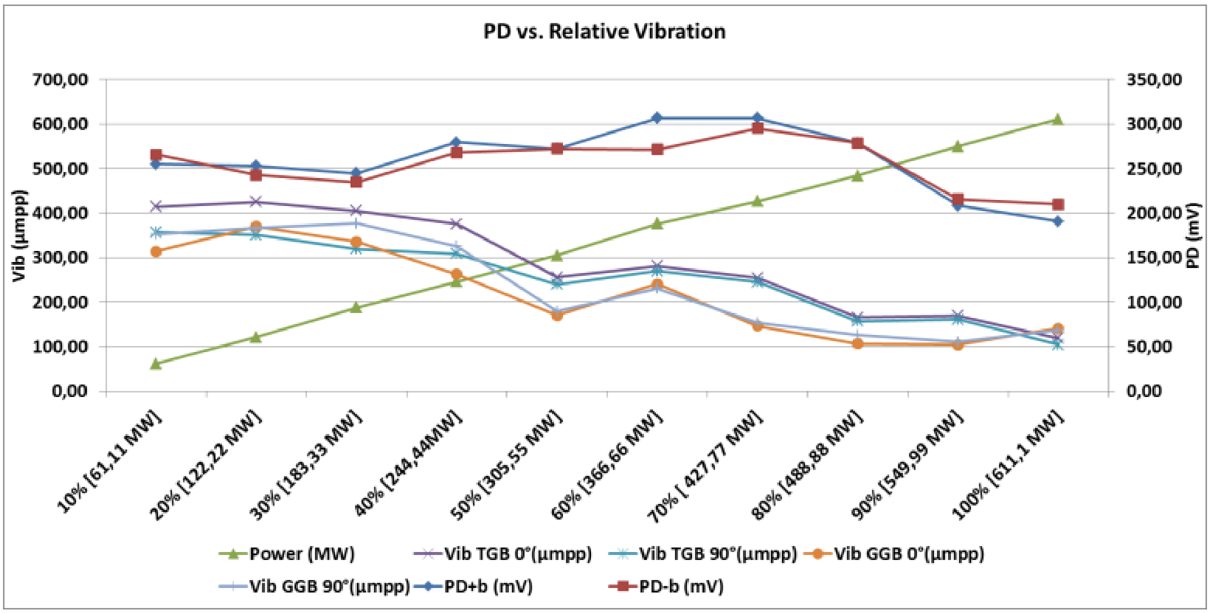


Figure 3 – PD B (mV) vs Vib TGB and Vib GGB (µm).

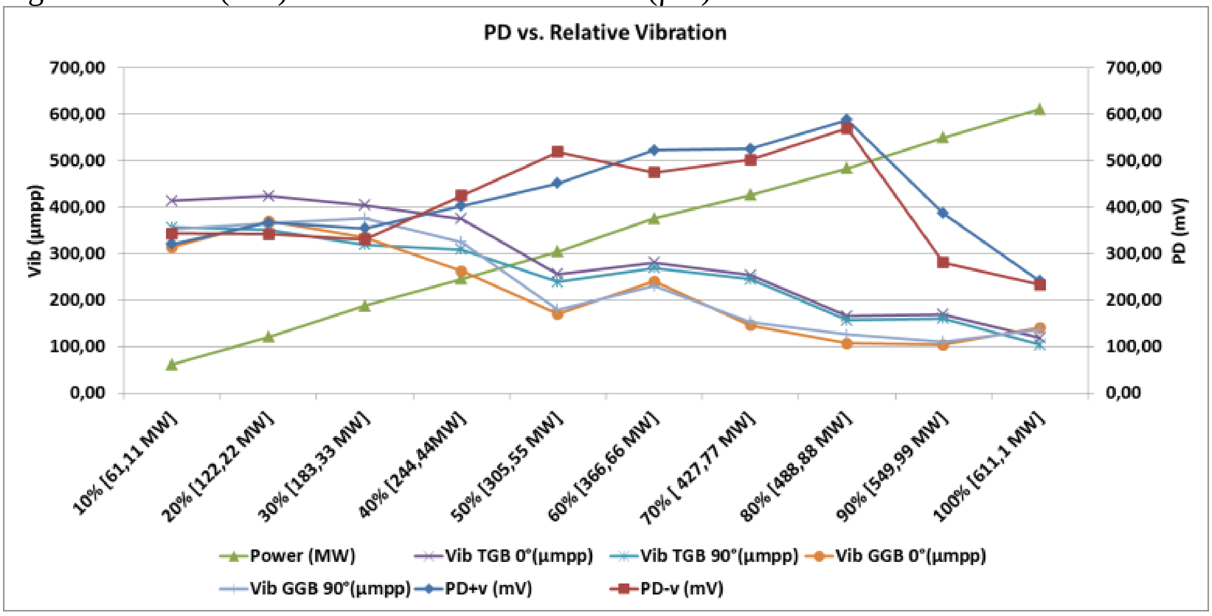


Figure 4 – PD V (mV) vs Vib TGB and Vib GGB (µm).

3. GENERATOR HEATING TEST

In the generator heating test with 75% and 100% of the machine nominal load, the loading method was used [4]. Temperature tests may be performed with the machine operating in many loading conditions. The information, which usually is required, is the machine temperature rise at one or more specified values of load. Since loading at a desired load condition is not always possible or practical, several other loading methods may be used to obtain data, which then may be used to determine the machine temperature rise for the desired load.
The chosen loading method was the power factor (pf) larger than 0.9. Continuous loading tests should be performed until machine temperatures have become constant within ± 2°C of the rise value for three consecutive half-hour readings. If the coolant temperature is not constant, the test may be terminated when the temperature rise, based on at least three consecutive half-hour readings, does not exceed the maximum previously observed rise. If the coolant temperature for three half-hour readings varies by more than 2°C, the test should be continued.

In the heating test the following machine parameters are available: active power [MW], reactive power [MVAr], power factor, voltage armature (phase) [kV], armature current [kA], field current [A], field voltage [V] and calculated rotor temperature [°C]. The temperatures of stator winding, stator core, heat exchanger, bearing metal, bearing oil, generator guide bearing metals, generator guide bearing oil, turbine guide bearing metal and turbine guide bearing oil allow comparison with the PD measurements in phases A, B and V.

In the generator heating test with 100% of the load, the stator and bearings temperature stabilized after 4.5 hours. A temperature variation of less than 0.5°C in a period of less than one hour was considered as stabilized. Concerning PDs, positive and negative persistent amplitude levels remained constant during the test in phases A, B and V, between 200 and 300mV, for a rated active power (P = 611MW) and pf = 0.9. During the test, the active and reactive power remained constant according to the main horizontal axis versus PDs on the secondary horizontal axis (Figure 5).

Table 1 shows the variation of PD persistent amplitude from beginning to end of the test. The maximum variation was in phase V (PD+v). According to [5], if PDs levels increases with increasing temperature (with load constant), then the stress relief coatings may be fragile .For the generator heating test at 75% of the load, the amplitude levels behavior was reduced considerably as the bearing temperatures stabilized.

Table 1 – PD variation from beginning to end of the heating test.

Phase	Coupler	Start of the Test	End of the Test	Increase
A	PD+a (mV)	285,31	339,22	19%
	PD-a (mV)	285,31	287,03	1%
B	PD+b (mV)	212,03	245,63	16%
	PD-b (mV)	230,47	286,56	24%
V	PD+v (mV)	217,26	292,50	35%
	PD-v (mV)	210,00	260,00	24%

PD+ Positive partial discharge pulse, PD- Negative partial discharge pulse.

In Figure 6, PD (mV) versus rotor temperature (°C), the calculated rotor temperature increased during the test by approximately 10°C (11.24%) and then stabilized, accompanied by the increase in PD levels (Table 1).

In Figure 7, PD (mV) versus stator temperature (ºC) is analyzed. To measure the stator temperature, 24 sensors were distributed along the stator. The stator temperature stabilized after 3 hours. After 4.5 hours of heating test with the stator stabilization and core temperatures, it was observed a stable behavior of the PDs persistent amplitude levels in the three phases.

As expected, the last temperatures to stabilize were those of the bearings: generator guide bearing and turbine guide bearing with stabilization after 4 hours of testing.

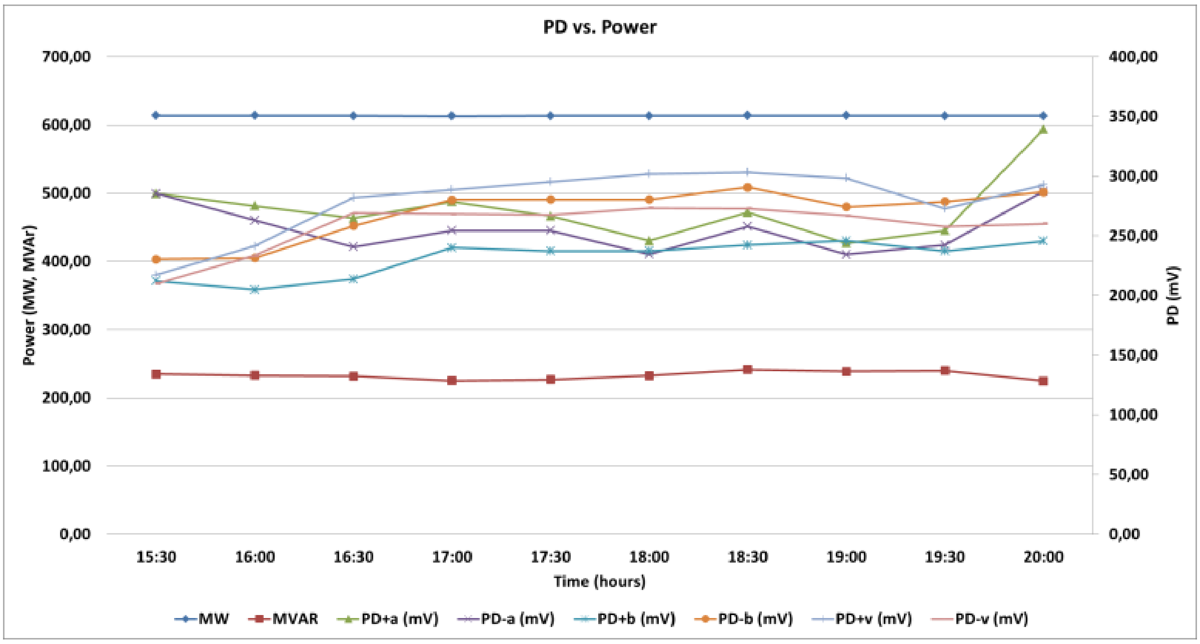


Figure 5 – PD (mV) vs Power (MW, MVAR).

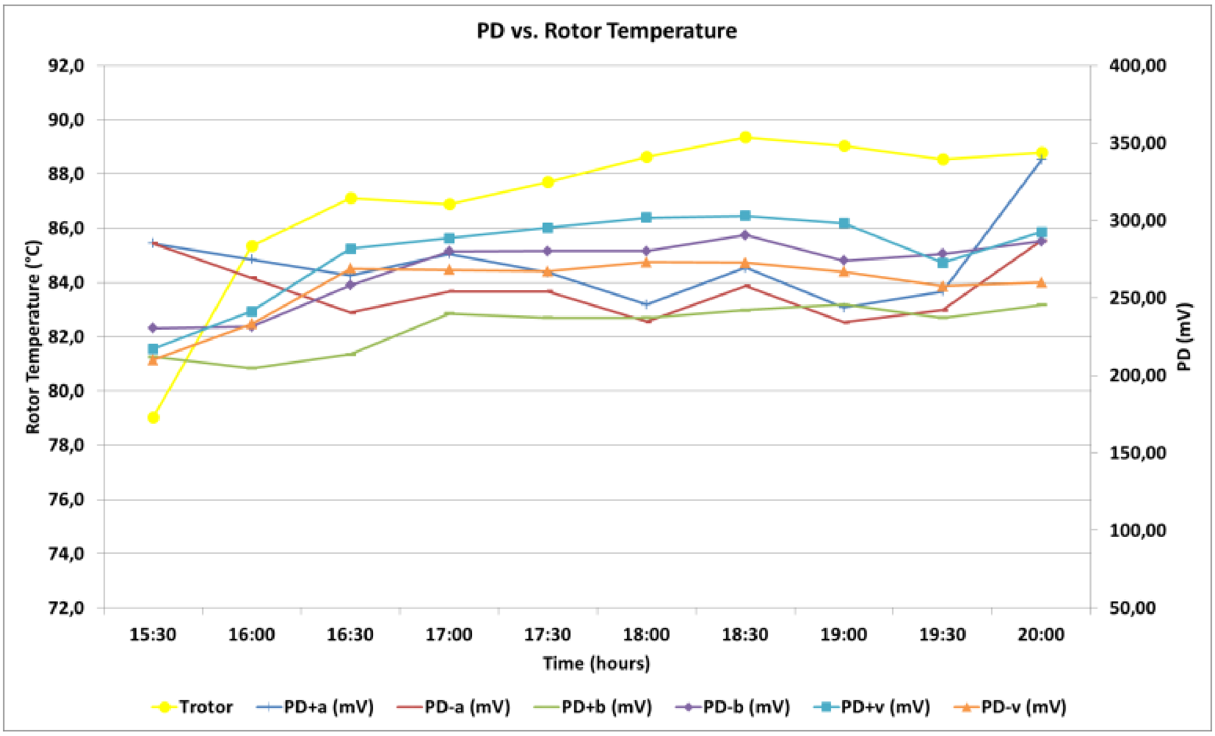


Figure 6 – PD (mV) vs Rotor Temperature (ºC).

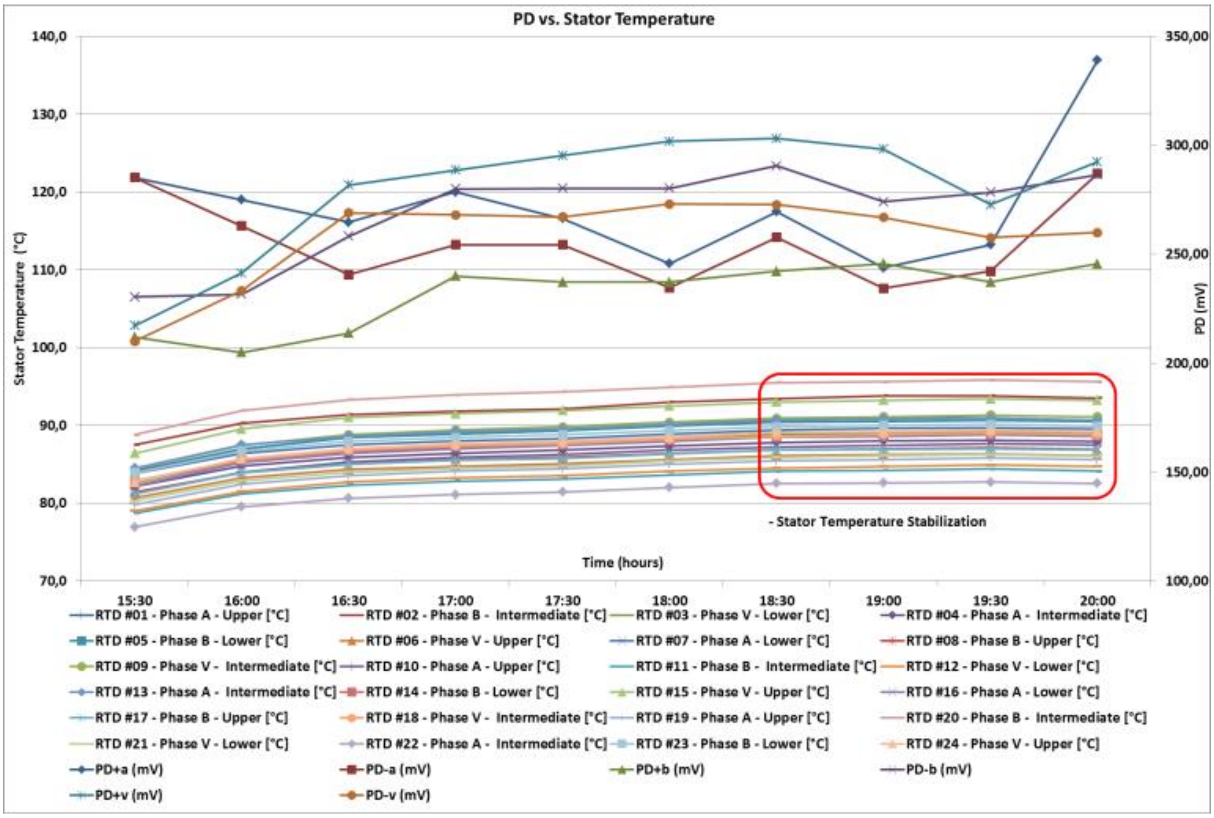


Figure 7 – PD (mV) vs Stator Temperature (ºC).

4. PARTIAL DISCHARGE BEHAVIOR OVER TIME

The graph (Figure 8) shows the generator unit measurement history since the first generator excitation, synchronism, generator unit operating range test, heating test, PD measurement after two months and after two years of commercial operation in phase A, manufacturer X.1. This machine was down for a period of one year for operational convenience. This Power Plant has three different manufacturers called X, Y and Z. Note that the last measurement showed the lowest magnitude values, because after two years the level of PD magnitude decrease, probably decrease over this period due to curing process of the impregnating resins.

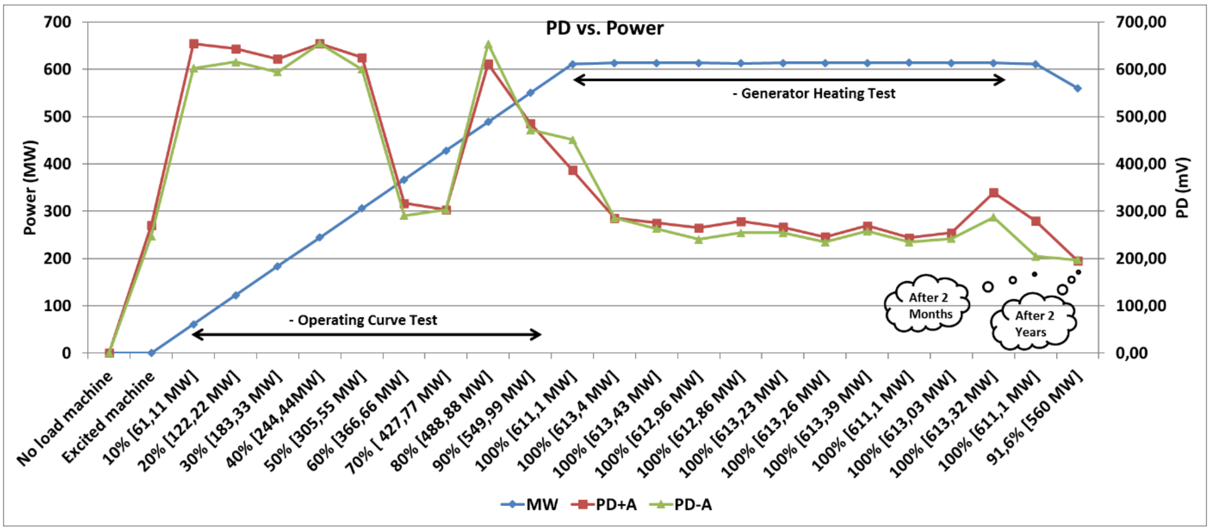
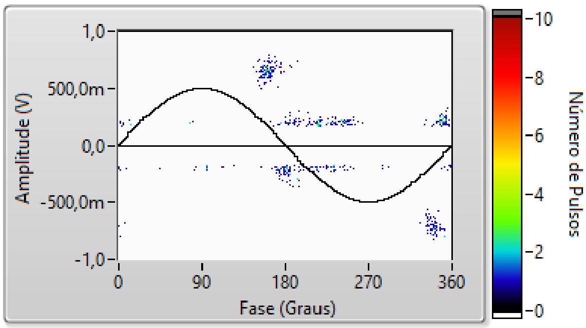
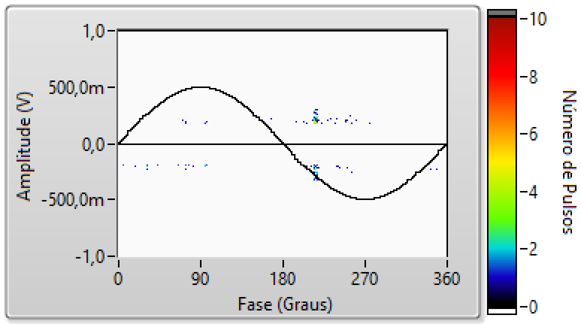


Figure 8 – Partial Discharge Behavior Over Time PD (mV) vs Power (MW).

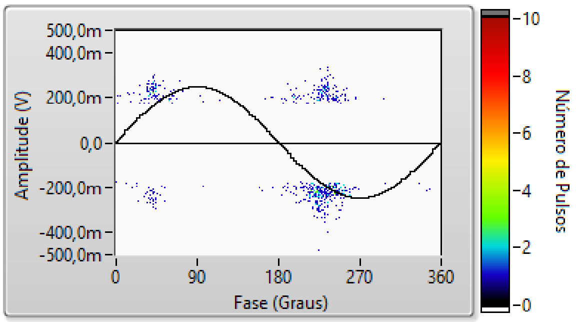
The records of the PRPD graphs (Figure 9) after two months and after two years of commercial operation, the results of phases A and B, from manufacturer X.1 are presented, in which a reduction in PDs activity can be observed, according to the graph in Figure 8, to phase A.



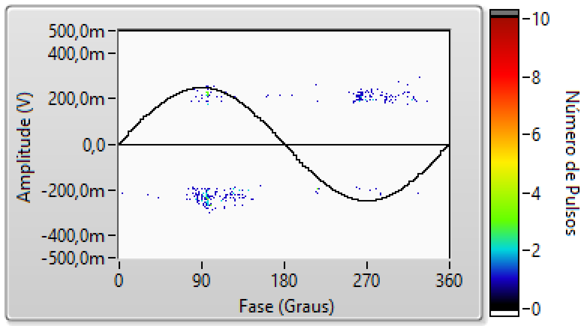
(a) Phase A PRPD – before.



(b) Phase A PRPD – after.



(a) Phase B PRPD – before.



(b) Phase B PRPD – after.

Figure 9 – PRPD two months (a) and after two years (b) of commercial operation in phases A and B.

This variation of measurements throughout the commissioning tests reinforces the need to consider the various factors such as vibration, temperature, load cycle, among others, that influence the PDs measurements [6].

In Figure 10, the reduction in PD activity has been observed over the period since the stator winding was commissioned and has this expectation been confirmed in manufacturer X.2 (Figure 10) and in manufacturer Y (Figure 11) too and in manufacturer Z, it was the similar behavior.

Besides, Figure 12 presents the measurements taken with the unit (manufacturer Z) synchronized operating as a generator (611MW) and as a synchronous compensator (-10MW and -290MVAr). Highlighted in blue dotted square the unit is operating as a generator and in red dotted square as a compensator. It can be seen that there was no change in the magnitude of the PDs with the unit operating as a synchronous compensator.

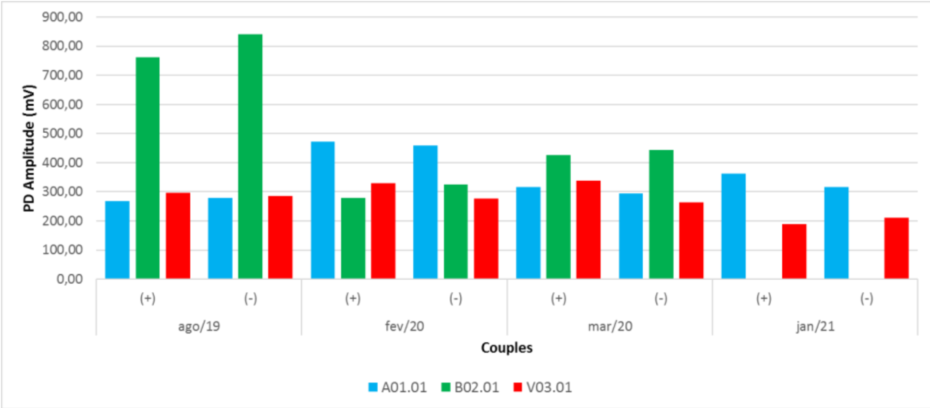


Figure 10 – PD Amplitude (mV) Over Time, manufacturer X.2.

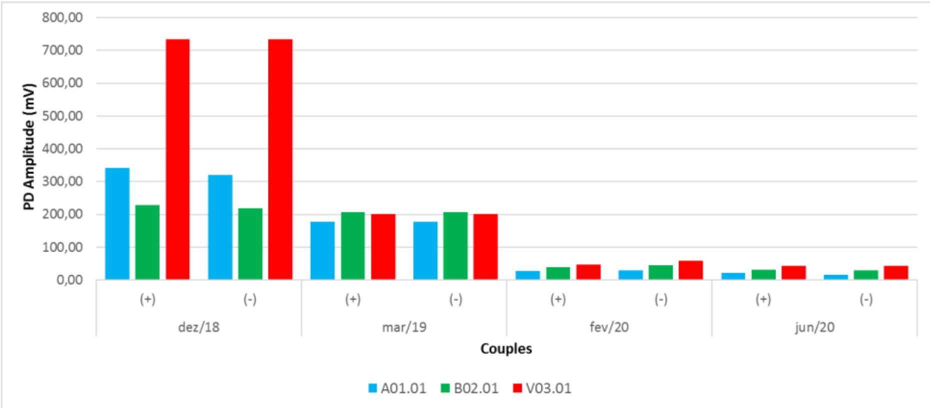


Figure 11 – PD Amplitude (mV) Over Time, manufacturer Y.

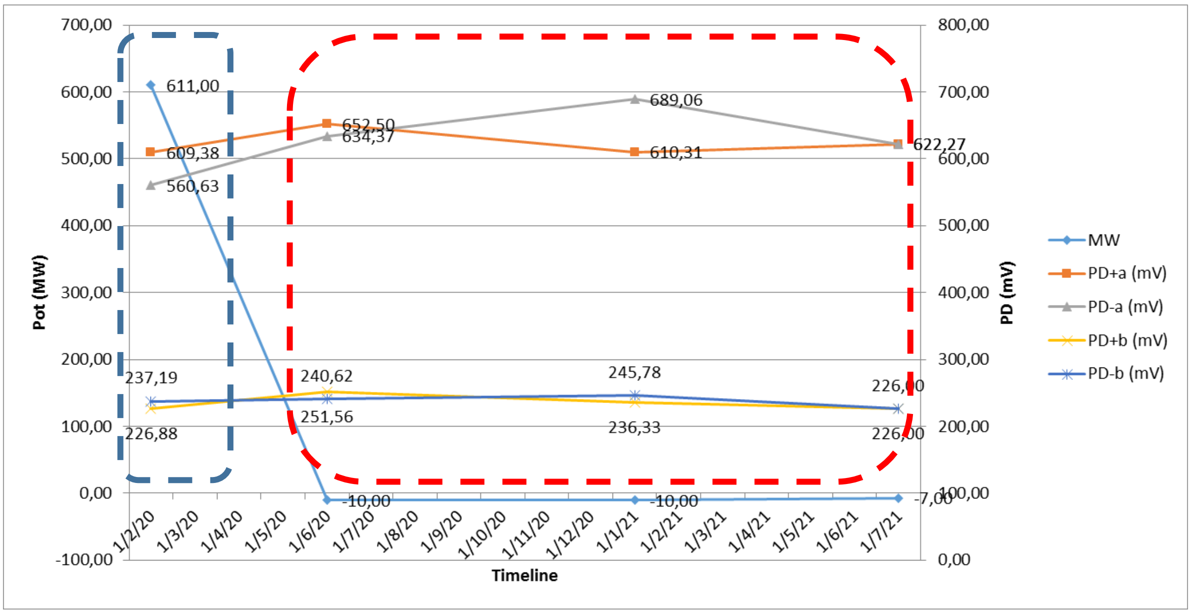


Figure 12 – PD measurements with unit operating as generator (blue dotted square) and synchronous compensator (red dotted square) over time, PD (mV) vs Power (MW), manufacturer Z.

5. CONCLUSIONS

This work presents the behavior of partial discharges in commissioning tests of a new generator, since the first generator excitation, synchronism, generator unit operating range test, heating test and PD measurement after two months and two years of commercial operation. This variation of measurements throughout the commissioning tests reinforces the need to consider the various factors such as vibration, temperature, load cycle, among others that influence the PD measurements describes in IEC 60034-27-2.

The operational range test showed the strong relationship between the PD magnitude and the relative vibration measured in GGB and TGB. After starting the test, the maximum values of relative vibration were measurements between power values of 10 to 40% of the nominal power, the levels of PD measurements were higher than the measurements with the nominal power machine.

In the generator heating test at 100% of the load, the stator and the bearings temperature stabilized after 4.5 hours. The PDs positive and negative persistent amplitude levels remained constant in phases A, B and V, between 200 and 300mV, during the test for rated active power (P = 611MW) and pf = 0.9, but the number of measured pulses increased with each measurement cycle and in the last measurement, it was possible to observe the configuration of PRPD pattern internal discharges in phase A, with a similar behavior in the other phases[7].

The PDs measurements were performed in the new generator commissioning test, i.e. when a new stator comes into operation. The main differences between PD measurements are due to various thermal and mechanical effects related to the machine operation, like vibration and temperature gradients between copper and iron core stators during the tests.

For predictive maintenance, these measurements will be part of the PD measurement history, they will be the fingerprint of this unit and for this monitoring variable where no significant variation in the PD trend curve was observed. These measurements were made under specific operating conditions and, after the stator curing process, these levels decreased until they stabilize with the machine operating close to the rated power.

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