INFLUENCE OF LARGE ROTATING MACHINE STATOR COIL DESIGN ON INSULATION SYSTEMS HEALTH ASSESSMENT

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Abstract - This paper studies the influence of stator coil geometry on the diagnostic test results of rotating machines with different types of insulation systems. Industry standards provide their own guidelines which are used by most service providers, OEMs and in the petrochemical industry. These guidelines and acceptance limits are helpful in assessing the overall health of the stator insulation, the presence of any defects and the level of deterioration of the insulation. It is vital to note that the acceptance limits could be affected by the coil geometry and type of insulation used and are not fully covered by the industry standards. To study the influence of coil geometry, diagnostic test data has been collected for hundreds of rotating machines with various sizes and geometries. The systematic approach presented in this paper provides an assessment with possible economic impacts for unit life extension and explains the reasons and outcomes of the decisions taken.

Index Terms — Stator winding, coil geometry, insulation system, health assessment, reliability.

I. INTRODUCTION

In utilities and large industries, a rotating machine is often the core of the system and considered as a critical component. Stator insulation failure is estimated to cause over 60% of high voltage rotating machines downtime. Consequently, stator insulation testing and assessment has become a key service practice across many industries. Industry standards have classified core methods for such tests to be performed consistently [1], indicating which of those are important, how to carry out the test and some guidelines on the interpretation of results. Tests considered core by industry standards to characterize stator insulation health are listed in **Table 1**.

TABLE I
KEY INDUSTRY STANDARDS FOR STATOR WINDING HEALTH ASSESSMENT

Reference Standard	Assissent Type	Acceptance Available
IEEE 43	Insulation resistance (IR) and polarization index (PI)	Yes
IEEE 4	AC over voltage hipot	Yes (Pass/Fail)
IEEE 95	Stepped DC hipot	Yes (Pass/Fail)
IEEE 286	Dissipation factor or tangent delta	No
IEEE 1434	Partial discharge analysis	No
IEEE 522	Inter-turn surge test	Yes (Pass/Fail)

Of the above tests a.c. or d.c. high voltage and inter-turn testing will mostly provide a qualitative condition assessment. Other types of tests can provide quantitative values that can be further analyzed to determine the insulation health status, identify existing defects and to trend insulation system condition evolution over time. Therefore, all quantifiable test methods or techniques will be the main focus of this paper.

Industry standards IEEE 43-2013 & IEC 60034-27-4 provide a more concise guideline for assessing insulation resistance (IR) and polarization index (PI) results [2][3]. However, a specific machine design (geometry and material composition), environment and site running conditions can still have an impact on such analysis, making difficult to establish concise standardized assessment guidelines on such tests. Given the criticality of the machines in the industry, it becomes very relevant to determine how reliable tests performed to a specific unit are in allowing technical staff in determining machine condition.

II. INFLUENCE OF STATOR GEOMETRY AND INSULATING MATERIALS ON IR AND PI

A study has been carried out on the data from over 600 large rotating machines, which were tested as a new after manufacturing at OEM location. These units have voltage rating from 2.3–13.8 kV, with rated speed range from 120–1800 rpm and an active power range of 0.5– 75 MW. Due to selection of above units, aging, running regime and environmental effects on insulation are eliminated. Factory test results from these units have been cross-referenced to several aspects of their insulation geometry and composition, to quantify the impact of these variations due to rotating machine design parameters. For each assessment, units tested in the same factory were chosen to analyze the effect of geometry on electrical test results. The units compared were chosen with the same global VPI insulation, to avoid any variations.

Machine stator insulation system uses varied materials such as mica, glass or a polymer matrix of epoxy or polyester. The measurement of insulation readings constitutes a direct-voltage test, and the test voltage must be restricted to a value appropriate to the voltage rating of the winding and the basic insulation condition. PI is defined as the ratio of the 10 min IR value to the 1 min IR value. It is indicative of the slope of the characteristic curve and can give further insight on the insulation condition [2][3].

A. *Insulating Material Influence*

The IR of a system varies inversely with the winding ambient temperature and the time elapsed since the start of the application of the DC voltage. Therefore, if the winding temperature cannot be controlled from one test event to another, international standards recommend correcting all insulation test values to a common base temperature, such as 40°C [2][3]. This adjustment is achieved by multiplying the measured IR at a winding temperature T by a temperature correction factor Kt. This correction factor is dependent on both the recorded winding temperature and the slope parameter “X” of the individual insulation system. In these standards, the slope parameter X characterizes the degree of insulation resistance temperature dependency of an individual insulation system; smaller temperature dependency is indicated by a larger slope parameter. Both standards recommend estimating the slope parameter of an insulation system through experimental measurements. Alternatively, stock slope parameter values are provided in the standards if experimental data is unavailable for a particular insulation system [2][3].

To estimate the influence of insulating material composition changes on the parametrization of Kt, four different insulation systems, common in industrial customer installed bases, were chosen. For each of them experimental determination of slope parameter was conducted in accordance with existing standards [2][3], using each slope parameter to construct a temperature correction factor distribution specific to its individual insulation system. The following insulation systems were parametrized in this process:

1. Mica-based global VPI insulation system I
2. Mica-based global VPI insulation system II
3. Mica-based global VPI hybrid system (HY)
4. Non-VPI resin-rich insulation system (RR)

These experimentally determined temperature correction factor distributions were then compared to standard distributions provided by those in standards [2][3]. Fig. 1 shows graphical plot of the 6 Kt variation curves at the same scale.

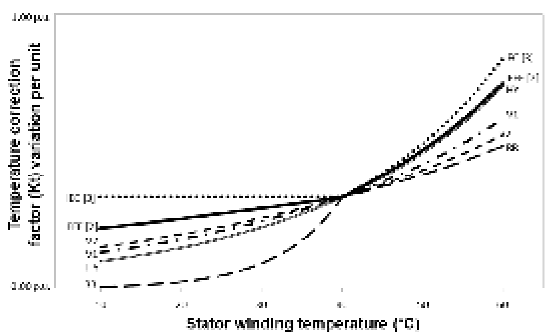

Fig. 1 Kt variation against [2][3] on 4 different insulation systems

As illustrated in Fig. 1, each of the experimentally determined temperature correction factors differ from the baseline distributions provided in references [2] and [3]. These variations were found to be over 70% lower as suggested in IEC 60034-27-4 [3] on the higher temperature range but substantially lower than referenced on the lower temperature range, with an averaged variation of the 4 insulation systems of 173% across the whole graph compared to IEC recommended plot [3] and an averaged variation of 143% compared to IEEE 43-2013 recommended plot [2]. Results obtained validate recommendations in references [2] and [3] of using an experimentally determined slope parameter specific to the individual insulation system, whenever possible.

A. Stator Geometry Influence

To assess the influence of stator winding geometry on insulation resistance, four key factors influencing rotating machine design and overall insulation levels were analyzed.

1. Nominal rotating speed
2. Stator core inner diameter
3. Stator coil overhang length
4. Stator core length

1) Nominal Rotating Speed: In Fig. 2, a statistical spread is established for the IR during the study of a large fleet. It can be clearly seen how IR improves as nominal revolutions per minute (RPM) increase on the units analyzed. Normally, higher RPM machines are designed for delivering increased power at higher voltages, therefore designed with thicker insulation builds and larger endwinding clearances. These clearances and extra insulation will reduce the leakage current and could explain the proportional increase in IR value.

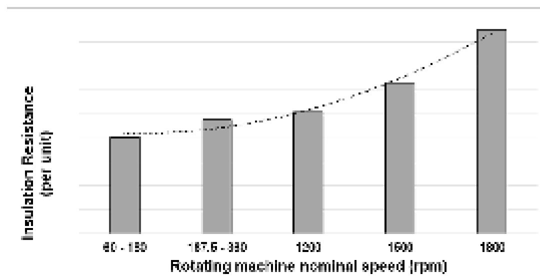

Fig. 2 IR value as machine nominal rated speed increases.

2) Stator Core Inner Diameter: As shown in Fig. 3 below, IR reaches a maximum at around 1016-1070 mm for core iron inner diameter. As machine inner diameter increases, typically speed RPM tends to drop as the number of poles also tends to increase. The overhang portions tend to get smaller on slower or multi-pole units and the number of coils per stator increases compared to a higher speed machine. The IR value increases as the inner diameter increases as well but drops close to 60% when the inner diameter surpasses 1775 mm due to smaller overhang in the endwindings and increased number of coils multiplying the number of parallel paths for the leakage current.

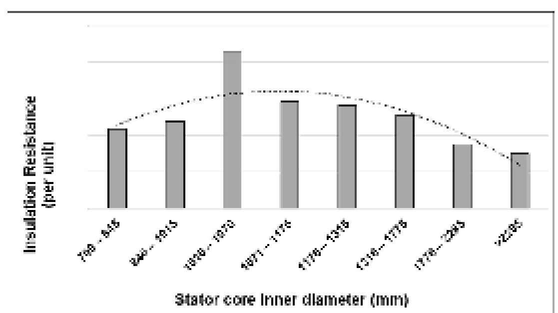

Fig. 3 IR value with regards to stator core inner diameter

3) *Stator Coil Overhang Length:* In Fig. 4, it can be found that the IR reaches a maximum around 410-434 mm. Typically, the lowest overhang corresponds to units with slower speed along with wider inner diameters and having more coils, but shorter core stacks, providing multiple parallel paths for the surface leakage currents. The longer overhang length is common for machines having a higher nominal voltage and longer core stack

length. The proportionately longer core stack length, higher electric stress and surface area in the slot could reduce the IR value as shown in the graph below.

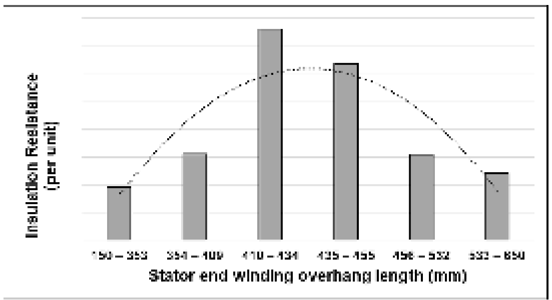

Fig. 4 IR value versus stator endwinding overhang

4) *Stator Core Stack Length:* In Fig. 5, the IR is at a maximum when the core length is around 1010-1379 mm. There is distinct decline in IR afterwards, as overall geometric proportions and nominal stator voltage remain high, while stack length increases. As insulation surface in the slot section of the unit is increased, the area under high electrical stress becomes larger as well, increasing the conduction or leakage current in the overall stator insulation.

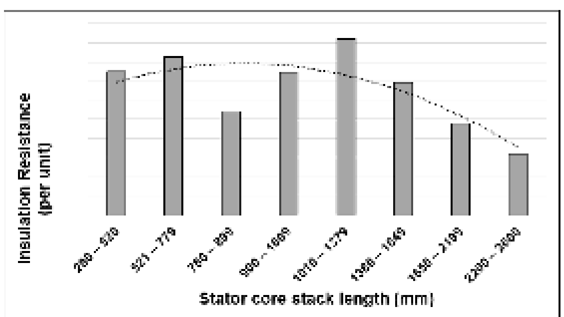

Fig. 5 IR value versus stator core stack length

From the data and analysis, it has been identified that insulation resistance maximizes at a specific range of physical dimensions (overhang length, stack length and inside diameter) of the coils and is also influenced by the combination of voltage and RPM used. In terms of which properties have a stronger influence on IR, it is difficult to determine exactly but this data proves that when one property increases or decreases, it affects other properties that gives a net result of the measured IR.

A more detailed knowledge of the overall unit design would be required to baseline better values for a specific machine, or one can follow the recommendations in the relevant industry standards. It is worth mentioning that, once a machine leaves the OEM facility, it will be subject to thermal, electrical, mechanical and ambient/environmental stresses, so IR results will likely derive, influenced by these external factors, and give an indication of the overall impact on the winding condition [2][3][4].

III. LIMITATIONS OF POLARIZATION INDEX (PI) IN ROTOR (FIELD) WINDINGS

As specified in industry standards [2] and [3], PI test requirement is not valid for rotor windings having exposed copper. The nature of the insulation materials used in rotor windings that have little or no polarization currents and little material to become polarized, and the relatively high amount of exposed copper, facilitates relatively larger surface leakage currents, which tends to overwhelm any polarization currents. Therefore, only one-minute IR test is sufficient to assess rotor windings health.

IV. INFLUENCE OF STATOR GEOMETRY ON DISSIPATION FACTOR

Dissipation factor is defined as the reciprocal of the ratio between the insulating materials capacitive reactance to its resistance at a specified frequency. The dielectric dissipation factor (DF) also known as tan δ (TD) is the tangent of the dielectric loss angle δ at a predetermined voltage (U), frequency, and temperature. The dielectric loss of the insulation system can be represented by series and parallel equivalent circuit elements.

The dielectric dissipation factor component arising from the dielectric losses generally changes very little with voltage, but a significantly higher than normal loss indicates some difference in the structure of the insulation such as may arise from incorrect resin composition or inadequate cure, as explained in references [5] and [6]. Therefore, standardized voltage rise differential factors are usually calculated during tan δ tests as tip-up (TU), representing the change in the dielectric dissipation factor measured at two voltages. Industry standards [5] and [6] recommend tip-up factor calculated between 20% U_N and 60% U_N (TU) as a key indicator of dissipation factor, where U_N represents nominal voltage of the test object.

A. Material Influence

It is intrinsic to the insulation dissipation factor that different insulation materials (or the same material aged or contaminated differently) will produce different TD test results; therefore, identifying the original insulation composition of a specific unit is key to comprehensive TD results analysis, as explained in [5]. Later studies, such as [7], explain that defining globally standardized values for DF and TU is not justifiable as the absolute values depend on the characteristics of the insulation system. The same study [7] also explains that the performance of insulation systems should not be arbitrated only by a single DF and tip-up value but by the establishment of a database for benchmarking normal production range for specific insulation systems. Nevertheless, a particular component of the insulation system deserves special attention when performing TD measurement, that is the action of the stress control coating and ambient surface condition which must be carefully considered, because higher voltage insulation systems will have such components present, while lower voltage machines may not, as referenced in [5] to [8].

Stress grading (or stress control coating) is a paint or tape applied to the outside of the groundwall insulation that extends several centimeters beyond the conductive slot coating in high-voltage stator coils and bars. Stress grading usually includes silicon carbide particles (non-linear high resistance material) that tend to linearize the electric field distribution along the coil or bar end-arm out of the slot, where high magnetic flux can create a localized highly energized area in the end-winding. Stress grading overlaps the conductive slot coating to provide a continuous electrical contact path. When testing a stator provided with stress grading, extra losses will be measured during DF or TD testing, combining the dielectric losses in the stress control portions of the end-winding, together with the losses dissipated in the resistive grading material, and affecting the test results. The semiconductive stress grading effect can be shielded off easily during measurements when testing individual coils, as explained in standards [5] and [6]. However, when testing fully assembled stators, this effect cannot be cancelled out and will be the main contributor to variations of TD for a healthy unit. The use of stress control coating is related to magnetic flux on the unit, which derives from rated voltage of the machine.

In the following section the variations due to the presence and length of stress control grading are presented. As can be seen in Fig. 6, when analyzing impact of the stress grading (or its absence) on TD test results for the test population selected, up to 20% U_N the TD values were found to be somewhat similar for all machine ratings from 3300V to 13800 V.

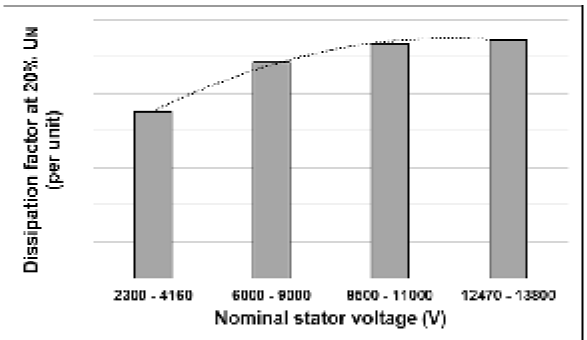

Fig. 6 TD value at 20% U_N as rated stator voltage increases

At these insulation excitation levels the contribution of stress grading on TD was negligible for high voltage rotating machines, therefore TD value being more associated to the characteristic nature of insulation system type. At 40% U_N the TD values start to diverge and at 60% U_N, the TD test results were significantly different, for stators designed to operate <6000 V compared to units designed to operate at higher voltages, who had TD values 2.38 times higher on average (see Fig. 7). This reflected the increased losses in the stress grading, which is typically applied to units rated 6000 V and above. However, the TD value differential among units between 6.0–13.8 kV rated voltage was small, irrespective of the length of their stress grading. These findings correlate with recent studies on stress grading response to TD testing, such as [8], that underline the influence of the stress grading thickness, but not the length.

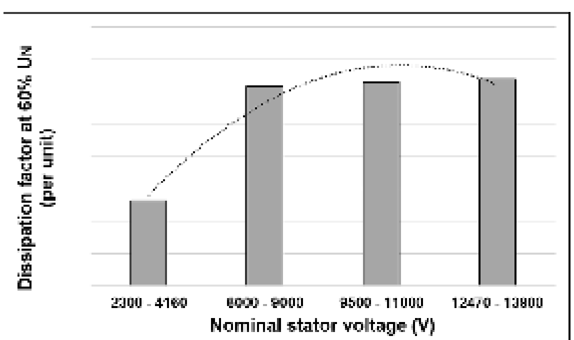

Fig. 7 TD value at 60% U_N as nominal stator voltage increases

TD value differentiation on units with stress grading, compared to units without it, maintains the proportional difference as the test voltage is raised to 100%, as can be seen in Fig. 8. This same correlation against rated stator voltage was found at 60% U_N to 20% U_N, tip-up (TU), where 6.0–13.8 kV stator TU was found 5 times higher than in lower voltage designs, while TU variations within the group were much lower, as shown in Fig. 9.

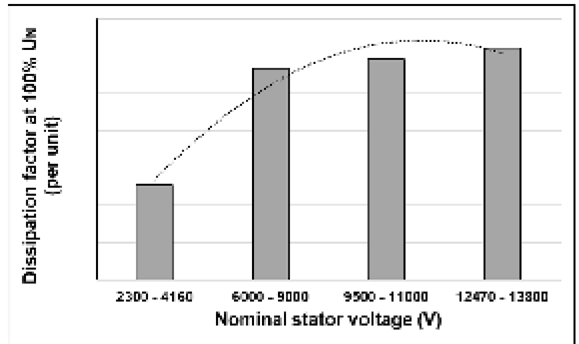

Fig. 8 TD value at 100% U_N as nominal stator voltage increases

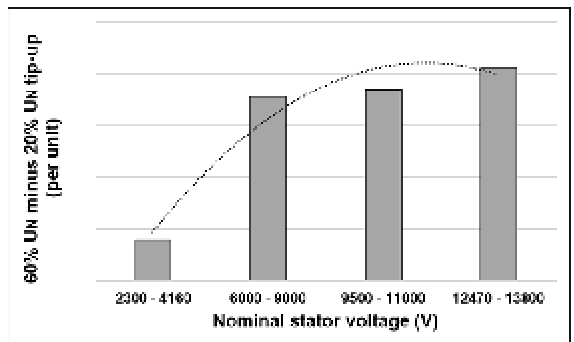

Fig. 9 TU value as nominal stator voltage increases

B. Dimensional Aspects

For this section, the calculated TU response to different geometric changes on stator was studied; for units manufactured with similar stress grading and voltage levels ranging from 12.4–13.8 kV. As shown in Fig. 10, a linear decrease of TU value occurs as overhang length increases, likely due to reduction in surface leakage current due to longer coil endarms.

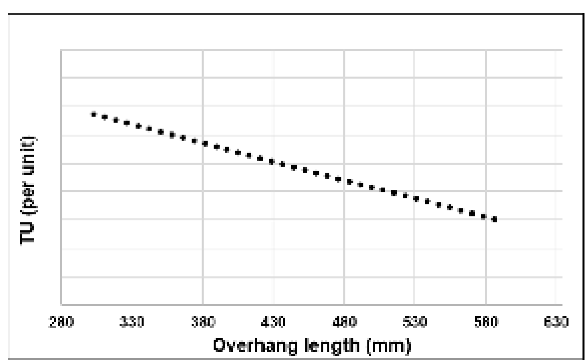

Fig. 10 TU value as overhang length increases

Fig. 11 shows a similar drop observed in TU as the stator stack length increased, due to the diameter of those units increasing proportionally equating, generally, to a longer overhang region and therefore being affected by the previous phenomenon on reduction of TU as presented in Fig. 10.

As commented earlier, higher speed units generally have longer endarm overhangs so once again the TD values will drop for machines with higher RPM. As presented, the presence or absence of stress grading coating on stator coils is a critical differentiator when analyzing TD results, as underlined in standards [5] and [6]. Overhang length remarkably influences TD results as well, which is usually related to an increase in other dimensions, such as speed, core inner diameter and core stack length, for units of same rated voltage. Nevertheless, there are design exceptions for non-standard industry specific applications, where these factors mix in a different combination. Industry standards [5] and [6] do not provide machine suitability for service values for TD, due to the many factors that can influence the results. The data presented here confirms that statement. Indeed, standards [5] and [6] indicate that TD analysis for a complete winding is a process that must be built over time where past tests are compared to most recent ones and looking for variations. Such a process benefits most from an early life background test, prior to any winding deterioration, which will be influenced by all stator design parameters commented in previous sections. Such parameters will affect proportionally any future TD tests (intermingled with insulation deterioration factors themselves), making baseline comparison complex unless results can be compared to similarly constructed healthy units, as suggested in [5], or original design constrains are known for the specific test object.

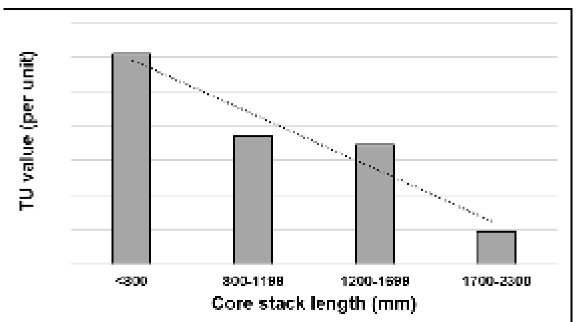

Fig. 11 TU value as core stack length increases

V. PARTIAL DISCHARGE ANALYSIS

As indicated in IEEE Std. 1434 [9], partial discharge (PD) is an electrical discharge that only partially bridges the insulation between conductors. A transient gaseous ionization occurs in an insulation system when the electric stress exceeds a critical value, and this ionization produces partial discharges". The same standard already clarifies in Section 11.7.1 that: "Acceptable levels of PD activity vary with the type of insulation system. For example, a particular level of PD internal to an insulation system might be acceptable for asphalt-bonded, large flake mica, but hazardous for epoxy-bonded mica paper". Therefore, it will not be object of this study to express those differences by insulation composition, which is already proven inconsistent in finding proportional patterns, but on the impact of different dimensions for units insulated with same type of insulation.

A sample of around ~100 units was selected that are manufactured with similar insulation composition and successfully completed all factory acceptance tests (FAT) with proven service life after installation and commissioning. Offline PD values during FAT were studied through this exercise. Three different design parameters were studied on these units, cross-referencing it to stator rated voltage, due to the influence of voltage on PD breakdown point:

- Stator core inner diameter
- Stator coil overhang length out of the stack
- Stator core stack length

During the analysis, no meaningful trend of PD results was found versus stator geometry variations; i.e. values did not follow any kind of proportional trend throughout the fleet studied. Indeed, analysis results suggested that PD variation is not a consistently fixed or proportional indicator even for windings manufactured through the same manufacturing process, tested on the same day with the same equipment and same ambient and electromagnetic conditions. This phenomenon had already been commented on PCIC-IEEE-2021-27 [11] for tests on individual sacrificial coils. Industry standards [9] and [10] rightly indicate the influence of multiple indirect factors when performing PD testing. To measure the weight of this broad variability on testing, the PD test results of each of the three phases of the units in the test population were studied. Two statistical indicators were chosen to analyze average variation among the three phases on each unit:

1. Mean absolute deviation (MAD), defining the mean deviation of each phase in each machine, per unit of the average PD reading for that same machine. Mean absolute deviation is expressed as:

$$MAD = \frac{\frac{1}{n}\sum|x-\bar{x}|}{\bar{x}}$$

Where:

n = number of phases (3)
x = each phase PD at 100% U_N
$\bar{x}$ = average PD at 100% U_N

2. Absolute dispersion (AD), defining the amplitude between the lowest and highest phase PD result in each unit, compared to the average phase reading.

$$SD = \frac{|x_{high} - x_{low}|}{\bar{x}}$$

Where:

x_{high} = highest phase PD at 100% U_N
x_{low} = lowest phase PD at 100% U_N
$\bar{x}$ = average PD at 100% U_N

An example with some arbitrary numbers for a stator with three phases PD test results at 100% U_N is shown to calculate MAD and AD.

U phase offline PD = 700 pC
V phase offline PD = 1100 pC
W phase offline PD = 1800 pC

$$\bar{x} = \frac{700\,pC + 1100\,pC + 1800\,pC}{3} = 1200\,pC$$

$$MAD = \frac{\left[\frac{|700-\bar{x}| + |1100-\bar{x}| + |1800-\bar{x}|}{3}\right]}{\bar{x}} = 33.33\%$$

$$AD = \frac{|1800-700|}{\bar{x}} = 91.67\%$$

The results of more than fifty units were assessed for tests where the results were expressed in measured PD in pC, and around forty were assessed for tests measuring the PD in mV; no changes in the pattern of variation were observed for neither of the two object population subdivisions; therefore, it was decided to present all values together on the following graph:

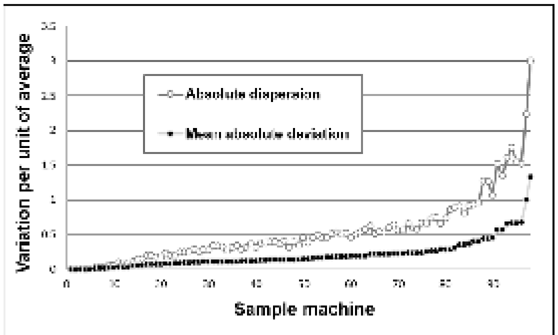

Fig. 12 Offline PD variation among phases of each machine

Even within the 3 phases of the same stator, 21% mean absolute deviation was found, while there were deviation results on certain units as high as 133%. Absolute dispersion was ~54% average, while there were dispersion results on certain units as high as 300%.

Subsequently, fifteen different multi-unit projects were chosen among the same population built to same design specifications and manufactured through same manufacturing process and tested on almost exact and controlled factory lab conditions. The same statistical parameters were assessed per project, deviation and dispersion being measured per unit of the average phase PD reading for the project, for each phase PD result within the same project.

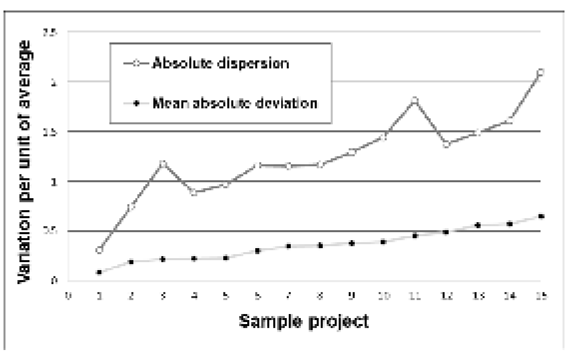

Fig. 13 Offline PD variation among machines of each project

Within similar units of the same project a 36% mean absolute deviation was found while there were deviation results on certain projects as high as 65%. Absolute dispersion was 125% average, while there were dispersion results on certain projects as high as 210%.

The values above confirm facts indicated by previous studies, such as [11], as well as indicated in standards [9] and [10], warning against the possibility of setting standardized PD acceptance criteria. As clearly indicated in IEC 60034-27-1 [10], "It is also not possible to establish any absolute limits for complete windings, for example as acceptance criteria for use during production or operation. Therefore, no specific limits that can be used for quality assessment will be given in this standard". In consideration of the variations presented, the recommendations made by [9] and [11], about basing PD test result assessment on statistical distribution of PD established by electric rotating machines manufacturers or other industrial agents with deep knowledge on particular rotating machine design and access to broad installed bases, have become even more important. As IEEE-1434 [9] indicates: "However, by establishing records of many tests on particular insulation systems and winding configurations, by means of a common detection system, unusually high PD magnitudes can be identified. Other tests and inspections are then required to establish the significance of these PD levels".

An additional offline PD analysis was performed for data taken at 100% UN on around 500 similar units manufactured between the years 2015 and 2021 at the same factory. In Fig. 14 below, PD test results per unit (shown as dots), plotted together with the polynomial average results over the period 2015 to 2021 (shown as solid line). By the trend in Fig. 14, FAT offline PD test results have improved over the years, as insulation system enhancements have been implemented. This shows the benefit of trending and assessing in process manufacturing to ensure they fall within the statistical distribution.

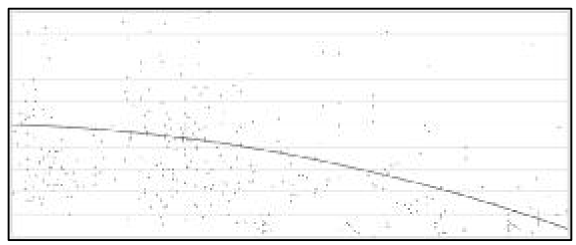

Fig. 14 Polynomial trend of FAT offline PD variation for machines built 2015–2021

VI. STATOR WINDING OVER-VOLTAGE HIPOT AND INTER-TURN TESTS

Reference [1] indicates, AC and DC over-voltage tests are generally pass/fail qualitative tests, oriented to guaranteeing safety of operation of the insulation system or finding an evolving weakness on it before it creates an in-service failure. Even when test results are quantified through controlled DC over-voltage testing, the resulting factor is the linearity of the DC leakage current compared to voltage raise; current will be relatively small compared to the impact that external factors, such as temperature and humidity will have on them, therefore making comparisons less meaningful. For these reasons, it was decided to exclude AC & DC over-voltage testing from the study.

Similarly voltage waveforms obtained through stator winding inter-turn testing are to be analyzed comparatively to healthy test objects, to obtain meaningful results (e.g. comparison of each phase to the others). Additionally, most surge test methods do not penetrate to all of the overall insulation under test, but only on the first few turns of the phase receiving the impulse. Therefore, the particular conditions of the insulation portion being stressed contribute to a higher degree than the overall geometry object of this study. For these reasons, it was decided to also exclude inter-turn testing from our study.

VII. CASE STUDY – ONLINE PD MONITORING

Online partial discharge monitoring has always been considered a useful insulation status diagnostic tool. Online PD monitoring can expose problems that would be difficult to identify otherwise. It is vital to note that evaluation of a single data point has always been difficult. A better option is to take periodic measurements, starting with a fingerprint or benchmark measurement on the new winding, to obtain trend data. Over the last decade, the electric utilities, plants and petrochemical industries trend has been establishing more stringent PD limit requirements when developing their technical specifications for high voltage motors and generators. In response to that requirement, the motor and generator manufacturers may introduce cost by over-design; but this does not necessarily produce a machine with a longer life or increased reliability.

The biggest challenge, often observed during site inspections and testing, is to carefully interpret the partial discharge data without causing unnecessary concern. Several site issues including improper cable routing, restricted airflow in the stator endwinding and surface contamination can aggravate PD activity. To confirm elevated PD due to aforementioned issues, it is considered useful to also perform a detailed visual inspection to better correlate data.

To better understand the benefit of the online PD trending and data interpretation, a 30,000 HP, 4-Pole,13.2 kV, synchronous motor installed in 2004 was studied. The scope of work was to carefully review 15 years of PD trend followed by a visual inspection. Preparations were made in advance to perform any remedial work during the shutdown followed by repeating the online PD testing.

Stator winding visual inspection revealed a corona shield degradation at slot exit locations on the line-end coils (see Fig. 15). During scheduled outage, the corona suppression system was restored using approved coating materials. Upon return of machine to service, online PD testing was performed to validate the successful completion of the field work.

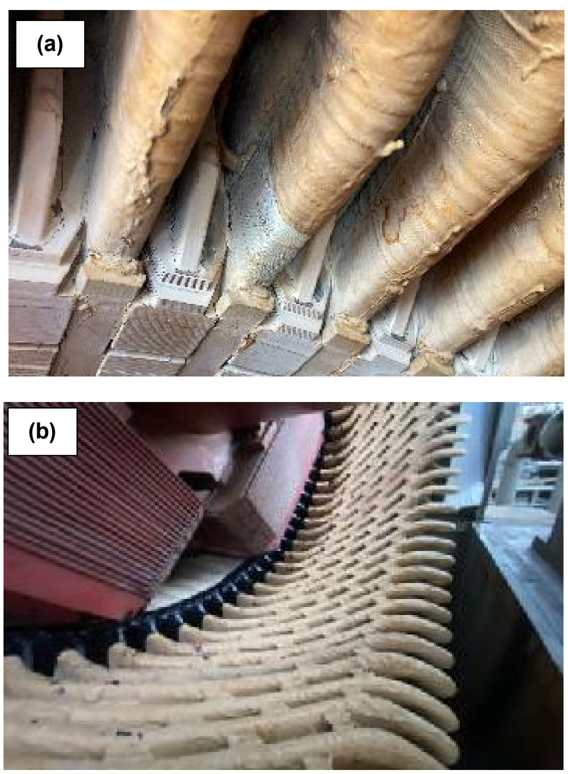

Fig. 15 Stator winding (a) before and (b) after remedial work

Online PD data was acquired in 2021 (see Fig. 16) and showed a significant drop in the trend. The results suggest success with the field recondition work and, most importantly, the swap of neutral connections with the line leads in the main terminal box. The unit should continue to provide reliable service until the next major outage, which is planned in the next 5 to 7 years [12].

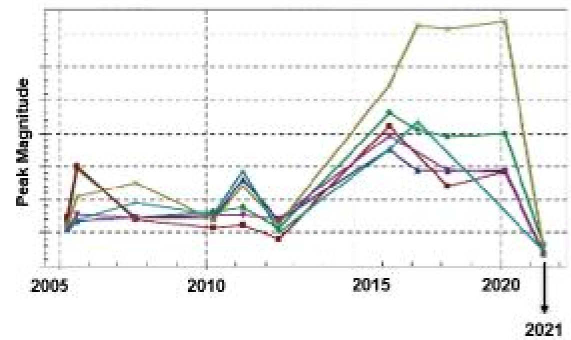

Fig. 16 Online PD trending during motor service life

VIII. CONCLUSIONS

Based on several studies made to produce this paper, following conclusions can be made:

1. In addition to the standards it will be reasonable to use the insulation resistance temperature correction factor (Kt) for IR normalization using insulation system specific correction established by the OEM.
2. A better understanding of stator insulation system and geometry is necessary to provide a more accurate health assessment of a rotating machine.
3. IR and TD test results can be influenced by insulating materials and geometric design of the machine making the establishment of a sensible acceptance criteria difficult.
4. No standardized PD limits can be set for complete rotating machines, not even within the same unit or series of machines with exact same characteristics. Therefore, it is recommendable to baseline PD after in service machine settling-in period and then continuously monitor it at an interval of 6-12 months for trending purposes.

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XI. VITAE

Hector Bordegaray graduated on Industrial Electronics Engineering, by the University of the Basque Country (UPV/EHU) in 2003, with specialty on Digital Systems. He started as a cooperant Technical Support and Projects Engineer in GE Power Management on 2001, moving to GE Power Services in 2004, as Field Services Specialist on protection relaying. Graduated as Generator Specialist by GE Learning Center in Schenectady on 2008, as Project Manager by GE Project Management University on 2010, and as Excitation Specialist by GE Learning Center in 2013. Hector joined GE Power Conversion in 2015 as North Europe, Sub-Saharan Africa and Oceania Rotating Machine Services Operations Manager, and was promoted to Global Rotating Machines Services Product Manager on 2017 (to date). Hector has a wide field services expertise, ranging from installation & commissioning to system upgrades, testing & diagnosis and onsite repairs, including full short-cycled onsite rewinds. His expertise covers machines from sub-kW to 570MW, and up to 15kV, on nuclear, fossil fuel and hydro industries, offshore and onshore.

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