A CASE STUDY ON LIFETIME ASSESSMENT OF STATOR WINDINGS IN LARGE MACHINES THAT CAN BE A CRITICAL AND EFFECTIVE TOOL IN A PREDICTIVE MAINTENANCE PLAN

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Abstract –
The cost of an unexpected plant shutdown due to failure of critical equipment such as a large motor in the Chemical Oil and Gas process industry could have a significant impact on earnings. Failure surveys of motors in petrochemical plants have indicated that in motors rated over 2000 kW over 60% of all failures are attributed to stator windings. Additionally, the downtime involved in repairing or rewinding a stator could be considerable.

Condition assessment and life time estimation techniques of stator winding could be very beneficial to determine the anticipated rate of degradation and estimate the existing and expected reliability till the next outage. A clear plan then could be devised for administering the necessary machine maintenance.

This paper explains how such an approach helped to make the right maintenance and budget decisions and to minimize the risk of unplanned shutdown a 17,433 HP (13000kW) synchronous motor. This motor, which drives a compressor that´s critical to production, has been in operation since ***2003*** and has no spare. By adding the routine inspection of the stator winding to condition assessment and lifetime estimation techniques that estimate the amount of life consumed and the anticipated rate of degradation, this team has increased optimal asset reliablity and machine life

I. INTRODUCTION

With the increasing reform in the COG sector, there has been renewed focus on reducing costs and increasing equipment availability. One way in achieving this objective is to increase the time interval between maintenance outages and reduce the time of the outage. This obviously has to be balanced with the need for maintaining the reliability of critical equipment in the plant. Towards this end, efforts have been directed to move from traditional interval based or scheduled inspections and maintenance, to condition based maintenance. It might be argued that when it comes to some applications, the benefits of such an approach may be limited, as the maintenance and inspection of large motors is generally scheduled based on maintenance needs of other major plant process or equipment. It is therefore not possible that optimally spaced schedules are planned, based on the condition of the motor alone. While this may be true when it comes to short term planning, it is imperative that developing a strategy to determine long term maintenance plans is critical to ensuring that motors can operate up to their full potential life.

Towards this end, detecting defects at an early stage, being able to model and predict the growth of such defects, and integrating maintenance to mitigate the consequent reduction in reliability, is critical to ensure that the machine survives from one outage to the next at desired levels of reliability. This is where condition assessment finds its place.

Considering the above when it comes to high voltage motors, the objectives of condition assessment would therefore be:

- to ensure that high voltage machines will operate for their full potential life at intended performance levels
- to devise a clear strategy for the operation and maintenance of old machines
- to ensure that there is no unexpected failure of the machine between scheduled maintenance intervals
- to detect developing problems in machines at a very early stage
- to ensure that the maintenance plan developed is focused enough to be accomplished within the intended outage period
- to prevent catastrophic failure
- to reduce operating and maintenance costs of machine

II. MOTOR RELIABILITY SURVEYS

Reliability surveys performed over the past decades indicate that bearings and stator windings account for 75%-80% of all high voltage motor failures. When examining a study [1] done on high voltage motors in the petrochemical industry, for motors rated above 2000 kW stator windings accounted for around ***60%*** of total failures..

A comparatively recent study done in 2013 covered both induction and synchronous motors, including some operated by converters [6]. Over 50% of motor failures were attributed to stator winding failures. Here are some key insights:

Converters seem to have a clear relation with failure occurrence. This is likely to be related to the increase internal stresses (high switching frequencies, etc.)

An interesting observation of the IEEE published surveys [1], [13] indicate that a significant share of failure contributors (contamination, poor cooling, moisture, aggressive chemicals, normal ageing) consistently originated from thermal and ambient stresses (65%-71%).

Failure of a stator winding could potentially result in considerable downtime. In a study on the mean time to repair of generators from experience in the nuclear industry [14], stator windings accounted for a share of around 41% of the total downtime.

Maintenance planning for large motors would therefore rely heavily on assessment of the insulation of the stator windings. In addition, it would help that during such assessment, special focus is given to the presence of contaminants in the winding, effects of humidity as well as ageing of the resin in the insulation.

Commonly used checks in routine maintenance practice, for the detection of the presence of contamination are an Insulation Resistance (IR) measurement, and Polarization Index (PI) measurement. Both these methods are based on a likely increase in the leakage current as a result of the contamination that is present in the windings. However, in modern insulation systems, that use thermosetting epoxy and polyester resins, and adopt Vacuum Pressure Impregnated (VPI) constructions, it has been increasingly difficult to identify the presence of contamination in a machine winding based on IR and PI measurements.

When it comes to ageing of the resin, the most common approach has been to use tangent delta measurements. Such measurements are aimed at identifying dipolar losses in the insulation that could result from depolymerization of the resin. However, the existence of multiple lossy components in the insulation makes it difficult to even trend the development of ageing of the resin. Moreover, it has been observed that such solid losses could even reduce as ageing of the resin progress, further complicating the analysis process.

In this paper, we shall focus on the use of alternative methods to assess contamination and ageing of the resin to support maintenance decisions on a critical motor in a petrochemical plant. This paper will focus on the electrical evaluation of this motor.

III. CASE STUDY: MOTOR REPLACE-MAINTAIN DECISION

A. The Motor

The experience reported in this paper is for a critical motor in a petrochemical plant - a 17,433HP, 2-pole synchronous motor built in a similar manner to a turbogenerator, fed with a Load Commutated Inverter (LCI) supply and driving a compressor. The rated speed of the motor is 5370 rpm with a rated supply frequency of 89.5Hz.

The stator has two windings each rated at 3051 V with separate neutral points. The stator winding uses a Roebel bar construction and is insulated with a Class F, VPI epoxy-mica based insulation system. The bars are connected to each other through brazed clips, encapsulated with epoxy-filled glass fiber caps. No end corona stress grading system was deployed as it was not required for this voltage class.

The motor was installed and commissioned in a process unit in **2003**. The motor has been operating almost continuously and has been trouble free since its installation. Critical recommended spare parts have been maintained at site, but no spare motor was maintained. Any unexpected failure could potentially have a significant impact on production resulting in downtime related financial losses (typically hundreds of thousands of dollars).

As the motor was designed and built for specific use, a new replica motor could have a long delivery time estimated to be around a year.

B. Maintenance Strategy

The maintenance strategy particularly for the stator windings, relied on inspections, checks and tests at periodic intervals set by other equipment and plant needs.

Maintenance has been performed based on the findings of the inspections and tests and scheduled based on available plant maintenance opportunities. During an outage the stator windings are visually inspected through its inspection windows or using borescopic tools without rotor removal. This is accompanied with electrical checks for condition assessment of the stator windings.

As part of this process, basic off-line measurements are scheduled and performed. The aim of these tests is to trend measurements to identify any developing anomalies in the stator winding insulation system.

The offline tests on stator winding insulation include insulation resistance and capacitance measurements to ground, which are aimed at identifying developing changes in the insulation condition. A trend of the values is maintained to check particularly for the presence of contamination or moisture(IEEE std 43).

C. Observations

Basic offline checks conducted in 2013 revealed an increase in capacitance values from previously recorded values, which was accompanied with a reduction in the insulation resistance measured.

A visual inspection carried out subsequently using a borescope camera revealed presence of some debris that had the appearance of resinous flakes below the stator end-winding areas in the 6 o'clock position (on the Non-Drive End) (see Fig 1) There were no signs of any leakage of water from the water coolers during the inspection.

The information from the inspection when combined with the change in the capacitance and insulation resistance measured triggered the need to investigate the matter further.

Fig 1 Presence of debris observed

With evidence of insulation degradation, the key questions to ponder were:

- Would it be possible to assess the level of degradation of the stator winding insulation with minimum disassembly? When would it be deemed to have stator failure risk levels that cannot be tolerated for continued operation?
- To what extent can service actions be performed that would help reduce the rate of degradation and allow for prolonged operation?
- What would be the best course of action to be taken to mitigate risks of future operation?

To help find answers to above questions it was decided to first use more detailed and advanced insulation analysis without major disassembly of the machine.

IV. ADVANCED STATOR WINDING DIAGNOSTICS

The insulation system under consideration was built for use with a variable frequency drive where the insulation was dimensioned with higher thicknesses to ground and longer creepage lengths than a typical 3 kV insulation system used with a regular grid supplied voltage.
Likely defects in this insulation system could include the presence of contaminants on the surface of the insulation or their ingress within the insulation, the extent of ageing of the resin, the presence of confined areas of high leakage currents due to local weaknesses within the insulation such as cracks, fissures or other local damage, possible delamination within the insulation and possible looseness/movement of the winding within the slots or on the overhangs. Not all these defects are identifiable with off-line electrical checks and it was decided to combine condition assessment measurements with an inspection through the inspection windows.

A package of measurement methods could be used to provide information of the stator winding insulation. This package would compose of a combination of ac and dc measurements, to analyze the ground-wall as well as surface condition of the insulation. The following package of tests were proposed and deployed:

1) Polarization depolarization current analysis [3]
2) Tan δ and capacitance analysis [2]
3) Off-line Partial discharge (PD) analysis
4) Nonlinear insulation behavior analysis [10,12]

It is to be remembered that internal neutrals meant that individual phases could not be separately checked, and that the dual winding construction permitted checks to be done on each of the windings separately As it was not possible to separate the phases in each winding, checks between phases was not possible. Let us briefly describe the tests and analysis performed

A. Polarization - Depolarization Current Analysis:

Polarization-depolarization Current **(PDC)** analysis is a dc measurement is largely aimed at addressing the problems of contamination and localized leakage, while providing concomitant information to assess some of the other stated likely problems.
The PDC analysis is performed using DC measurements that collect insulation current data obtained on polarization or charging and depolarization or discharging the insulation for 1000 seconds.

Traditional Insulation Resistance (IR) and Polarization Index (PI) measurements provide useful information when assessing the insulation condition, determined by the extent of leakage currents in the insulation. However, when leakage currents are low, it is often quite difficult to identify the presence of contaminants on the winding when IR and PI measurements are in the so called “acceptable” range [3,4]. Furthermore, IR values are some extent related to function of the capacitance of the winding under test and the type of insulation system, and a reasonable assessment of the presence of contaminants in the insulation is not generally possible particularly in VPI epoxy mica insulation systems(IEEE std 43).

The inclusion of depolarization current analysis provides more information on charge storage within the winding. Charge storage analysis is useful since it is possible to identify whether charge is stored in normal “traps” within the insulation or within contaminants that promote dispersive behavior. Such analysis is therefore aimed at increasing the success rate of identifying the presence of contaminants in the insulation.

The quantity of charge storage calculated from the discharging process is normalized with the capacitance of the measured winding and the test voltage. Appropriate normalization to account for temperature effects are also performed.

From this analysis, it is possible to derive charge storage values and distributions for winding insulation and compare it to reference database of analyzed data of over 15,000 stators from where normally observed value ranges are determined.

The approach of PDC analysis not only looks at abnormal charge storage, but also its distribution. One approach is to model the depolarization current in the time domain by an approximation of exponential components representing three polarization processes.

Other approaches that have relied largely on mathematical methods, also use three exponential terms to describe the model and a nonlinear optimization algorithm to calculate the relaxation times or time constants and the specific currents for the polarization mechanisms.

In the approach adopted in [Pinto 2, 3] the three mechanisms are representative of space charge and interfacial polarization mechanisms in slot and end-winding regions. These phenomena are assumed to have negligible spatial interdependence. The analysis of depolarization current data calculates three relaxation times or time constants, T1, T2, T3 and stored charge values Q1, Q2 and Q3 attributable to the respective polarization mechanisms. See [3] for more details.
Other calculated parameters include:

1) Aging Factor: Aging Factor: It provides an indication of the increase in ionic mobility that could occur from de-polymerization of resin in close vicinity of the electrodes. The ageing factor is directly proportional to the square of the ion migration time constant and inversely proportional to ion migration charge. For example, conductor overheating could result in depolymerization of the resin near the conductor stack, which could directly influence the ageing factor. Values typically reduce from around 100 (unaged) to 35 (aged), over the operation period of the insulation systems. There is greater concern when the ageing factor values drop lower than 35
2) Equivalent volume resistivity: This parameter is estimated from the difference between the polarization and depolarization currents at long times and the capacitance of the measured winding. The parameter includes both

leakages through both the surface and volume of the insulation. For epoxy mica windings we typically see values that are greater than 1014 Ohm-m when we have leakage currents as normally observed.
When the charge storage and its' distribution is within a normally observed range, and values are lower than 1014 Ohm-m this could be more representative of leakage through local confined defects when e.g., in the terminations or even other local damage.

3) Ic/Ir or the ratio of capacitive to resistive surface currents (on the end-winding) is estimated from the polarization current at long times (around 1000 secs). The ratio is meant to be indicative of the nature of the contaminant at the slot ends. Values near 1 and less than 1 have been observed in windings contaminated by carbon particles/carbonized oil (conductive contaminants) or other conductive dust deposition at the slot ends. In case of oil/grease type contaminants, discontinuity in the stress grading system at the slot ends, the values are greater than one. Negative values are at times observed due to the creation of homopolar charges at the slot end regions, due to the present of moisture in the contaminant or on the surface of the windings or even when there are metal oxides in the contaminant or on the winding surface.

PDC analysis were performed with polarization measurements made at 2500V DC on each winding with the other grounded.

Time Domain Analysis: Both windings displayed similar behavior when analyzed in the time domain. The charge storage in the windings was seen to be higher than normally observed, but leakage currents are low from the equivalent volume resistivity estimates and the likelihood of surface contaminants being present is low.

A higher assessed charge storage is attributed to the presence of greater number of mobile ions in the insulation, either due to ongoing depolymerization of the resin or due to the presence of contaminants on the surface or with some ingress into the insulation.

The nature of the surface currents on the insulation at the slot ends is reflected by the Ic/Ir value and is influenced by the presence of moisture on the winding surface or due to the presence of metal oxides (e.g., rust).

Surface leakage currents are low from the equivalent volume resistivity calculated and there are no signs of cracks or fissures in the insulation. When combined with the charge storage values, the impact of the contaminants present in the windings is not seen to be significant.

The ageing factor is an indicator of the concentration and mobility of ions near electrodes (either copper or iron) and is seen to be midlife range (Table 1).

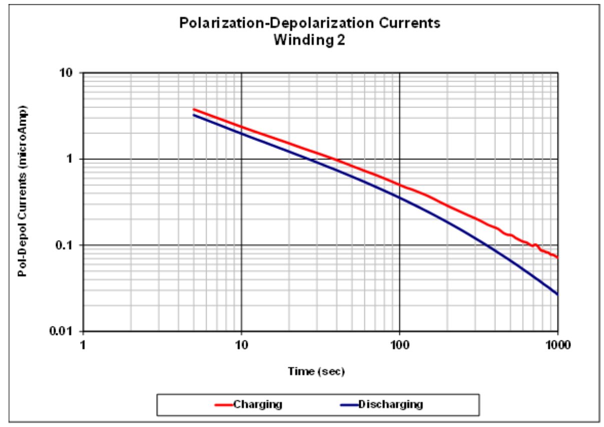

Fig 2- PDCA Curve

Test Voltage 2500 V Winding Temperature 21°C	Winding-1	Winding -2	Normally observed values
IR (Insulation Resistance) [MΩ]	3425	3407	
PI (Polarization Index)	6.6	6.7	> 2
T1 (Ion Migration Time Constant) [secs]	19	19	10-30 Sec
T2 (Slow Relaxation Time Constant) [secs]	107	107	65-150 Sec
T3 (Interfacial Polarization Time Constant) [secs]	595	600	300-1000 Sec
Q_1 (Ion Migration Charge) [%]	13	13	< 7 %
Q_2 (Slow Relaxation Charge) [%]	21	21	< 10 %
Q_3 (Interfacial Polarization Time Constant) [%]	28	29	< 20 %
AgF (Ageing Factor)	51.86	52.54	35-100
Ic/Ir (Nature of Leakage Current)	-3.91	-5.37	----------
DR (Dispersion Ratio)	1.62	1.63	< 1.25
Equivalent Volume Resistivity Ohm-m	2.2×10^{14}	2.1×10^{14}	$> 10^{14}$

Table 1 PDCA Calculated parameters

Frequency Domain Analysis: When analyzed in the frequency domain Winding 2 (see Fig 3) is seen to be a bit more lossy, with a loss peak and shifted towards higher frequencies n the frequency range below 0.01Hz. This could be related to degraded areas in the end-winding area further away from the slot ends.

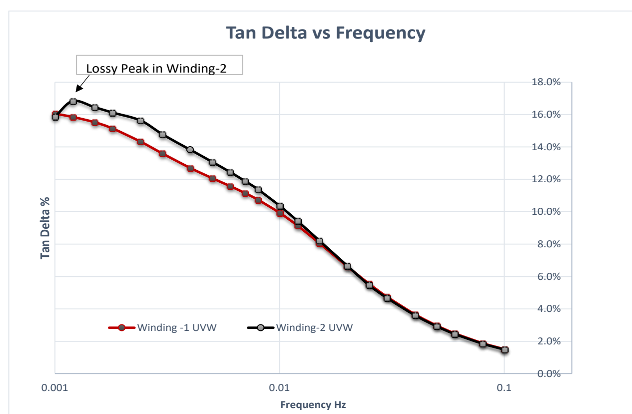

Fig 3 Tan Delta vs Frequency

B. Capacitance and Tangent Delta Analysis:

The other three measurements mentioned in the introduction of this section are ac measurements aimed at getting a better evaluation of the insulation volume, and in this case when the star point is internal, largely of the slot/slot end insulation.

Capacitance and tangent delta measurements are performed to identify major lossy processes at voltages lower than pd inception, and to evaluate the extent of pd activity at voltages higher than pd inception. The evaluation above discharge inception voltage is done through a process of estimation of the volume of the discharging air spaces compared to the total insulation volume [2,8]. At voltages below pd inception, the modification of normal properties of the stress grading system, are also evaluated [9].

The analysis does not use an approach of trending historical measurements, as they are sensitive to several physical phenomena that could co-exist simultaneously, influence both tan delta and capacitance values and could be difficult to separate. It instead estimates certain parameters like effective phase shift at voltages below pd inception and discharging void volume content at voltages above pd inception, which reduces the dependence on historical trends for analysis.

Capacitance and tan delta measurements were performed, simultaneously with partial discharge measurements on both windings up to a maximum test voltage of 2kV i.e., the rated voltage to ground. No partial discharge activity was observed. This was due to the higher-than-normal insulation thickness used.

Measurements indicated very low loss (tan delta <1%) with increasing tan delta values with voltage that could be attributed to solid and surface losses. Capacitance values reduced with an increase in voltage reflecting anomalous insulation behavior, possibly due to the effect of space charges [9]

C. Non-Linear Insulation Behavior Analysis:

The test is supplementary test to both PDCA and Tan Delta & Capacitance Analysis. Traditional measurements performed on stator winding insulation indicate variation in capacitance and tan delta values with voltage, even in absence of partial discharges. One of the most obvious reasons for this variation is the presence of non-linear field stress grading system employed at the slot ends. Other reasons include space charge and interfacial polarization phenomenon [9], due to variety of reasons including contamination of the windings, ageing of the insulation, contact of the coil with the slot and the effects of electrostatic forces on delaminated stator insulation. Besides, partial discharge activity results in change of instantaneous capacitance with voltage and hence is also a contributor of such non-linear behavior. In this test, an AC high voltage is imposed on the insulation system, and the current drawn by the insulation is subjected to a special non-linear analysis. Due to charge storage mechanisms, the behavior is non-linear and results in harmonics in the current flowing through the insulation.

The relative content of harmonics in the admittance of the insulation are estimated, predominant harmonics and the pattern of harmonic magnitudes is indicative of anomalies in the insulating system such as ionic activity in slot region, presence of contamination and the occurrence of partial discharges. The test also provides a clearer indication of aging of the resin in the insulation. The greater the contribution of the higher order harmonics the more is the concentration and mobility of ions within the insulation.

The non-linear behavior of the insulation was analyzed based on the approach outlined in [10,12]. Even harmonics of the insulation admittance exhibited a peak somewhere around the 10th harmonic of the admittance for both windings (Fig 4), indicating a high level of ion concentration in the resin. As the level of depolymerization in the resin increases the peak has been seen to shift towards the 14th/16th harmonic of the admittance. In the present case the condition of the resin could be described to be "mid-life".

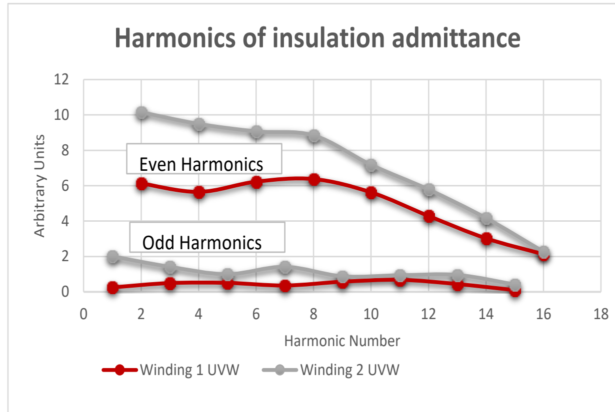

Fig 4 Harmonics of Insulation Admittance

D. Off-line Partial Discharge analysis:

It is extremely useful to include off-line PD measurements in the overall package of measurements as very useful information on the nature of pd processes is obtained. When combined with tangent delta and capacitance measurements, the evaluation is supplemented. Typical evaluation is done by evaluating damage to the slot corona protection system and end corona protection stress grading system.

As indicated in part B of this section, no pd was detected up to the maximum ac test voltage of 2 kV.

E. Visual checks through the Inspection windows

A visual check was performed through the inspection windows at the NDE side of the windings.

In areas that were visible, some contaminants in the form of carbonized particles were observed between coils particularly in areas between phases. The most significant observation was the presence of what appeared to be resin that was specifically deposited at the joint areas over the finish varnish. The disposition of the resin was not the same in the areas near the lower or 6 o'clock position and the upper or 12 o'clock positions, with a greater presence on rotor facing side in the upper end caps and greater presence on the outer winding radius on the lower end caps. The resin appeared to have come out from the encapsulated joint areas. See Fig 5 for a closer view of what was observed. No signs or discoloration due to overheating was observed in the end-winding arm areas.

F. Analysis

Let us start with the visual checks. No repairs have been performed on the stator since it was commissioned. Additionally, inspections in 2013 indicated the presence of what appeared to be resinous deposits with similar coloration as the resinous

Fig 5 Resin exuded from insulation end caps

deposits on the knuckle end caps. Images of the inspection performed in 2013 were reviewed and similar resin deposits (Fig 5) on the end caps were observed, perhaps with a lighter coloration.

The motor operates with a maximum stator winding temperature of 93 deg C, measured with PT100 RTDs placed in the slot areas. One possibility is likely higher temperatures in the areas of coil-to-coil joints due to eddy currents from converter harmonics.

Contaminants though present in the winding do not impact leakage currents. There was no pd activity and from an evaluation of the solid dielectric, the level of depolymerization is seen to generally be commensurate with the operating age of the stator winding when considering the slot insulation. However, from PDC analysis there were additional possibilities of degradation observed specifically in winding 2 in the end-winding areas away from the slot. This was perhaps also reflected in the visual observation performed.

From earlier visual checks in 2013, there does not seem to be a significant change in the observations.

There are of course, unobserved parts of the winding for which a full rotor out inspection would be very useful, but this needs to be addressed with the risks of insulation failure with continued operation.

G. Life expectancy analysis to estimate failure risk

In order to convert the insulation assessment into an actionable maintenance plan, it would be very useful to get an idea of the insulation level of degradation in relation to its expected life. An approach that triggers specific maintenance actions based on the assessed levels of degradation and how such degradation evolves with continued operation, could help translate such an assessment into a clear maintenance plan. This is particularly useful when for process and production reasons, tolerable downtime could make it very difficult to do major maintenance on a critical asset like the motor that was tested. It is for this reason that the level of degradation based on the evaluation of lifetime expectancy becomes useful.

Even in critical equipment, it is often recommended that major maintenance with the rotor pulled out, is performed at least once in its lifetime. In other words, if the level of degradation goes past the 50% level, major maintenance of the assessed component – in this case the stator – would be due.

And if this is still a problem to put in place, then one would have to examine options more closely such as the maintenance of critical spares or even a spare motor.

It was in this connection that it would be useful to have inputs from a lifetime expectancy analysis. The aim of such an analysis is mainly to get a clear indication of levels of degradation in order to plan maintenance, and not essentially to look at how many hours of useful life remain.

A combined stress phenomenological model, that is based on one proposed originally by Simoni (2,3) is used to assess the extent of degradation of the insulation and perform a lifetime expectancy analysis. The model accounts for thermal, electrical, and mechanical stresses, whose relative effects on the life of the insulation are estimated based on the analysis from the measurements performed, and from the operating and other historical details available.

Constructional details of a class F, VPI epoxy mica insulated stator winding are used to arrive at threshold stresses below which levels of degradation are considered negligible. A life expectancy analysis using the maximum operating temperature of the winding in the model is first performed to get the maximum potential life of the insulation.

It is then assumed that the stator winding has in the past followed this rate of degradation till the time of the measurements. Quantities estimated from the condition assessment checks (for example the charge storage, equivalent volume resistivity) are then used to update stress levels from a new construction and used in the model to get a new rate of degradation to arrive at a new estimate of the remaining life. This analysis is done with an 80% confidence level on the estimates. More information is available in [11].

The steps indicated above when applied to the present situation indicated that the level of degradation of the stator winding was around 60% that of the original, which implied that major maintenance was called for. If one was looking for a time scale this would amount to an indicative remaining lifetime of approximately **90,000** operating hours (see Fig 6). The assessment is based on steady state conditions and does not account for transients that could result in premature failure.

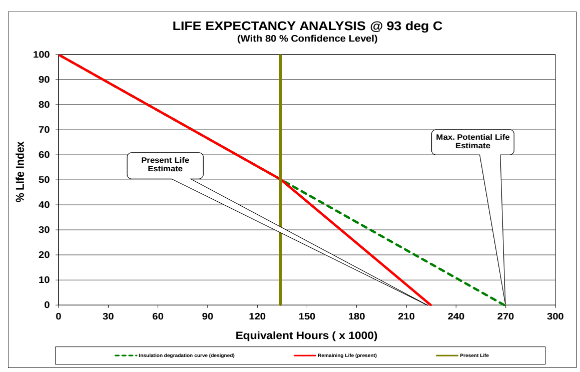

Fig 6 Life time graph of stator winding insulation

V. REPAIR VS REPLACEMENT

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While a rotor out inspection could add more value to the overall analysis, with the irreversible nature of the key degradation identified (ageing of the resin), such an inspection would have limited value when addressing remedial actions.

The following scenarios were considered:

Scenario 1 – continued operation of the motor without resorting to major maintenance, planning for the use of contingent spare coils and winding hardware, and rewinding the stator at an opportune time

Scenario 2 – keeping a spare motor in stock and replacing the existing with the existing one when the stator degradation level reached a value of around 80%-85% from the existing 60%

These scenarios were evaluated. The cost of downtime was a significant determinant in the economic estimate, that also accounted for the risk of failure on an annual basis. The adoption of scenario 2 indicated adequate benefits that justified the investment for a spare motor.

VI. CONCLUSION

Stator winding condition assessment of critical motors can pose several challenges to a maintenance engineer who has to use available tools to decide what may have to be done in the short term and also need to look into long term maintenance plans especially in COG sector where time between outages is only increasing, and sometimes are not adequate for major motor maintenance.

An approach to using condition assessment and lifetime expectancy analysis has been demonstrated to be of considerable value in optimizing maintenance implemented in a critical application i.e the life of a stator winding. Alternative methods have been suggested for use in gaining more insights and evaluating degradation processes commonly believed to be responsible for failures of stator windings - particularly when useful approaches that rely on pd measurements might not always be applicable. In addition to the insights gained from the analysis of the measurements, the importance and the role of visual inspections has also been highlighted with its contribution to the process for assessment and lifetime expectancy of the insulation. What was most useful is the incorporation of the outcomes from the condition assessment and life expectancy analysis into a repair-replace decision model that provided a clear course of action.

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VIII. VITAE

Cajetan Pinto graduated from the Mumbai University in 1982 with a BE degree, and from the University of California Irvine in 1985 with an MSEE degree specializing in electro-magnetic energy conversion systems. He has been working with ABB for over 24 years in various roles and for over half that period has been the Head of R&D for ABB Motors and Generators Service. Cajetan is currently Innovation Champion ABB Motion Services and is based in Madrid. His focus areas of research include diagnostics, condition monitoring & reliability, motor and generator re-engineering, maintenance technologies, new service processes and materials for service.

He has authored and co-authored over 40 conference papers in the field of condition monitoring and diagnostics.

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