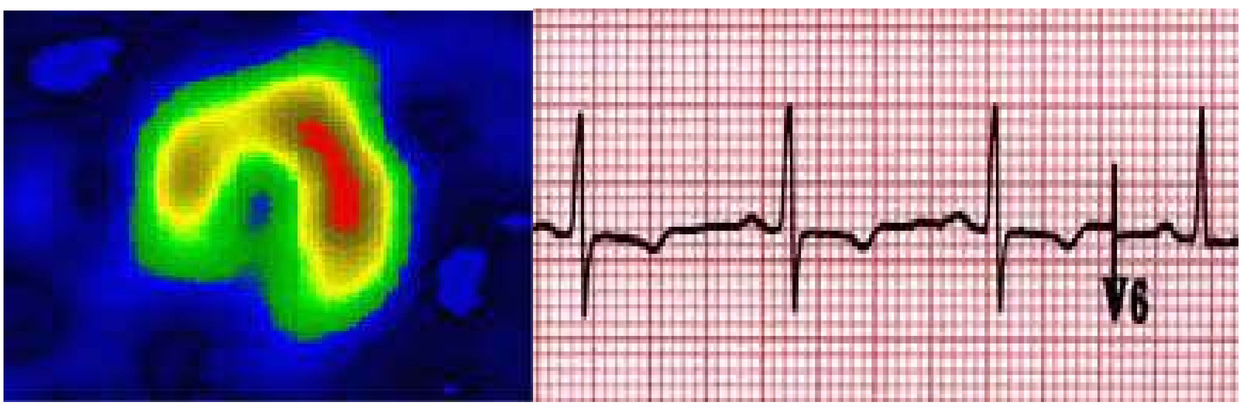
ROTARY RESIDUAL LIFE ASSESSMENT SERVICES

ELECTRICAL ROTATING MACHINES



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Condition Based Maintenance (Predictive Maintenance) is considered as a productive tool because it helps eliminate unscheduled downtime of expensive equipment and reduce the overall cost of maintenance. This approach relies on planned inspections, testing, analyzing and trending of the relevant equipment parameters, which determine equipments health and must be followed by proactive actions that change the way equipment is operated to reach the goals set out above.

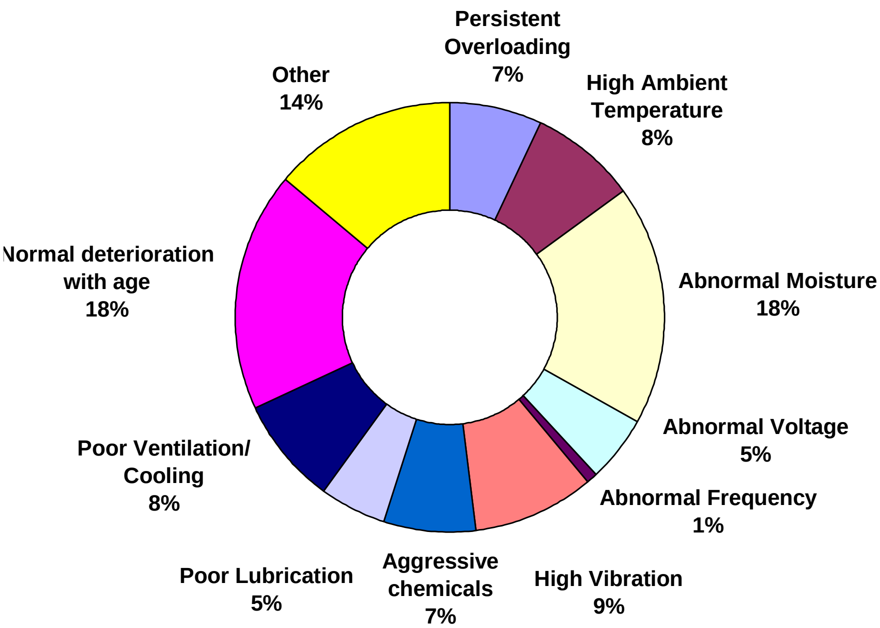
The concept of simple replacement of power equipment in the system considering it as weak or a potential source of trouble is no more valid in the present scenario of financial constraints. Today the paradigm has changed and efforts are being directed to explore new approaches / techniques of monitoring, diagnosis, life assessment and condition evaluation and possibility of extending the life of existing equipment.

In this effort of extending the life of existing equipment, we offer a package involving residual life assessment and condition evaluation of electrical rotating machine. This document consists of methodology involving residual life assessment technique for electrical rotating machine, scope of work, various requirements for residual life assessment and time involvement. The main objective of this residual life assessment will be to generate a report which gives the information to achieve following tasks

- To arrest the deterioration in performance
- To improve the availability, reliability, efficiency and safety of equipment.
- To regain lost capacity
- To extend useful life beyond design life and save investment on new equipment.

Failure of insulation is considered to be major factor in electrical rotating machine. Aging of insulation generally follows a chemical rate degradation curve and in addition is severely affected by the number of stops and starts, the frequency of stops and starts as well as large load variations. In addition, the stresses imposed on the insulation designed today, are at levels higher than ever before, which are further aggravated by environmental conditions, presence of contamination, partial discharges and such other physical conditions, thereby increasing the requirement to assess machine reliability with greater accuracy.

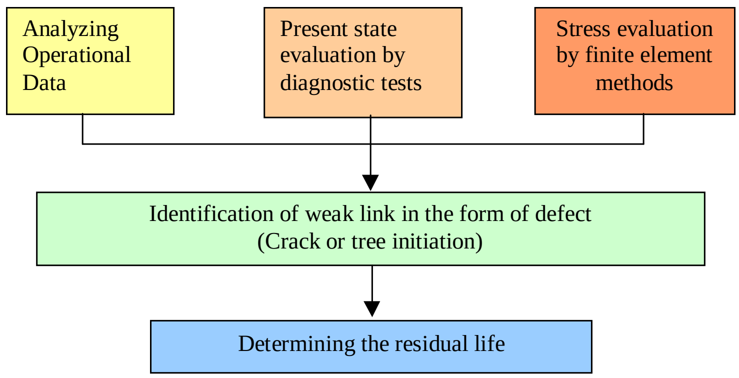
IEEE and EPRI survey: Causes of failure in Stator Windings



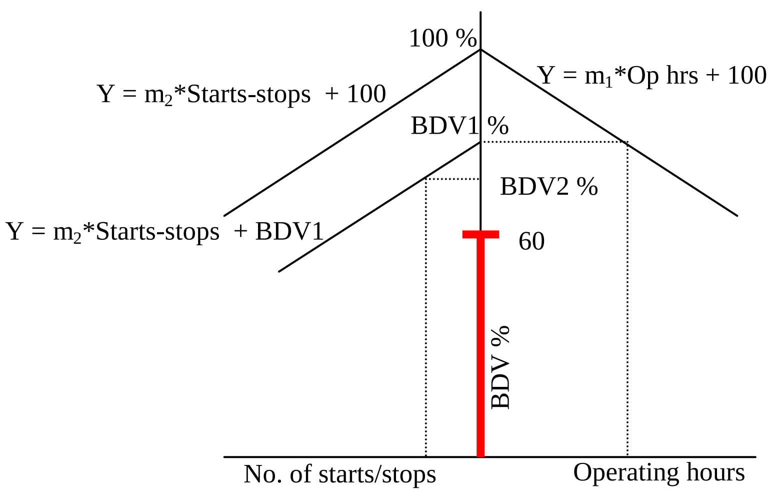
Besides for a plant, smooth power generation with minimum outages, maximum availability of generators with reduced breakdowns/faults and minimum downtime holds the key to enormous savings and profits.

In this residual life assessment package, we will assess the life and condition of total insulation system of electrical rotating machine consisting of high voltage generators and motors.

Rotary, with over five decades of experience in the field of servicing of electrical rotating machines, have found out several innovative tests and technologies for assessing the current physical condition of the machine. With a backup of large database, build after performing the **Root Cause Failure Analysis** on several hundred machines, Rotary now offers **Residual Life Assessment (RLA) Services**, as per the following flowchart:



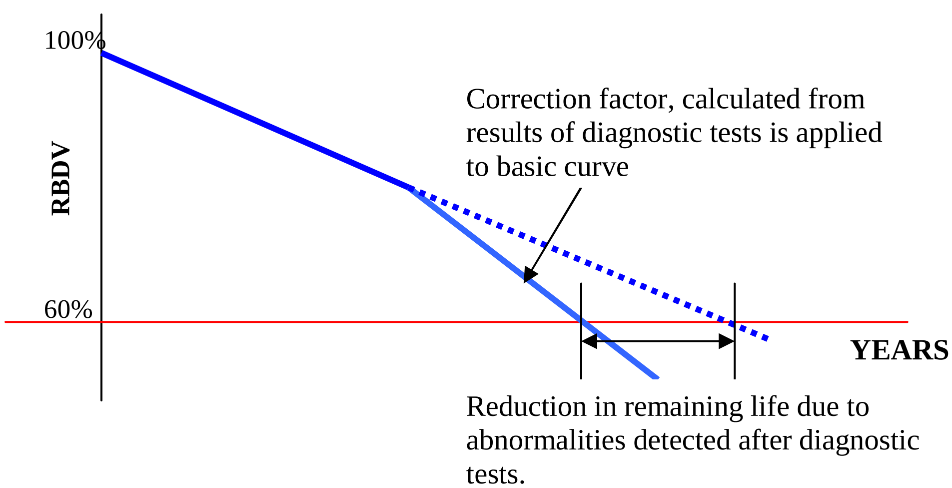
The machine insulation is subjected to constant thermal stress that causes aging as given by the Arrhenius chemical degradation rate equation and charts for different insulation class. Besides this, there are cyclic thermal stresses caused by frequent starts/stop of the machine. This causes reduction in tensile strength of the insulation, which can be expressed in terms of residual breakdown voltage (RBDV). The basic Arrhenius curves are modified to account for the operational hours and starts/stops as shown.



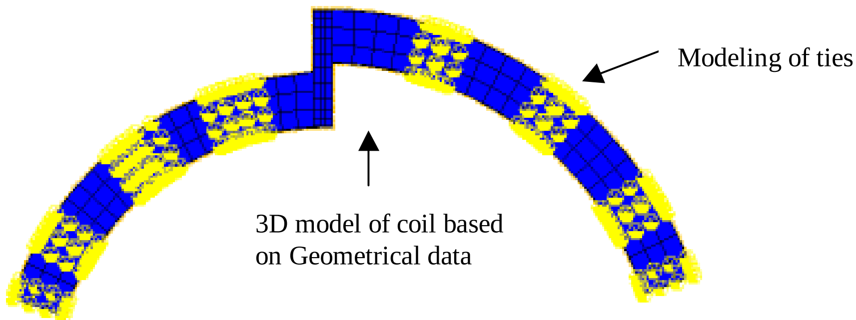
It is assumed that the BDV for new machines is 100%. There is initial reduction in BDV (shown by BDV1) due to stresses caused by heating of windings and insulation, corresponding to the operating hours. The stresses are high during starting and stopping conditions, which further reduce the BDV (shown by BDV2). The value of 60% for BDV is taken as the critical value, below which the machine is at high risk of insulation failure.

The above analysis based on operational data can offer life estimation at 65% confidence level. The next step in RLA is to evaluate the present machine condition by diagnostic test. Rotary presents you a special bouquet of tests that doesn't just tell you the machine is good or bad, but goes far ahead in understanding the physics involved and answers your query lucidly informing which component needs attention and why.

This bouquet of tests gives in depth information regarding machine abnormalities like contamination, charge storage within the machine, lack of contact of coil with core, looseness of coil/wedges, presence of voids within insulation, presence of partial discharges and its location, core lamination shorting and so much more. These parameters will further degrade the insulation properties and reduce the RBDV or tensile strength. The curves are suitably corrected to yield the residual life of the machine.



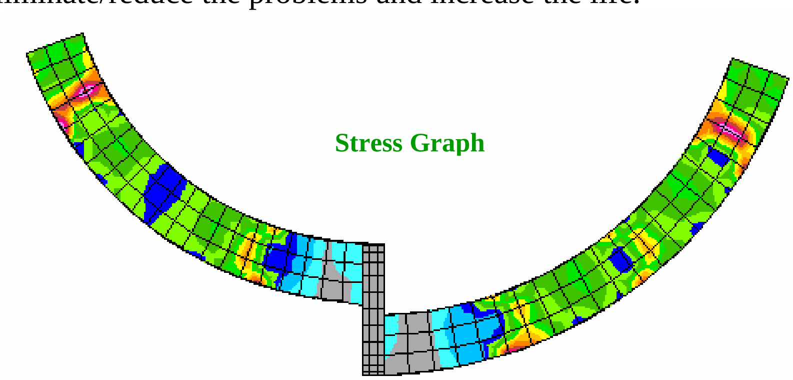
The next stage offered by Rotary is stress analysis, During operation, an electrical rotating machine is subjected to thermal, electrical, mechanical and ambient stress either singly or in combination, ultimately resulting in aging of insulation. Based on design data and actual measurements of the key dimensions of the machine, these stresses can be evaluated using finite element techniques. From the knowledge of the operating stress, machine health and aging extent, a weak link in the insulation can be identified and plotted.



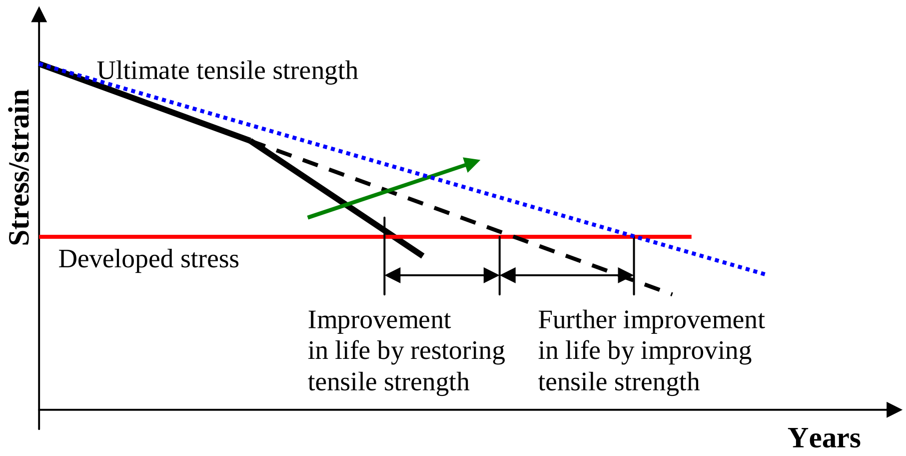
The change in the winding temperature from a cold to hot condition and from a hot to cold condition constitutes a thermal cycle. Thermosetting insulation systems generally are stable dimensionally with increase/decrease in temperature. However, the copper of the bars tends to expand on application of heat. The restraining force is generally offered by the end-winding bracing supports that are used to limit winding movement due to electro-magnetically-generated forces. These constraints result in a mechanical strain at certain bracing support locations. Also, the conductor bends and twists due to a change in the direction of expansion of the coil, resulting in additional development of stresses.

The developed stresses are computed using a three-dimensional finite element (FEM) package. The coil dimensions and material data is collected and an FEM model is constructed as shown above. The temperatures and frictional forces in slots and at ties are then incorporated and the software calculates the Von-Misses stress along the coil. The intersection of the tensile strength curves and developed stress calculated gives the remaining life.

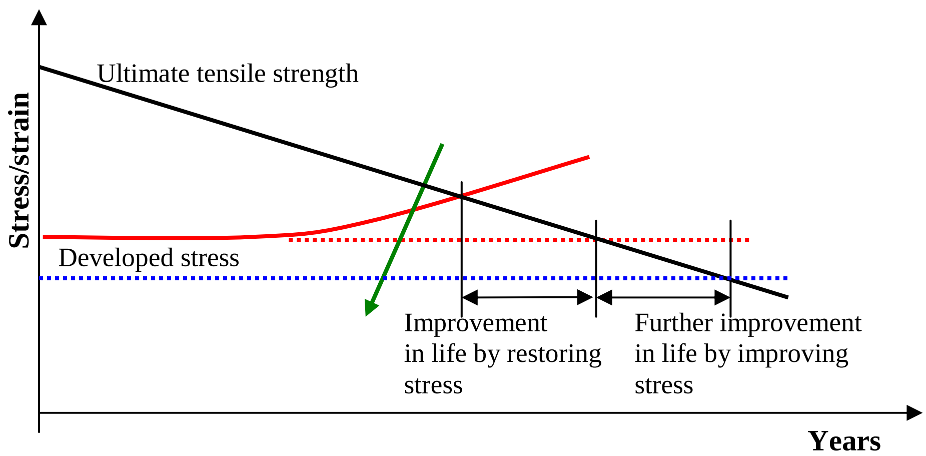
We at Rotary, are not satisfied by just calculating the residual life of the machine. We use our expertise and experience to understand the root cause of problem and recommend suitable actions to eliminate/reduce the problems and increase the life.



The various ways in which remaining life of the machine can be improved are illustrated below:



The problems such as contamination, machine running hot, lack of contact of coil with core and partial discharges etc. cause reduction in ultimate tensile strength. The early detection of problems and appropriate maintenance actions, like cleaning/overhauling of the machine can help in restoring the tensile strength. By improving the cooling efficiencies, better heat dissipation, removal of blockages in ventilating ducts, the tensile strength can be improved as shown by blue line above.



The problems such as looseness of coils and partial discharges cause acceleration of aging problem and hence the developed stresses may not be constant but increasing as shown by solid red line. Placing the coils tight in slot by inserting adequate side packers, rewedging etc can arrest the looseness and prevent increase in developed stresses, causing improvement in remaining life. A further improvement can be achieved by reducing the developed stress (blue line) by rewinding/revarnishing options.

RESIDUAL LIFE ASSESSMENT – SCOPE OF WORK

1.0 OPERATIONAL DATA ANALYSIS – SCOPE OF WORK:

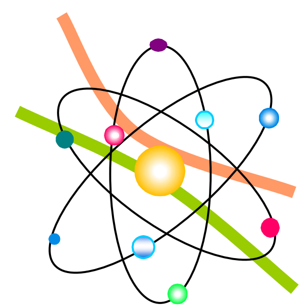
We need from you certain details like the total number of hours of operation, no. starts/stops, frequency of starts/stops, measurements of certain starting parameters, historical data on past maintenance/repair and faults witnessed, temperature profile, loading details, and such other information. The Rotary engineer will hand an operational data form and collect the data by interviewing your plant personnel. The client may pass on the relevant information and hand over any supporting documents/drawings/photographs related to requested information to our engineer. This data is linked to a known Arrhenius fit for insulation degradation. Reduction in the tensile strength is calculated on the basis of the Arrhenius theory. The amount of used up life is calculated on the basis that 50 % reduction in the tensile strength maps to 100 % depletion of life, or, in other words, end of life.

2.0 DIAGNOSTIC TESTS – SCOPE OF WORK:

The RLA test package consists of a bouquet of tests, which have been aptly chosen for Generators. The tests and analysis are based on modern Rotary technologies, which go beyond the conventional tests, to reveal actual physical information about the machines in great depth. These tests enable pinpointing accurately the root cause of failure by studying physical condition of various components of the generator. They have been divided in two parts based on client's shutdown and maintenance requirements:

The following tests are conducted:

2.1 POLARIZATION-DE-POLARIZATION CURRENT ANALYSIS



The winding is charged by megger for 17 minutes at 2.5 kV or 5 kV (depending on rated voltage of the machine). It is then discharged through resistance for 17 minutes. The IR and discharge currents are recorded at fixed intervals as per a sheet provided by Rotary. The data is then plotted on a log-log scale and analyzed using Rotary special software to reveal a wealth of information that conventional IR-PI tests does not provide.

Benefits:

- Detailed analysis and single test that determines machine winding condition with respect to presence of contamination, its nature and location, resin condition, leakages within machine, lack of contact of coil with core, charge storage and such other physical insights.
- Goes beyond IR-PI tests, which are dependent only on leakage mechanisms, by also studying charge storage and transport mechanisms.
- Evaluation of present machine winding condition without opening the machine.

2.2 CAPACITANCE AND TAN DELTA ANALYSIS

The PDCA test described above is based more on surface physical phenomena. For an in depth understanding of insulation characteristics there is a need for ac tests. Tan delta & Capacitance Analysis is one such test. Tan delta is indicative of the in phase component of current drawn by the insulation, in other words, represents the power dissipation in the insulation system. This test is conducted at various voltage levels upto the rated phase voltage of machine, by using a transformer ratio arm bridge balance method to record the tan delta & capacitance values. These curves are later analyzed using special Rotary software for before discharge inception voltage to reveal physical abnormalities like lack of contact of coil with core, interfacial polarization, presence of contamination, looseness of coils/wedges and after discharge inception voltage to reveal presence of partial discharges and its location.

Benefits:

- Detailed analysis that determines machine condition with respect to presence of contamination, resin condition, presence of air-gaps/voids within insulation, lack of contact of coil with core, looseness of coil/wedges, interfacial polarization and such other physical insights.
- Tan delta values may change depending on several factors intrinsic to machine and even environmental conditions and thus its trending may not reveal any information. Rotary technology calculates certain parameters like void volume content etc and trend these parameters instead of absolute values to reveal developments of any abnormality.
- The test is one time test and does not depend on previous tests.
- Provides explanation to conditions even before discharge inception voltage.
- Does not just reveal the presence of PD but also its location.

2.3 NON-LINEAR INSULATION CURRENT ANALYSIS (NLIC)

The test is supplementary test to both PDCA and Tan Delta & Capacitance Analysis. In this test, an AC high voltage is impinged on the insulation system and the current, drawn by the insulation, is subjected to a special non-linear analysis. Due to charge storage mechanisms, this current is replete with harmonics. The relative content of harmonics, predominant harmonics and the pattern of harmonic magnitudes is indicative of anomalies in the insulating system such as ionic activities in slot region, presence of contamination, partial discharges. The test provides a very clear-cut indication of aging of insulation (if any).

Benefits:

- In depth revelation of abnormalities that are essentially non-linear in nature, present within insulation, localized defects, aging etc.

2.4 PARTIAL DISCHARGES AND CORONA PROBE TEST

Partial discharges have been known to accelerate the aging process. They cause erosion of insulating material and propagate through treeing mechanism eventually bridging the electrodes and causing insulation breakdowns. While the C-Tan Delta and Non-Linear tests gives us the indication of presence of these discharges, this test records such pd signals. Based on the pattern recognition techniques, Rotary can provide information regarding the type and nature of these discharges and accurately pin-point the location within the machine, besides assessing the level of damage caused.

Benefits:

- Determining the type of discharges/location based on proven pattern recognition techniques, without opening the machine.
- Suggesting maintenance actions to minimize such discharges.

2.5 VISUAL INSPECTION

With rotor threaded out, Rotary engineers will perform a detailed inspection of the various generator components such as stator core for signs of damage, burnt marks etc, laminations for looseness or shorts, wedge looseness, anti-corona shields, tie-ups, presence of contaminants, insulation peeling, heating signs, rotor poles for looseness/damage, brush arrangement etc. Visual inspection also includes the **Knife test** to detect stator core looseness and **Endoscopic observations** to detect abnormalities deeper within the machine such as blockage of ventilating ducts, erosion of anti-corona shield in slots etc. These observations are supplemented with diagnostic test analysis to provide high accuracy.

Benefits:

- Detection of abnormalities that are visible to the eye
- Increased accuracy due to visual evidences
- Detection of mechanical defects deep within the machine
- Provides visual clues to problems identified in diagnostic tests.

2.6 WEDGE MAPPING

Wedge looseness is a dangerous condition for two reasons, firstly it may foul with rotor causing mechanical damage and secondly the coils are not held tightly in the slots. This may lead to coil surface erosion due to its rubbing with core and eventually partial discharges in slots. While these effects can be detected by the diagnostic tests, wedge mapping is performed to identify which wedges are partially or completely loose/damaged. The tightness of wedges is checked by tapping each wedge in all the slots, at three locations, with a hammer and listening to the emanating sound. A map is prepared to represent an overall picture of wedge tightness. Rotary also provides analysis regarding the criticality and looseness percentage.

If ripple springs are used in the slots, as is the case with larger alternators, wedge deflection test is to be performed as the tapping method is not applicable. This is done by applying pressure on the wedges using a known weight and measuring the deflection of the wedges.

Benefits:

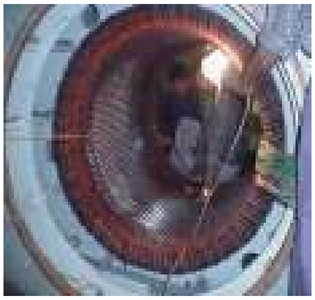
- Colorful map display identifying loose wedges
- Analysis of the severity of wedge looseness and effect on the machine.

2.7 ELCID TEST

Electromagnetic core imperfection detection (ELCID) test is an alternative test to the Full Flux test. Around 4% flux will be created in the stator core with the help of a "loop" wound torodially around the core. A pick-up coil will be used to access the leakage fluxes that bridge adjacent teeth. Fault currents generated at the sit of "hot spots" or shorted laminations, between the accessed leakage fluxes and the exciting fluxes will be noted, to detect the shorted laminations, using an ELCID kit specially developed for the purpose.

Benefits:

- Identification of core faults such as interlaminar shorts and hot-spots.
- Timely detection of the core defects helps in prevention of earth faults.



2.8 COUPLING RESISTANCE TEST

In this test the contact resistance between the coil slot wall insulation and ground (Slot wall) is measured for both the top and bottom bars and a chart showing the coupling resistance readings at each slot is prepared. This test provides information on extent of contact of coil side with core and therefore the extent of coil looseness due to side clearances. This test is used to quantify the lack of contact of coil with core problem that is detected in the PDCA and C-Tan Delta Analysis and is hence supplementary test.

Benefits:

- Graphical representation of coupling resistance and Identification of "lack of contact of coil with core" defect.
- Identifying the slot where the problem exists.
- Timely detection can enable corrective actions, which may otherwise lead to slot pd and insulation corrosion.

2.9 DYNAMIC MECHANICAL RESPONSE OF ENDWINDING TEST

The operational condition and stresses on the endwindings may loosen the ties and blocks and may cause the coils to vibrate or move. The natural frequency of endwindings should not be matching with the system's natural frequency, which may otherwise cause high amplitude vibrations due to resonance, increasing stresses on the machine. This test is thus conducted to identify the natural frequency of endwindings. The response of the end winding to the tap of a hammer will be recorded using an accelerometer pickup and analyzed to characterize the relevant end winding resonant properties.

Benefits:

- Identifying natural frequency of endwindings
- Suggesting corrective actions to hold endwinding in place
- Prevention of resonant condition.

2.10 STATOR WINDING RESISTANCE AND IMPEDANCE TEST

The stator winding resistance and impedance is measured to check for unbalance.

2.11 DC LEAKAGE CURRENT TEST

DC Leakage current is an hipot test conducted to assess whether the insulation is capable of withstanding the applied voltage. The test is ideally not recommended since it stresses the insulation. The maximum test voltage is mutually decided by client and Rotary. Machine is applied the test voltage gradually in steps ad the leakage current through insulation is measured.

2.12 RECURRENT SURGE OSCILLOGRAPH TEST

A fast fronted step voltage impulse (12 V) is repeatedly applied using a Recurrent Surge Oscillograph (R.S.O.) to the rotor winding at one of the leads and the terminal voltage waveform, consisting of reflections from rotor windings, is examined at the other lead. The process is repeated after interchanging the leads and the two waveforms are superimposed to check for rotor winding abnormalities like shorted turns, earth faults, interturn faults or rotor high resistance areas. The method is largely suited for 2 pole machines.

Benefits:

- Effective detection of rotor winding interturn shorts or high resistance joints

2.13 ROTOR WINDING RESISTANCE AND IMPEDANCE TEST

The rotor winding resistance and impedance is measured to check for unbalance, high resistance joints, open/short conditions.

2.14 TEST ON EXCITER AND PMG MACHINE

The following tests are conducted on exciter armature/field windings & PMG stator/rotor windings.

a) Winding resistance and impedance
b) IR and PI at low voltages

2.15 MISCELLANOUS TESTS

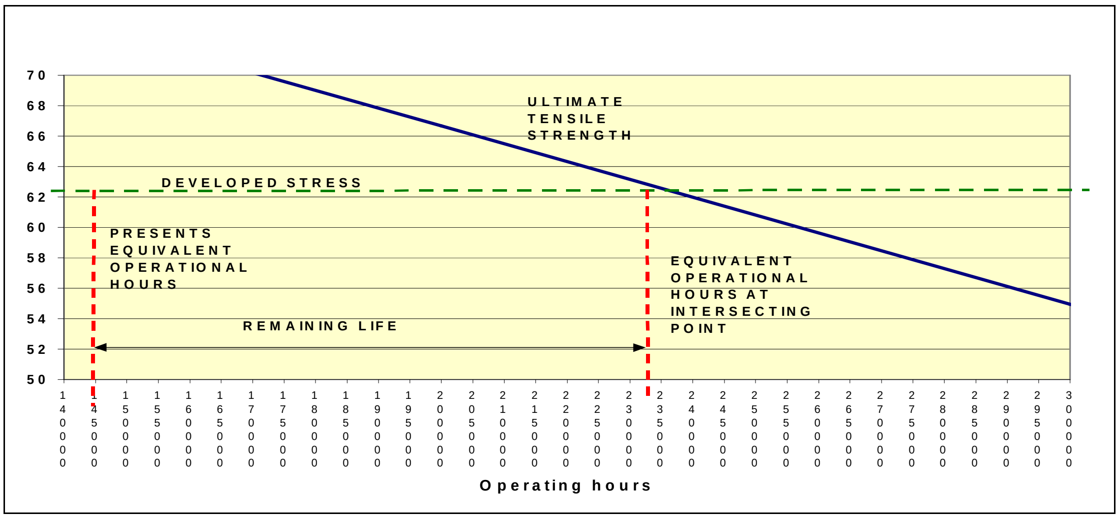
It includes:

a) RTD/Thermocouple Integrity checks
b) Diode checks

3.0 STRESS ANALYSIS – SCOPE OF WORK:

During operation, an electrical rotating machine is subjected to thermal, electrical, mechanical and ambient stress either singly or in combination, ultimately resulting in aging of insulation. The tensile curve determined from operational data and critical stress values are assumed for the particular class of insulation. The tensile curve is corrected based on the diagnostic tests, while critical stress levels are assumed. This helps in remnant life estimation with enhanced accuracy.

The next accuracy stage is to determine the actual stresses within the machine. These stresses can be evaluated using finite element techniques. The data regarding geometry of the coil, materials used, operating temperatures, arrangement of blocks and ties etc are collected by Rotary engineer. These are later modeled using FEM software that calculates the Von-Mises stresses. From the knowledge of the operating stress, machine health and aging extent, a weak Link in the insulation can be identified. Thus, the life can be calculated with highest accuracy.



PRE-REQUISITES FOR RESIDUAL LIFE ASSESSMENT:

1. The machine stator terminals should be disconnected from the main bus bars.
2. Rotor should be taken out and terminals should be made available.

TIME REQUIREMENT:

1. Time involved conducting the diagnostic tests required for RLA – Four working days.
2. Time involved submitting final report – 10 working days after completion of testing.