CHAPTER 3

CONDITION ASSESSMENT METHODS ON HIGH VOLTAGE ROTATING MACHINERY

3.1 INTRODUCTION

Stator insulation failure occurring during the normal operating condition can result in a catastrophic failure which in turn leads to forced outage (Sang Bin Lee et al. 2005). It is really a major problem for the manufacturer and the power utilities, to avoid the outages which cause a significant revenue loss due to the overhaul and renewal process. In this context, there is a mandatory need to do quality assessment on stator insulation. From the literature review, it is evident that notable amount of determined attempt has been put forth for finding the root cause for the insulation degradation and failure in the stator. Moreover, it emphasizes the need for condition assessment (Siddique et al. 2005) (Montanari et al. 2016) and its techniques to determine the status of the stator winding insulation systems. The condition assessment methods and maintenance will increase the reliability of the machine which decreases the probability of unplanned outage.

3.2 IMPORTANCE OF DIAGNOSTIC STUDIES ON INSULATION SYSTEM

Insulation is the weakest but vital part in a rotating electrical machine. It is termed as the heart of the machine. It becomes the important single parameter influencing the reliability of the rotating machine (Lenko et
Diagnostic studies of insulation systems play a major role in life prediction and extension programmes. Diagnostic studies can access the condition of the insulation i.e. whether the machine can run safely till the next maintenance overhaul. These studies become a reference for building up a systematic data when the diagnostic studies are repeated in near future. The data will assist in tracking the rate of deterioration and in turn the remaining life.

The factors influencing occurrence and rate of deterioration are:

i. Levels of temperature, voltages and mechanical stresses
ii. Operating environment.
iii. Type of insulation systems and materials.
iv. Quality of manufacture and assembly
v. Frequency of Maintenance and its quality.
vi. Random events such as mal-operation, surges and presence of foreign objects.

3.3 CONDITION ASSESSMENT APPROACH

The ultimate aim of the condition assessment on insulation systems is to assess of the present physical state or condition and its soundness. This could be achieved with the help of diagnostic measurements (Kang et al. 2007). The Common Failures in the electrical rotating machines include delamination of insulation, erosion of anti-corona paint, Coil damage, due to slot PD and loose blocks between adjacent coils (Stone & Warren 2006). The flowchart for condition assessment approach is presented in the Figure 3.1.
Figure 3.1 Flowchart for Condition Assessment Approach

The condition assessment of high voltage apparatus includes the following:

i. Planned inspection
ii. Testing
iii. Trending
iv. Analysing
v. Determining or assessing its health
vi. Inputs for maintenance actions

3.3.1 Benefits of Condition Assessment

The benefits of the condition assessment techniques on insulation systems of HV rotating machinery include the following:
i. Life extension

ii. Avoids catastrophic failures

iii. Reduces downtime

iv. Reduces maintenance cost

v. Enables budgetary decision making

vi. Increasing information on assets

vii. Safety environment

3.4 DIAGNOSTIC TESTS FOR STATOR INSULATION MONITORING

Stator windings are subjected to diagnostic testing to ascertain the quality of the insulation. It has become a well known fact, after the research made on a good number of machines for a decade, that no single test is sufficient to identify the problems. The most commonly conducted diagnostic tests (Kaufhold et al. 2002) on stator windings are detailed in Table 3.1. They convey the exceptional physical characteristics of stator insulation condition. Each test is very essential and effective to diagnose the definite types of insulation problems.

The common reason for doing testing and condition monitoring is for determining the winding condition and estimating the expected remaining useful life of a winding. Further, the diagnostic testing and monitoring is used to determine the risk of failure of machines on a comparative basis in a plant consisting of a more number of generators and motors. This can be combined with the repair cost and the impact of in-service failure on plant production to prioritize which machines must be maintained.
Table 3.1 Stator based Tests conducted on HV Generators and Motors

<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Resistance (IR) and Polarization Index (PI)</td>
<td>Detects moisture absorption and cleanliness of the winding</td>
</tr>
<tr>
<td>Capacitance Test</td>
<td>Indicates thermal deterioration, absorption of moisture, and contamination in end winding.</td>
</tr>
<tr>
<td>Tan Delta / Power Factor</td>
<td>Evaluation of dielectric losses and homogeneity of the winding insulation</td>
</tr>
<tr>
<td>Winding Resistance</td>
<td>Detects poor connections and conductor shorts</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>Detects insulation weakness and possibility of warning of breakdown due to faults</td>
</tr>
<tr>
<td>Partial Discharge</td>
<td>Evaluation of the quality of the insulation based on the severity of internal discharges</td>
</tr>
</tbody>
</table>

3.5 CAPACITANCE AND DISSIPATION FACTOR TEST

The dissipation factor test also referred as Tan Delta Test or Loss Angle Test is a routine test used to measure the quality and homogeneity of stator bars and coils. Dissipation factor testing is aimed to determine the dielectric loss in groundwall insulation. Power factor is the cotangent of the loss angle termed as delta whereas dissipation factor normally denotes the tangent. The tangent and cotangent values almost remain the same at low values of loss angle. If the dielectric loss in an insulating medium is larger, it implies that there will be a higher dissipation factor. Flaws such as voids and delamination in an insulation system result in PD which results in dielectric loss. Thus, dissipation factor testing and monitoring may be employed to identify the presence of void content within the insulation material / medium (Farahani et al. 2007).
3.5.1 Equivalent Circuit of an Insulation System

The occurrence of dielectric loss is a property of any insulating material. To be precise, in the ideal case, the winding insulation acts like a capacitor. It will store the energy. In actual practice, the material cast-off for the groundwall insulation normally gets heated up due to ageing and the presence of impurities which provide the conducting path for the flow of current. Therefore, a large leakage current flow involves resistive component, and hence winding insulation dissipates energy. In addition, the good condition of the insulation system can be revealed by the ratio of resistive to capacitive component. This ratio is normally termed as $\tan \delta$ or tan delta.

![Figure 3.2 Equivalent Circuit of an Insulation System](image1)

![Figure 3.3 Vector representation of insulation equivalent model](image2)
In view of the above fact, the electrical equivalent of the winding insulation can be modelled as a capacitor (C) and a resistor (R) connected in parallel (Yang et al. 2007) as shown in Figure 3.2. The vector diagram is depicted in Figure 3.3 when it is subjected to the applied voltage. The resultant leakage current (I), is the vector sum of capacitive current (I_C) and resistive current (I_R) with respect to the applied voltage (V).

In the vector representation shown above, the test voltage (V) and the conductive current due to flow of leakage current in the resistive component (I_R) is taken along X - axis. The capacitive component of leakage current (I_C) leads system voltage by exactly 90°. It will be taken on Y-axis. At this instant, total leakage current I (I_R + I_C) makes an angle δ with Y - axis. From the vector diagram, it is very clear that the ratio of I_R to I_C is termed as tan δ or tan delta or dissipation factor. In other words, the Dissipation Factor (DF) is well-defined as the tangent of the angle (δ) between I_C and I. If the stator insulation system is healthy, the leakage current is almost capacitive in nature.

\[
Dissipation Factor = \tan \delta = \frac{I_R}{I_C}
\]  

(3.1)

The tan δ value can be expressed in terms of impedances offered by the parallel combination of R and C as

\[
\tan \delta = \frac{X}{R} = \frac{1}{\omega CR} = \frac{1}{2\pi f CR}
\]

(3.2)

where, X is the capacitive reactance and f is the frequency of the supply.

The cosine of the angle between I and I_R is denoted as power factor (PF). Smaller angles of δ denote the similar value of DF and PF. These two parameters are utilized in the industry as a sign of dielectric losses in the insulation systems and the materials in which they are made upon.
\[ \text{Power Factor} = \cos (90 - \delta) = \frac{i_R}{i} \] 

(3.3)

### 3.5.2 Method of Tan Delta Test

The DF is a valuable characteristic parameter which provides essential information about the condition of the insulation. The condition of the insulation system can be determined with the utility of tan \( \delta \) values. The capacitance and dissipation factor of the winding will be done with transformer ratio-arm bridge. Measurements are carried out in step increments that will not exceed 0.2\( V_L \) (Farahani et al. 2010). The test voltage is applied across the section of the stator winding whose insulation is to be tested. Initially, the stator winding should be detached from the contacts on both impartial sides. During the testing of one phase section of the stator winding, the remaining phase sections are shorted and grounded to the stator frame. The dissipation factor is normally expressed in percentage. This dissipation factor testing is governed by IEEE 286 and IEC 60034-27-3 standards. This test is highly pertinent to form-wound stator windings only. This testing method can definitely attain 0.01% accuracy.

A DF measurement yields valuable data pertaining to the condition of the winding insulation. Usually, the measurements are trended after a reasonable period and even compared between phases under identical test conditions. The DF test itself is sufficient to indicate the implicit dielectric losses and the overall condition of the stator winding insulation system rather than PF.

The DF values get influenced by three important factors viz thermal deterioration, contamination and moisture absorption. The reasons for the above statement are given below.
i. The dielectric losses increase with the effect of thermal deterioration. This will cause oxidation which increases the repetitive movement of polar molecules.

ii. Conduction current is increased due to cracking or detaching of the insulation initiated by thermal deterioration with the added effect of contamination.

The measurements made in this study provide the indications of the condition of a winding. Thus DF and C are accountable for indication of the total insulation quality in all the three individual phases. The progression of aging in the insulation system creates change in the DF and C measurements. It has been learnt from the experimental practices that the insulation aging mechanism decreases the value of R and consequently an increase in the DF value. The condition of the insulation ultimately depends on the variation in C.

The following circumstances point clearly about the variation in the DF and C measurements (Bhumiwat 2010) due to various insulation aging process and its reflections.

i. The trend representing a decrease in C and increase in DF during experimental measurements, is a firm indication of thermal deterioration.

ii. The trend of promising increase in C and DF indicates the losses in the insulation surface or majority contamination or humidity effect.

iii. The trend of increase in DF indicates the damage within the insulation due to partial discharge events.

From the literature studies, it has been specified that worsening of the insulation condition exhibits a variation in the DF value. There is a slight variation in DF at the initial level, has a tendency to increase when the
insulation life is heading towards the ending level. Deterioration in insulation increases capacitance, which in turn leads to an increase in electrical stress and added deterioration.

3.5.3 Result of Tan Delta Test

If the insulation system is perfect in HV rotating machines, the variation in dissipation factor is very small when the applied voltage increases in steps. But if the insulation is not appropriate, the value of dissipation factor increases in the greater range of applied voltage. In this case, the measured tan δ value is proportional to the volume of voids present within the insulation system, which in turn increases with aging of the apparatus (Farahani et al. 2004). In addition to the volume of voids, the creation of delamination occurs due to various stresses acting in the insulation system which also increase the value of dissipation factor. Figure 3.4 shows the variation of tan δ value with respect to the applied test voltage for the perfect and degraded insulation systems.

![Figure 3.4 Result of tan delta test](image)
3.6 PARTIAL DISCHARGE TEST

It has been a well known fact that failures in motor and generator stator windings are mainly due to Partial Discharges (PDs). By assessing the partial discharge levels of the machine winding, the deterioration can be effectively monitored (Stone & Sedding 1996). In accordance with the IEC standard, PD is defined as a localized electrical discharge (formation of a streamer) that only partially bridges the gap between the conductors under HV stress. PD usually contains acoustics, light, heat and also causes chemical reactions which cumulatively lead to premature insulation failure. Partial discharges activity is a sign of an insulation breakdown or a symptom for the insulation failure of HV assets. The presence of void, conducting particles, de-lamination and surface in-homogeneities are the reasons for the occurrence of PD (Stone & Warren 2006).

![Diagram showing defect locations in machine slots leading to PD](image)

**Figure 3.5 Defect locations in machine slots that leads to PD**
PD generally originates within voids, cracks or enclosures within a solid dielectric and conductor-dielectric interfaces. PD may occur in the boundary between dissimilar insulating materials. As per the definition, PD occurrence is restricted to only a section of the insulation. The PD is very destructive for the dielectric medium as well the HV apparatus. The severity of the discharges shortens the useful life which in turn decides the remaining life of insulation. PD can ensue at the junction of two different dielectric materials, in the conductor nearby regions and in certain points or only within the void region, as depicted in the Figure 3.5. These defects may arise in any of the situations like built-up of insulation, installation process or normal operation of the HV apparatus (Illias et al. 2011).

3.6.1 Partial Discharge Equivalent Circuit

![Figure 3.6. Insulation specimen with void inside and its equivalent model](image)

Solid insulation contains imperfections or a small void which leads to PD can be depicted with an equivalent circuit as shown in Figure 3.6. From the equivalent circuit model, $C_c$ relates to capacitance of the void or cavity present in the insulation; $C_b$ denotes the capacitance of the insulation in series with void capacitance $C_c$ and $C_a$ indicates the capacitance of healthy portion of the insulation seems to be parallel to the void. During the normal operating condition, an increase in applied voltage will lead to electric discharge when critical value is reached across the void capacitance (Nenad Kartalovi 2011). The gas filled voids have low breakdown strength than the
remaining portion of the solid insulation. It implies that there exists high electric field across the void. PD originated inside the gas-filled voids within the dielectric cause small current flow which will be reduced by the voltage divider network formed by $C_b$ and $C_c$, in parallel with the healthy part capacitance $C_a$.

When the voltage attains the critical value of $V+$, discharge inside the void takes place (Maheswari et al. 2012). This phenomenon is a repeated event that occurs several times during the application of the voltage in each cycle. The duration of the discharge persists for nano-seconds to a micro-second when compared with the time period of the applied voltage. The discharge mechanism is clearly explained with the aid of the voltage and current waveforms as shown in the Figure 3.7.

![Figure 3.7. Partial discharge inside the void](image)

**Figure 3.7. Partial discharge inside the void**
3.6.2 Discharge Detection and Measuring Systems

PD measurement is regularly done to evaluate the dielectric quality of the insulation system of HV rotating machines (Stone 2005). These measurements have advantages to categorize the winding insulation condition (healthy or faulty) of the stator used for testing. Such conditional testing provides appropriate direction to carry out suitable maintenance and renovation methods to be planned and organized well in advance. The effects of PD in stator winding can be found out based upon the effective monitoring of its severity levels. Wide assistance on offline PD test systems is specified in IEEE 1434 and IEC 60034-27. In the present study, offline PD detecting scheme is utilized because the adoption of the online PD diagnosis is very critical (Heesang Shin 2011). Further, it requires additional capacitive couplers for detection and the effective technique for elimination of noise present in the PD signal (Zhao and Liu 2009).

![PD offline detection circuit](image)

**Figure 3.8 PD offline detection circuit**

Figure 3.8 shows the test system for measuring the PD intensity in pC in compliance with IEC 60270 (Reid et al. 2011). After withdrawal and separation of the generator windings, a coupling capacitor (C_k) arrangement is
made in close vicinity to the power leads which are momentarily coupled to the phase to be verified. The offline PD testing is carried out for particular test conditions say, stress levels under different voltages. The winding is energized using a conventional or resonant transformer which could be free from internal discharges.

A resonant filter (Z) is used to avoid any pulses emerging from the capacitance offered by the windings and bushings in the transformer. The coupling capacitor which offers low inductance value is connected to the power leads of the generator for detecting the PD pulses. The detected PD signal and the phase value of the voltage are transferred to the Measuring Instrument (MI) through the Coaxial Cable (CC). The measuring system performs quasi-integration with frequency range from 100 to 400 kilo Hertz. The unit usually utilized to measure the PD is pC which denotes the area under the PD pulse. The flow of charge at the defect will cause an equivalent charge transfer within the apparatus will be reflected in the external circuit (Lemke 2012). This can be modelled by the Equation (3.4) stated below

\[ q = C_b \Delta V_c \]  \hspace{1cm} (3.4)

where, \( \Delta V_c \) is the voltage across the void.

This PD test gains the following advantages for the power utilities:

i. Prompt detection of insulation impairment

ii. Improved ease of use with better utilization of the enduring service life of the HV insulation without much functional risk.

iii. Prevents high-cost substantial destruction

iv. Preparation of maintenance based on existing insulation state.
3.7 **IR, PI and LEAKAGE CURRENT TEST**

Due to the machine function and a host of other components, the winding insulation is subjected to moisture, oil, dirt and electrostatic stress during the normal operating condition of the rotating machinery. Therefore, aging and deterioration occurs in the insulation. In order to avoid catastrophic failure of machines, the health condition of the insulation has to be examined frequently.

The measurement of Insulation Resistance (IR) is simple and regularly used diagnostic test for stator windings. This test is used to find the presence of pollution and contamination issues only. It is carried out by applying recommended DC voltage across the conductors and the core of the stator for 1 minute duration. The leakage current is measured from which resistance of the electrical insulation can be determined. The IR at time $t$ is given in the Equation(3.5) by Ohms law as

$$R_t = \frac{V}{I_t}$$

where, $V$ is the applied voltage and $I_t$ is the total current. In the ideal case, the measured resistance value should be infinite. The reason is, in spite of everything, the ground wall insulation is provided to restrict the flow of current between the copper conductors and the stator core. In actual practice, the IR value is not extremely high. If the IR value is low, there is an increase in the dielectric losses (Sang Bin Lee et al. 2006) which confirms an issue in the insulation. i.e it contains moisture and dirt.

The Polarization Index (PI) is obtained by recording the value of insulation resistance measured just after 60 seconds ($R_1$) and the same measured at 10 minutes ($R_{10}$) after the application of the voltage. Therefore, the PI is the ratio given by the Equation(3.6) as
\[ PI = \frac{R_{10}}{R_1} \] (3.6)

Low PI value indicates that the stator winding may be contaminated or wet. The IR/PI tests applicable for the rotating machinery are guided by the IEEE 43 (Stone 2013). There is no specific IEC standard for these tests until now, but such circumstances will be transformed during the forthcoming publication of IEC 60034-27-4. The test results of these tests will give an indication to undertake the added diagnostic test with the application of the high voltages. It is appraised that nearly 80% of all maintenance actions in the industry are connected to testing the insulation of machines. Both tests are carried out simultaneously in the same instrument.

After the test is over; the winding has to be “discharged”. The insulation acts as a dielectric forming a capacitor between the winding and the earth. This can store charge and can deliver a shock if not discharged. Discharging can be done by connecting to the ground.

3.8 RESULTS AND DISCUSSIONS

The diagnostic test has been carried out on generator stators of 11kV and 6.6kV rated voltage capacity in order to access the state and condition of their insulation system. The data obtained from these tests have been presented and interpretation of the same are furnished in the following section for generator stators of 11kV and 6.6kV rated voltage capacity each. The test parameters considered for assessment of insulation condition are

i. Insulation Resistance
ii. Polarisation Index
iii. Leakage Current
iv. Tan Delta
v. Partial Discharge Magnitude.
3.8.1 Test Results and its Inferences

The results of IR and PI measurements obtained on the 3-phases of the 6.6kV rating generator stator winding, having class F insulation at the test voltage of 2.5 kV DC are presented in Table 3.2.

Table 3.2 IR and PI Test results of 6.6kV machine

<table>
<thead>
<tr>
<th>Phase</th>
<th>Windings To Ground</th>
<th>Insulation Resistance (GΩ)</th>
<th>PI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R₁</td>
<td>R₁₀</td>
</tr>
<tr>
<td>R</td>
<td>Y &amp; B</td>
<td>9.28</td>
<td>48.5</td>
</tr>
<tr>
<td>Y</td>
<td>B &amp; R</td>
<td>9.35</td>
<td>53.6</td>
</tr>
<tr>
<td>B</td>
<td>R &amp; Y</td>
<td>9.10</td>
<td>52.0</td>
</tr>
</tbody>
</table>

From the test data shown in Table 3.2, it is inferred that the IR and PI values obtained on all the 3-phase sections of the windings are in the acceptable level. According to the standard, the PI value should be higher than 2.0 which implies that the insulation is healthy, clean and dry. Since the IR and PI measurements provide the information about the pollution and contamination issues, the main focus of this research work is contributed towards the measurement of non-destructive characteristic parameters like leakage current, capacitance, PD and dissipation factor (tan δ) as a function of the applied test voltage. These characteristic parameters are investigated to reveal the insulation status of high voltage rotating machines.

The dissipation factor signifies the defects and total dielectric losses occur in the insulation. PD Data acquired through Testing can be responsible for acute facts on the insulation quality and its influence on health of the apparatus under test. The monitoring of PD plays a vital role which helps to do intentional resolutions for repair of the apparatus since PD event...
often occurs well in advance of insulation failure. The results of Tan δ, Capacitance and PD measurements obtained on the 3-phases of the 6.6kV rated generator stator winding at the recommended test voltages are together presented in Table 3.3.

Table 3.3 Tan δ, Capacitance and PD Test results of 6.6kV machine

<table>
<thead>
<tr>
<th>Phase</th>
<th>Winding to Ground</th>
<th>Test Voltage (V)</th>
<th>Leakage Current (mA)</th>
<th>Capacitance (nF)</th>
<th>Tan δ Value (%)</th>
<th>PD value (pC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Y &amp; B</td>
<td>1320</td>
<td>46.70</td>
<td>105.7</td>
<td>1.010</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2640</td>
<td>92.00</td>
<td>106.1</td>
<td>1.422</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3960</td>
<td>140.10</td>
<td>107.4</td>
<td>2.244</td>
<td>1200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5280</td>
<td>183.80</td>
<td>108.6</td>
<td>2.773</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6600</td>
<td>238.10</td>
<td>109.9</td>
<td>3.096</td>
<td>3400</td>
</tr>
<tr>
<td>Y</td>
<td>B &amp; R</td>
<td>1320</td>
<td>45.91</td>
<td>106.3</td>
<td>0.998</td>
<td>250</td>
</tr>
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<td></td>
<td></td>
<td>2640</td>
<td>92.48</td>
<td>106.7</td>
<td>1.375</td>
<td>600</td>
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<td></td>
<td></td>
<td>3960</td>
<td>139.30</td>
<td>107.9</td>
<td>2.173</td>
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<td>109.3</td>
<td>2.763</td>
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<td></td>
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<td>6600</td>
<td>239.80</td>
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<td>B</td>
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<td>1.006</td>
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<td>2.792</td>
<td>2500</td>
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<td></td>
<td></td>
<td>6600</td>
<td>237.60</td>
<td>109.7</td>
<td>3.149</td>
<td>3800</td>
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</tbody>
</table>

From the test data shown in Table 3.3, it is inferred that the tan delta values obtained on all the 3-phases of the windings are in the low level which indicate that the dielectric losses in the stator winding are quite low. Further, the magnitude of the PD is lower than the maximum permissible value as suggested in the international standard in practice. It is well known
that PD activity is deleterious to the insulation and causes chemical and mechanical damages to the surrounding medium. In overall conclusion, these tests state that the insulation condition of the stator winding is in healthy state so that the deterioration of the insulation is minimum at the normal operating voltage.

It is of great importance that the aging condition of insulation can be evaluated based on non-destructive characteristic parameters like PD and loss factor (tan δ) measurements. The results of Tan δ, Capacitance and PD measurements obtained on the 3-phases of the 11kV rating generator stator winding at the recommended test voltages are together presented in Table 3.4.

**Table 3.4 Tan δ, Capacitance and PD Test results of 11kV machine**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Winding to Ground</th>
<th>Test Voltage (V)</th>
<th>Leakage Current (mA)</th>
<th>Capacitance (nF)</th>
<th>Tan δ Value (%)</th>
<th>PD value (pC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Y &amp; B</td>
<td>2200</td>
<td>82.7</td>
<td>114.3</td>
<td>1.707</td>
<td>600</td>
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<td></td>
<td></td>
<td>4400</td>
<td>163.9</td>
<td>114.4</td>
<td>1.745</td>
<td>1100</td>
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<td></td>
<td></td>
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<td>247.3</td>
<td>114.8</td>
<td>1.992</td>
<td>2600</td>
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<td></td>
<td></td>
<td>8800</td>
<td>329.7</td>
<td>115.4</td>
<td>2.352</td>
<td>3500</td>
</tr>
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<td></td>
<td></td>
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<td>376.4</td>
<td>115.7</td>
<td>2.507</td>
<td>5500</td>
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<td>B &amp; R</td>
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<td>750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4400</td>
<td>164.9</td>
<td>115.1</td>
<td>1.826</td>
<td>1200</td>
</tr>
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<td></td>
<td>6600</td>
<td>248.5</td>
<td>115.3</td>
<td>2.071</td>
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<td>8800</td>
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</tr>
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<td></td>
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<td>116.3</td>
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<td>5600</td>
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<td>2500</td>
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<td>11000</td>
<td>372.9</td>
<td>114.8</td>
<td>2.515</td>
<td>5800</td>
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</table>
From the test data shown in Table 3.4, it is concluded that the tan delta values obtained on all the 3-phase sections of the windings are in the low level. Moreover, the magnitude of the PD is lower than the maximum acceptable value as recommended. These tests indicate that the insulation condition of the stator winding is healthy.

3.9 SUMMARY

This chapter described the significant tests like Partial Discharge, Dissipation Factor, Capacitance, Insulation Resistance and Polarization Index for condition assessment of the stator winding insulation. Since most of the tests discussed are used to provide the data on the prescribed testing procedures. As a result, measuring winding condition alone is insufficient to assess its present condition or predict the remaining life of the insulation. Therefore, expert intervention and trending process to correlate results and to perform an economic evaluation is needed.

In this context, the computational intelligent techniques were recognized that enable the construction of “expert system”. It attempts to renovate the reasoning methods that an expert uses to understand test outcomes, as well as other appropriate informations. If the proposed system is effective, an expert system creates chance for the non-experts to transform measured data into valuable information which helps to determine the status of the insulation condition with better accuracy as like that of an expert.