Conventional Electrical Testing on Stator Windings

The goal of this document is to give an overview about the most common electrical testing methods, what they can detect and their limitations. These tests are common practice for most test engineers all over the world and they are mentioned in international standards. In this document, the following four test methods will be discussed:

> DC insulation resistance measurement
> Polarization index (PI) measurement
> High voltage withstand test
> Winding resistance measurement

DC insulation resistance measurement

To get a rough overview about the insulation condition, the DC insulation resistance measurement is performed. Heavy insulation problems can be detected with this simple test. Additionally, the test allows for an estimation of the winding surface condition by comparing previous measurement data.

The insulation resistance is the quotient of applied direct voltage across the insulation divided by total resultant current at a given time:

$$\mathbf{IR: U_{test} / IT_{(total.)}}$$

The total resultant current (IT) can be modelled as the sum of these four different currents:

> Surface leakage (IL)
> Geometric capacitance (IC)
> Conductance (IG)
> Absorption (IA)

Polarization Index (PI)

The Polarization index (PI) is derived from the insulation resistance measurement and is a simple value that gives a rough indication of the insulation condition. It is defined as the ratio of the 10min resistance value to the 1min resistance value.

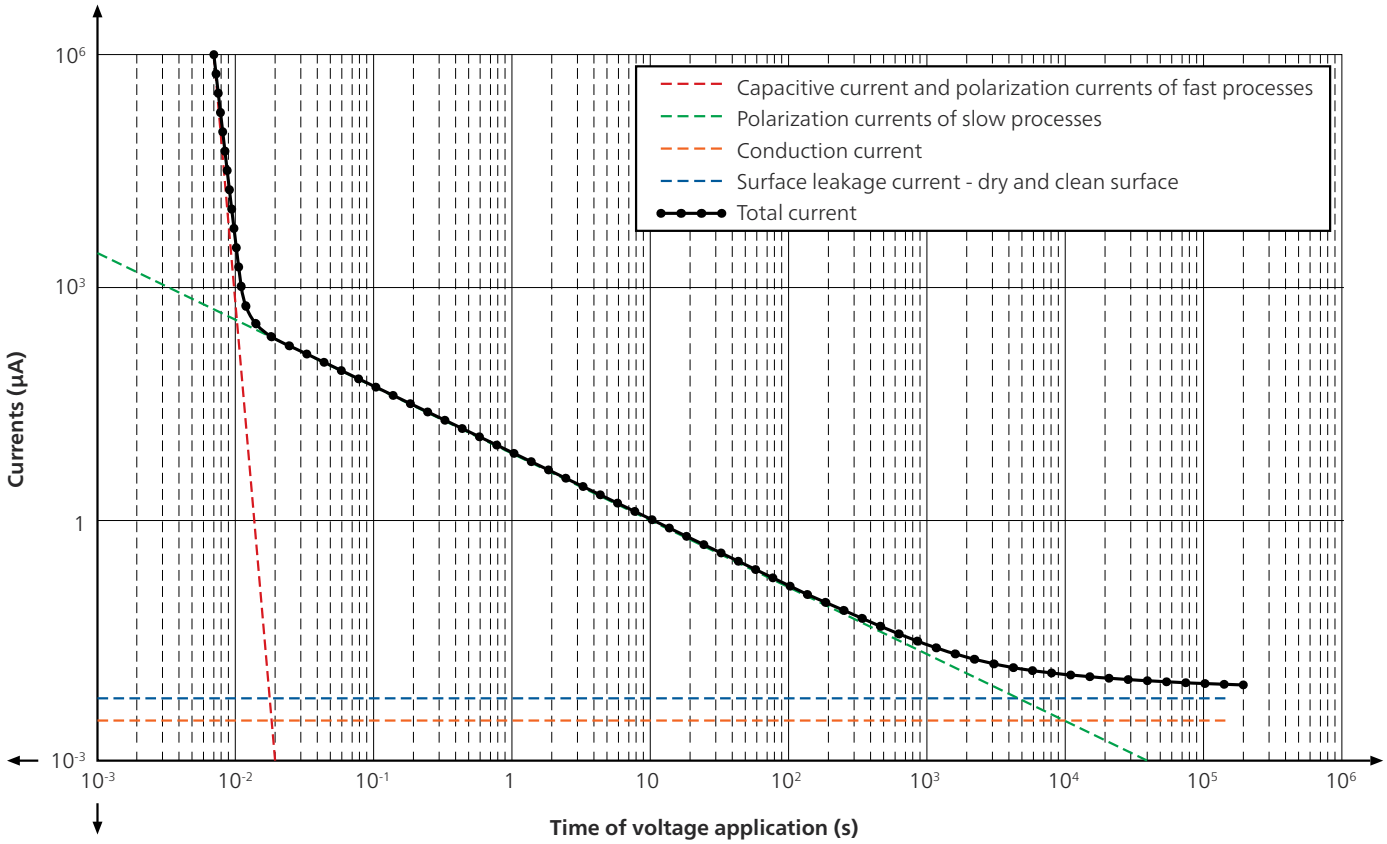

Figure 1: Relative current over time of voltage application. Typical behavior for a synthetic resin based dry and clean winding (the scales are logarithmic); Source: IEC 60034-27-4:2018

Advantage of DC insulation resistance measurement:

> Easy to setup
> Detection of large defects possible

Disadvantage of DC insulation resistance measurement:

> Long test duration
> DC measurement: Voltage distribution not the same as during operation
> No single defects are detectable

Recommended limits exist for the PI value depending on the thermal class of the insulation system. This does not eliminate the responsibility to know the insulation system and its typical behavior. As for every test, a phase-to-phase comparison (if possible) or a comparison of the measurement results over time are the most powerful methods for determining insulation condition.

Voltage withstand test (AC)

The voltage withstand test is an AC test with a simple pass/fail criteria. The test is performed with high AC voltage usually higher than rated voltage for a certain time. If the device under test withstands the voltage during this period, the test is passed.

The goal of the test is to trigger possible weak spots with the same electrical condition as during normal operation (AC voltage). These weak spots are not always detectable with other tests. If the tests provoke a breakdown, the winding portion must be repaired afterwards before going back into operation.

Although this is a potentially damaging test, it is a very powerful method for identifying weak spots. As the energy during testing is comparably low compared to the energy during operation, the damage caused during testing is only local. Since the test is performed during maintenance, additional standstill times due to a triggered failure can be avoided.

DC winding/contact resistance measurement

A DC winding resistance measurement is performed in the factory or during the commissioning of a machine to check for the calculated losses and if any soldering or contact problems are present. Winding resistance tests are also done during routine measurements.

Advantage of the voltage withstand test (AC):

> Easy assessment (Yes/No criteria)
> Voltage distribution in the insulation like during operation
> "Hidden spots" are detected

Disadvantage of the voltage withstand test (AC):

> Potentially destructive test
> Medium setup effort

It is a powerful tool to detect contact problems in windings, pole connectors or pole windings. For example, contact problems due to bad soldering contacts are an issue especially in older machines.

A DC current is injected into the stator winding and the voltage drop is measurement. Due to the high inductivity of the stator winding, the current shall be recorded after it is stabilized. Winding resistance is calculated by $\mathbf{R_M = U_{Test} / I_{Test}}$. Due to low resistivity of the windings (µΩ range), the 4-wire measurement setup as shown in Figure 2 must be applied. Otherwise, the contact resistance would falsify the measurement. The resistance value shall be temperature (as per applicable IEC/IEEE standard) corrected in order to compare results.

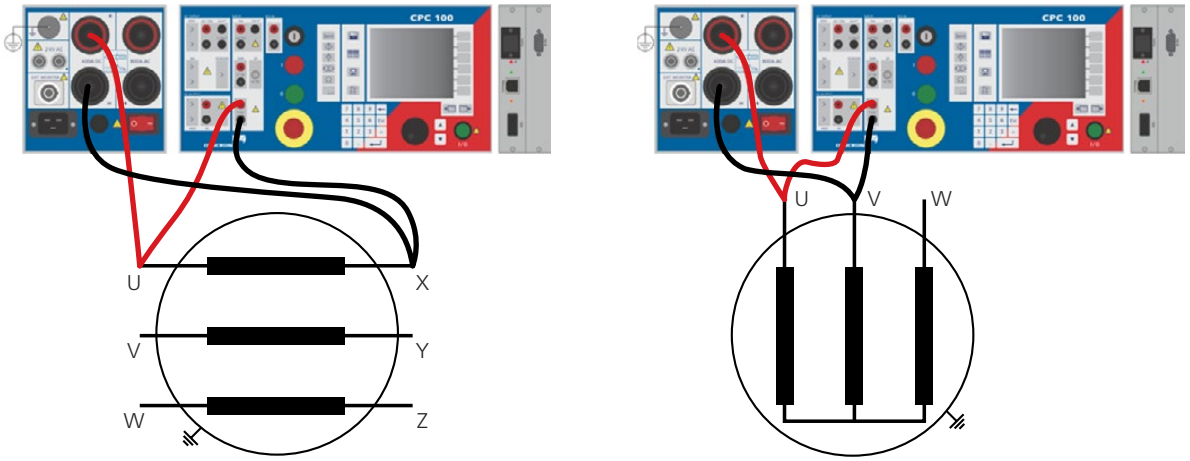

Figure 2: Four wire DC winding resistance measurement on stator winding with open star point (left) and closed star point (right).