# Insulation Resistance and Polarization Index Test of Generator & Motor

*The IR & IP test are an excellent means of ascertaining winding conditions that are contaminated or soaked with moisture. The tests are also good for detecting major flaws where the insulation is cracked or has been cut through. They are used to check for thermal deterioration in thermo-plastic insulation systems too. So it is advised in order to keep the windings in good conditions, to keep them clean from dust, oil, lubricants etc. absorption of moisture becomes dangerous when the machine is idle, because condensation on electrical machines occurs when the surface temperature of the windings must be at least $5^0$C higher than the ambient temperature. And for this, there are space heaters that automatically start with a time delay when the machine is switched off.*

*- Mayadhar Swain*

The insulation resistance and polarization index tests of an electric motor or generator has been regarded as a useful tool in evaluating its windings for build up of dirt or moisture., deterioration of the insulation, fitness for high potential tests and suitability for further operation. IEEE Standard No. 43-2000 covers the producer for determining Insulation Resistance and Polarization Index in detail. However, this paper provides a summarized guide for carrying out insulation resistance and polarization index test.

Insulation system prevents winding faults. The stator winding is generally designed to achieve a satisfactory service life of typically 20 to 40 years. But it all depends on the operating condition. Practically insulation is in the form of organic compound that contains water as a part of chemical make-up. Excessive temperature rise dehydrates and oxidizes and makes the insulation brittle. Subsequently it disintegrates under vibration and shock.

As the life of a generator or motor mainly depends on the insulation, the condition of the insulation should be ascertained at a regular interval. Insulation Resistance (IR) and Polarization Index (PI) are two universally accepted diagnostic tests for insulation tests. These are in use for more than 75 years.

The IR test measures the resistance of the electrical insulation between the copper conductors and the core of the stator or rotor. Ideally the value of this resistance is infinite since the purpose of the insulation is to block current flow between the copper and the core. But in practice, it is not possible. However, the resistance should have a high value to avoid any appreciable leakage current. Lower value of IR indicates that the insulation has been deteriorated.

PI is a variation of the IR test. It is the ratio of IR measured after voltage has been applied for 10 minutes ($R_{10}$) to the IR measured after one minute ($R_1$), i.e.

$$PI = \frac{R_{10}}{R_1}$$

Low value of PI indicates that the winding may have been contaminated with oil, dirt etc or absorbed moistures. In the test, a relatively high DC voltage is applied between the copper conductor and the stator or rotor core usually between the winding and ground as the machine core & body are grounded). By applying Ohm's law, IR ($R_t$) at time t is then,

$$R_1 = \frac{V}{I_t}$$

V is the DC Voltage applied and It is the current flowing in the circuit.

The characteristics of the insulation are such that the current. It is not constant and it varies with time. The purpose of measuring PI can be understood by knowing the flow of the different currents in the flow of different currents in the insulator. There are four currents in the insulator. There are four currents that may flow when a DC voltage is applied to the winding. These four are:

Capacitive Current ($I_c$)
Conduction Current ($I_R$)
Surface leakage current ($I_L$)
Polarization current ($I_P$)

### 1. Capacitive Current

Insulator behaves as a capacitor when a DC voltage is applied to a capacitor, a high charging current first flows and then it decays exponentially. The size of the capacitor and the internal resistance of the voltage supply, typically a few hundred kilo ohms, set the currents decay. In case of generator or motor windings, the current effectively decays to zero in less than 10 seconds. Since the capacitive current contains little diagnostic information, the initial IR is measured once the capacitive current has decayed. Hence the first IR measurement has been set as one minute to ensure that this current does not distort the IR calculation.

### 2. Conduction Current

This current is due to flow of electrons between the copper and the core. This is galvanic current through ground wall. Such a current through ground wall. Such a current can flow if the ground wall has absorbed moisture, which can happen on the older thermoplastic insulation systems. The current may also flow if there are cracks, cuts or pinholes in the ground insulation and some contamination is present to allow current to flow.

This current is constant with time. With modern insulation this current usually is zero (as long as there are no cracks, cuts etc).

### 3. Surface leakage Current

This is constant DC current that flows over the surface of the insulation. It is caused by conductive contamination (oil or moisture mixed with dust, dirt, insects, chemicals etc) on the surface of the windings. This current is also constant with time.

### 4. Polarization Current

Electrical insulation is hygroscopic in nature and presence of moisture will be there either in low quantity or in excess. Water molecules are very polar. When an electric field is applied across the insulation start absorbing electrons from the hydrogen molecules causing ionization of hydrogen. In other words, the molecules constituting water align in the electric field, just as magnetic field. The energy required to align the molecules comes from the current in the DC test voltage supply. This current is called polarization current. The water becomes completely polarized when the absorption of electron from hydrogen merging with oxygen is completed. Once the molecules are all aligned, the current stops. The approximate time for complete polarization is 10 minutes. That is why the IR is measured after 10 minutes of applying voltage.

Now, the total current is the sum of all above currents, i.e.

$I_t = I_C + I_R + I_L + I_P$

As we have analysed, after one minute, $I_C$ is zero.

So $I_t$ (1 minute) = $I_R + I_L + I_P$

As we have seen that, after 10 minutes, $I_P$ is zero,

So $I_t$ (10 minute) = $I_R + I_L$

$$PI = \frac{I_R + I_L + I_P}{I_R + I_L} = R_{10}/R_1$$

### *Effect of Temperature on IR*

One may argue that by measuring argue that by measuring IR after one minute, one can diagnose the condition of the insulator. If it is less, the insulation will be considered to have been deteriorated. Unfortunately, just measuring $I_R$ has proved to be unreliable, since it is not tenable over time. The reason is that IR is strongly dependent on temperature. A $10^0$C increase in temperature can reduce IR by 5 to 10 times. When readings of temperature and insulation resistance are plotted on ordinary equally divided co-ordination, a curved characteristics is obtained. On the other hand if graph paper is used on which the insulation scale is laid out in logarithmic division, the graph becomes a straight line. Further, the effect of temperature is different for each insulation material and type of contamination. Although some temperature correction graphs and formulae are given in the IEEE-43 and some other books, they are acknowledge as being unreliable for extrapolation by more than $10^0$C. The result is

that every time IR is measured at different temperatures, one gets a completely different IR. This makes it impossible to define a scientifically acceptable IR valve over wide range of temperatures.

### *Importance of PI*

PI was developed to make interpretation less sensitive to temperature. PI is the ratio of two IR at two different times. Temperature of the winding does not rise during the test period of 10 minutes. So it is fairly assumed that both $R_{10}$ and $R_1$ are measured at same winding temperature. Then the temperature correction factor will be same for both cases and will be cancelled during the calculation of PI. Thus PI is relatively insensitive to temperature.

Further in the formula of PI, the polarization current is used as a 'yard stick' to see if the leakage and conduction currents are excessive. If these later currents are much larger than the polarization current, the ratio will be about one. It is known from the experience that, if PI is about one, leakage and conduction currents are large enough that electrical tracking will occur. Conversely, if the leakage and conduction current are low compared to polarization currents, PI will be greater than 2, and experience shows that electrical tracking problems are unlikely. Thus during test, if we see the decay in the total current or rise in the IR in the interval between 1 minute and 10 minutes, then this must be due to polarization current ( since the leakage and conduction currents are constant with time) which implies that the leakage and conduction currents are low.

## Test Method

### *1. Instrument*

IR is measured with a 'mega-ohmmeter'. Sometimes this is called Megger Tester after the name of the instrument first developed for this purpose (Megger is a trade name of AVO). Mega-ohmmeter generates and applies a regulated DC supply. It measures the flow of current and IR is directoly read on its dial. Hand driven and motorized mega-ohmmeters are available. But for constant rotation and steady DC voltage, a motorized meter is preffered. Modern mega-ohmmeter can apply voltages exceeding 10 KV, and measure resistance higher than 100GΩ

### *2. Test Voltage*

Test voltage should be well below the rated peak line-to-ground voltage of the winding as it is not a 'high potential' test. But the voltage should be high enough to find defects such as cuts though the insulation in the windings.

Guidelines for DC voltages to be applied for the test are given in Table-1.

Table – 1: Guidelines for DC Voltage to be applied for IR test

| Rated voltage (line-to-line) of the winding in volts | Test voltage (DC) in volt |
|---|---|
| <600<br>1000-2500<br>2500-5000<br>>5000 | 500<br>500-1000<br>1000-2500 |
| | 2500-5000 |

### *3. Test Procedure*

IR & PI tests shall be done simultaneously. If the winding temperature is below the dew point, the winding may be heated to dry off the moisture that has condensed on the winding. If the temperature is below the dew point, there is no way to correct the IR & PI for humidity Otherwise, the test is very simple. The procedure is as follows:

Remove all external connections to the machine and completely discharge the windings to the grounded machine frame

Apply required DC voltage between the winding and ground using a direct indicating, motor driven mega-ohmmeter.

Continue to apply the voltage for 10 minutes.

Measure the insulation resistance after 1 minute and 10 minutes. Switch off supply to the meter and completely discharge the windings to the grounded machine frame.

Calculate the polarization index by dividing the 10-minute insulation resistance by the 1-minute insulation resistance.

Note the winding temperature.

If test is carried out only on one winding of three phase equipment, then other windings should be grounded during the test.

### Interpretation of Results

1. There is no established rule or method for determining the minimum value of IR at which machine may operate without failure. However, standard values of IR have been recommended as the least value as given in Table-2.

| Table-2 Recommended minimum IR value Equipment | |
|---|---|
| | Minimum IR measured after minute at $40^{0}$C in mega ohm |
| Random wound windings manufactured before 1947 | R, min = KV+I |
| Random wound winding manufactured after 1947 | RI min = 5 |
| Form wound windings and DC Armature | Ri min = 100 |
| K.V = Rated line – to – line voltage of the machine in KV (rms) | |

2. If IR is below the above recommended value, the winding should not be subjected to high potential test or be taken to service, since failure may occur. However, if historical record indicates that a low IR value is always obtained on a particular winding, then the machine can probably be returned to service with little risk of failure.

3. Interpretation of PI value is given in Table-3.

If IR or PI is below the minimum value in a modern stator winding, it is an indication that the winding is contaminated or soaked with water.

| Table – 3 Interpretation of PI value | | |
|---|---|---|
| PI. | Condition of winding | Measures to be taken |
| <1.0 | Hazardous | Dry winding |
| 1-1.5 | Bad | Dry winding |
| 1.5-2.0 | Doubtful | Drying is recommended |
| 2.0-3.0 | Adequate | |
| 3.0-4.0 | Good | |
| >4.0 | Excellent | |

For modern form wound stators, if a very high value of IR is measured (say greater than 5GΩ) then PI is not likely to indicate anything about the winding. Thus the test may be stopped after one minute to save time.

If a high PI result is obtained on an older stator winding, then there is a possibility that the insulation has suffered thermal deterioration. This occurs because thermal deterioration fundamentally changes the nature of insulation and thus the polarization currents that flow.

In general IR & PI test are an excellent means of ascertaining winding conditions that are contaminated or soaked with moisture. The tests are also good detecting major flaws where the

insulation is cracked or has been cut through. The test can also detect thermal deterioration for form wound stators using thermoplastic insulation system.

It is seen that some testing engineers take the PI as the ratio of IR after 60 seconds to that measured after 15 seconds. This is done to save time and as explained in the theory part, it does not indicate anything. Sometimes it is known as spot test and the result is normally recommended for comparison in trend insulation.

It is advised that to keep the winding in good condition it should be cleaned off the dust, oil, lubricants etc from its surface regularly. Moisture is the main culprit for deterioration of the insulation. Absorption of moisture becomes dangerous when the machine is idle. During this period the moisture is condensed on the insulation and is absorbed by it. Condensation of moisture on electrical machines occurs when the surface temperature falls below the dew point. Therefore, during idle period the winding temperature should be kept at least $5^0$C higher than the ambient temperature. For this space heaters have been provided and these should be automatically started with a time delay when the machine is switched off. Further, the machine should be operated within its rated temperature limit. As a general rule, it may be said that life expectancy of insulation reduces by 50% with each $10^0$C rise in the operating temperature.

Mayadhar Swain is a B.Sc. Engg (Elect) from the University College of Engineering –Burla in Orissa, and M.E. in Water Resources Development from IIT Roorkee. After being with NTPC, Talchar Thermal Power station, and Orissa Hydro Power Corp in different capacities, he is now ASST General Mnager at MECON Ltd-Ranchi. He has always worked in Erection, commissioning, Operation & maintenance of Thermal and Hydel Power Plants, and presently in Consultancy for R, M & U of Hydel Plants.

**Reference book:**

Electrical India, Vol. 47 No. 1
January 2007