DIAGNOSTIC INSULATION TESTING

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A stitch in time..
When it comes to the maintenance of plant and equipment, the old adage 'A stitch in time saves nine' is as true today as it ever was. The need for engineers in both industrial and utility environments to adopt the 'stitch in time' philosophy has been increased by the value put upon smooth operation when looking at the total costs of any failure - including down-time or 'customer minutes' lost.

Predictive maintenance
There is a trend to adopt the techniques of 'Predictive' Maintenance - a development of the 'Stitch in Time' philosophy that uses data from testing and monitoring to adjust the maintenance activity rather than relying on fixed maintenance intervals. The hard-pressed utility or plant maintenance engineer needs to focus limited time and money into the areas that are most critical and most at risk. The benefits come in both optimising the cost of the maintenance program and meeting high reliability and safety standards. The origin of the predictive maintenance 'movement' was the US aviation industry and it has been widely adopted in Power and Petrochemical Industries around the world.

Diagnostic Insulation Tests
A major cause of equipment failure is breakdown of the insulation. There is a range of diagnostic techniques that can be applied to monitor insulation condition in order to take timely maintenance action. These can be broken down into 'simple' DC Tests, complex DC tests and ac tests. Simple DC tests include; Insulation Resistance Test, Polarisation Index test and the Dielectric Discharge test. More complex DC tests include the Isothermal Relaxation Current (or KDA) test and the EDA Test. The commonest a.c. based Insulation tests are the Power Factor or 'Tan Delta' Tests.

Each test gives one perspective on the overall condition of the equipment and their combination can form a more complete picture than is provided by any one test. In the practical operational world, of course, there is not the time to completely analyse a piece of equipment and choices have to be made on the appropriate test strategy for different types of equipment. This review will look at a range of tests aimed at field testing.

The deterioration of the Insulation has a number of interlinked causes and a test is looking for a response from the insulation that is indicative of the condition of the insulation.

Insulation Degradation
There are 5 basic initiators for degradation of the insulation; electrical stress, mechanical stress, chemical attack, thermal stress and finally environmental contamination. Normal cycles of operation will lead to 'aging' through these mechanisms. Even air will oxidise organic materials while the ingress of moisture, oil and salt will degrade effectiveness even more rapidly. This is therefore one of the most important problems to pick up on a routine test basis. Electrical stresses, particularly sustained overvoltages or impulses caused by faults will lead to discharges in voids which will thereby expand and can develop into electrical treeing. The aging of insulation is a slow process of degradation as these factors interact with each other in a gradual spiral of decline. At some point, dependent on both original and operating conditions the decline can speed up significantly.

Testing
As insulation deteriorates leakage current may increase, the dielectric loss characteristic will change and the degree of polarisation of the material will alter. Insulation tests look for a change in one of these responses to indicate the deterioration.

Diagnostic Insulation Tests
The traditional insulation resistance test is the simplest way to gain an overall indication of the condition of the insulation. Although the Insulation Resistance test can be applied as a simple Go/NoGo test, it can also be used to give more extensive diagnostic information. The Power Generation and Petrochemical industries have for years been the most widespread users of diagnostic insulation tests, such as the Polarisation Index (PI test). The commonest voltages applied for non-destructive DC Insulation tests are 2.5 and 5kV.

Insulation Test Currents
The test current in the body of the insulation can be split into three components; the capacitance charging current, the polarisation (or absorbtion) current and the conduction or leakage current. The capacitive current is initially large, but goes to zero as the test piece is charged. The polarisation current is caused by charges in the insulation material moving under the effect of the electric field or by molecular di-poles lining themselves up with the applied field (orientational Polarisation). It is greatly affected by moisture or contamination in the insulation, as the water molecule has additional orientational polarisation. This process takes much longer than the capacitive charging. Finally we have steady leakage current through the insulation, which is usually represented by a very high resistor in parallel with the capacitance of the insulation. So what are the testing choices ?

'Spot' Test
This is the simplest insulation test, giving a reading of Insulation Resistance in MΩ. The test is applied for a short, but specific period of time, after which a reading is taken. On installation or on re-test, these readings will be compared to the required minimum specification.

Time-Resistance test such as the 'Polarisation Index'
Time-Resistance tests take successive readings at specified times and have the great advantage of being independent of temperature. They also help in the situation where past test records are sketchy, as, being a ratio, they are also independent of the size of the equipment, although it is always more valuable if a trend can be established. Good insulation generally shows an increase in resistance over the 10 minute period, but with contaminated insulation the polarisation effects are masked by high leakage currents and the readings are flat. In essence the PI test uses the polarisation current as a reference with which to compare the degree of leakage current. PI is a more sensitive parameter for monitoring the drying out process for a winding than a 1 minute spot test. But it would also be useful to use the polarisation effects more directly - which is the reason for the development of a range of 'discharge' based tests.

Discharge based tests
There are a range of techniques looking at the response of the insulation during its discharge. These tests all target the polarisation behaviour of the insulation, for, as we have already said, this property is sensitive to moisture in the insulation. As all three components of current are present during charging phase of an insulation test, the determination of polarisation or absorbtion current is hampered by the presence of the capacitive and leakage currents. The discharge phase of the test can more rapidly
remove these effects, giving the possibility of interpreting the degree of polarisation of the insulation and relating this to moisture and other polarisation effects.

Isothermal Relaxation Current Test (IRC Test)
This test has been derived for testing cables and grew out of the problems associated with pressure testing of plastic cables. The installed base of these cables from the 1970's and early '80's are particularly problematic. The IRC test uses a 1kV test voltage for 30 minutes to polarise the dielectric.

The polymer polarisation traps charge at specific discrete energy levels and during the discharge process these energy levels give rise to different time constants in the discharge current. The major use of the effect in the IRC test is to look for the time constant associated with water trees in degraded XLPE cable material. The 'relaxation current' occuring after the capacitance has been discharged is digitised for processing in PC based software.

The software processing is based on a modelling technique, which converts the current into Charge and plots this Charge against Time. The total charge plot is then treated as a composite of standard shapes whose time constants are 'fitted' to the composite curve by iteration. Aging of the cable is identified by the relative values of the time constants. The test was initially developed using artificially aged cable and has now been applied to operational XLPE cables.

The Dielectric Discharge Test
This test also operates during the discharge of the dielectric and was developed for application to large rotating machines by EdF in France. The insulator is charged for a sufficient time to be 'stable'. The insulator is then discharged and the current which flows is measured. This current constitutes the capacitive discharge and the 'reabsorbtion current', combining to give the total 'dielectric discharge'.

In order to make comparisons between equipment, the current is measured after a standard time of 1 minute, which is much greater than the primary time constant of the capacitive discharge. The resultant current is dependent on the overall Capacitance, the final test voltage and the degree of polarisation of the dielectric. During the discharge, the voltage and capacitance of the equipment are measured so that the 'Dielectric Discharge can be quoted as a simple number;

Dielectric Discharge = I1 min / V x C (mA/V/F)
The Dielectric Discharge can identify absorbed moisture in an insulation as this affects the absorbtion behaviour of the dielectric and is masked by capacitive effects if we try to measure it on the charging cycle. The DD test also helps to show if an internal layer is damaged. The time constant of this individual layer will mismatch the other layers, generally giving rise to a higher value of current than for insulation which is 'good' in this respect.

EDA Test
This test was also developed for motors and generators, but is of much wider applicability than the simple DD test. The EDA test also monitors current, voltage and capacitance, and the software calculates a wider range of parameters from both charging and discharge cycle at two voltages, to give enhanced information on insulation condition. The test therefore combines attributes of PI, Step Voltage and Dielectric Discharge tests to give the broadest diagnostic information it can. The software also takes information on insulation type and motor operation history to assist with the diagnosis.

Tan Delta/Power Factor Testing
In ac testing, the polarisation current never has time to die away and capacitive and polarisation current predominate in the total dielectric loss. It is therefore also sensitive to moisture and degradation of the insulation material. The loss angle / tan delta / power factor of the insulation is more sensitive to small movements in the condition of the insulation than the raw d.c insulation resistance and in some circumstances this may be important. It is therefore a very useful test for monitoring insulation condition from initial installation.

The use of an ac source makes the Power Factor test set heavier and more expensive than a dc tester, and there is a limit to the capacitance that can be tested, but the early warning given by monitoring this parameter makes it an essential part of the diagnostic armoury.

Summary
It has already been mentioned that a key element in predictive maintenance is monitoring the trend of diagnostic test results and planning is very important to the success of the programme. Not all tests are appropriate to all circumstances and neither can any single test give you the complete answer. Each type of test is like a small window looking into the condition of your equipment and by putting together a number of different tests you build up a more complete picture.