Salvaging Flood-Damaged Equipment

Flood damage is one of the most common causes of failure in electrical equipment. It can be caused by external factors such as natural disasters, storm water, and fire, or internally by water splashed into equipment during servicing. However, the presence of moisture is one of the prime causes of damage, as it can lead to corrosion, rusting, and the formation of electrolyte solutions which can damage conductors and cause arcing.

The key to salvaging flood-damaged electrical equipment is to find ways of drying it out effectively, without risking further damage. A number of options are available for this, the most satisfactory of which is to use a temperature-controlled oven with efficient air circulation. In many cases, however, this is not possible either because the equipment is too large to be moved to an oven, or because no oven is available.

In these cases, infrared lamps can be used, or a housing can be built around the equipment, with steam coils or electric elements used as the heat source. In these cases, it is important to make provision for free circulation of air so that moisture is allowed to escape; the use of blowers can be helpful.

Another method of heating sometimes used with items like motors and transformers is to pass a current at low voltage through the windings.

While the comments above give general information on salvaging flood-damaged equipment, it is worth looking in more detail at what can be done with various specific types of equipment.

Switchboards and Electrical Controls

Thoroughly clean and dry out all equipment, dismantling where necessary. After drying, re-varnish all coils. Check contacts for corrosion and oxidation, and make sure that all moving parts operate freely.

Dip all oil-filled devices, clean them and refill with fresh oil of the correct dielectric strength. To ensure that the oil conforms to the appropriate standards, check it with an oil test set. Dry all insulating barriers, or replace them if they have warped.

Monitor the insulation resistance of the machine with a modern tester that uses a low applied voltage for the kilohm ranges. Once a value of at least 100 kΩ is reached, the megohm ranges of the equipment can be used for further monitoring.

Commutators can be hard to dry out, and it may be necessary to loosen or even remove the clamps to let water out of the inside of the commutator. On large commutators, it may be necessary to use drying temperatures as high as 130 °C to achieve effective results.

Check the bands on armatures or rotors for tightness, as the drying out of the underlying insulation may loosen them. If this happens, they will need to be replaced. Some slot wedge materials may be affected by moisture. If this has happened, new wedges must be installed.

Field coils in DC motors, generators and synchronous machines can present particular problems, and it may be necessary to remove them from the machine for drying in an oven and re-varnishing. After this, the coils should be checked for shorted turns with a modern tester that uses a low applied voltage.

Dismantle the brush rigging and clean the insulators. Some types retain water and must be dried very thoroughly.

Most Monitors and protection relays will usually have to be reconditioned by the manufacturer. To ensure that the equipment is returned to service as quickly as possible, it may be preferable to fit replacements. Clean and dry thoroughly all busbar insulators and control wiring. A minimum of 2 MΩ insulation resistance must be achieved before the equipment is energised. This can be confirmed by any good quality insulation tester.

Check standby batteries for functionality using a battery impedance tester or a load tester, and check battery straps for corrosion or excessive resistance using a low-resistance ohmmeter.

Rotating Electrical Machines

Completely dismantle all parts and, except for ball and roller bearings, either wash them with clean water or steam clean them. Follow this with a thorough cleaning using a grease solvent.

Thoroughly clean all bearings and housings, paying particular attention to oil grooves and reservoirs. Disconnect and swab oil lines or steam clean them.

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Cables and Wiring
All open wiring, including non-metallic sheathed cable, can usually be retained after thoroughly cleaning and drying the cable and the junction boxes, and remaking connections. Armoured cable will usually have to be replaced, as well lead cable if the ends have been under water.

Rubber-covered cable in rigid conduit can sometimes be reused, but it must be pulled out of the conduit so that the conduit can be cleaned. The conduit must be thoroughly cleaned and removed, and then replaced.

Perform a comprehensive insulation resistance test before returning the installation to service. Hopefully, this article will have given you a useful indication of the measures that can be taken to salvage electrical equipment after it has been subjected to flooding. It is essential, however, to remember that safety is always of paramount importance. This can only be assured by careful testing of the salvaged equipment, during and after the repair process, using appropriate test equipment.

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Convenient testing for GIS circuit breakers
Damon Mount - Power sales manager

Assessing the condition of the contacts in GIS circuit breakers presents challenges that can make this important task costly and disruptive to perform. But it doesn’t have to be that way. If the right test method is chosen.

Accurately determining the condition of the main and arcing contacts in power circuit breakers has always presented problems. The most obvious approach is to dismantle the breaker and physically examine the contacts, but this is rarely possible.

Dismantling a large circuit breaker to access the contacts is time consuming and costly, and in most cases it is difficult or impossible to take the breaker out of service for long enough to allow this exercise to be carried out.

This situation with breakers used in gas-insulated switchgear (GIS) is even more challenging. Not only are such breakers more difficult to dismantle than conventional oil-filled types, there’s always a risk of the SF6 gas used for insulation escaping into the atmosphere. Since SF6 is a potent greenhouse gas, this is an important issue.

A much more satisfactory solution would be to use a method of assessing the condition of the contacts in situ. One such method – known as dynamic resistance measurement (DRM) – has in fact been in use for many years.

The idea behind DRM is straightforward. A known test current is arranged to flow through the circuit breaker contacts and the voltage across the contacts is measured throughout an “open” operation. Using Ohm’s law, the contact resistance can be calculated and a graph of this resistance can be plotted against time. The plot will show a step change in resistance at the point the main contacts open, since all of the current is then carried by the arcing contacts and, a short time later the resistance will increase almost to infinity when the arcing contacts open.

This method is often satisfactory with conventional breakers but with GIS breakers there’s a problem.

If water has entered the tank, flush the windings with clean insulating oil. If the transformer is small, remove the coil and core and dry in an oven at up to 90°C. If necessary, dip and bake the windings. windings for larger transformers can be dried in the tank by forcing hot, dry air (not above 90°C) around the windings after the tank has been drained, by short-circuiting one winding and energising the other with a low voltage, or by using a combination of these methods.

During the drying process, plot a curve of insulation resistance against time, initially measuring with a low-voltage tester and subsequently, if the process proceeds successfully, changing to a high-voltage insulation tester. If the process is not successful, and the curve shows no sustained increase in insulation resistance, the transformer will need to be re-wound.

Alternatively, dehydrated hot oil (not above 65°C) may be circulated through the tank to heat the paper insulation. If the tank is so rated, a high vacuum may be pulled for a period of time to dry the insulation. Once vacuum has been broken, DFR tests can be performed to confirm the success of the dry-out.

Once the dry-out is complete, a final test should be made with a transformer turns ratio tester to confirm that the transformer has been returned to full performance.

For DRM to work well, a large test current has to be used, otherwise it is difficult to detect the change in voltage across the contacts when the main contacts open and the current path moves to the arcing contacts. In the case of the IEC standards, the minimum test current is specified as 50 A, while the IEEE standards call for a minimum of 100 A.

Unfortunately, these high currents may magnetise the CTs associated with the circuit breaker, and there is a significant possibility that this will cause the breaker to trip when it’s returned to service. Such a trip will almost always be highly disruptive and, in the worst cases, may lead to a complete substation shutdown. A solution is to remove the CTs while the circuit breaker is being tested. This may be possible, though inconvenient, with conventional circuit breakers, but this approach simply isn’t viable with GIS circuit breakers where the CTs are, in effect, an integral part of the switchgear.

To address these issues, Megger has developed an alternative method of circuit breaker testing – dynamic capacitance measurement (DCM). DCM views the circuit breaker contacts as two plates of a capacitor that, in conjunction with the stray capacitances in the contact assembly, form a resonant circuit. The key to the operation of this method is that, as the contacts move, the capacitance between them – and hence the resonant frequency of the circuit – changes.

A test set that uses DCM operates by first applying a sweep frequency in the megahertz range to the contact assembly. This enables the baseline resonant frequency to be determined. The instrument then tracks the changes in this frequency throughout the breaker operating cycle, and the information obtained allows the exact contact timing to be readily evaluated.

The key benefit of this method is that at the test frequencies used, the external circuits connected to the breaker appear as high impedances. Grounding these external circuits therefore has no effect on the accuracy of the test results, or the ease with which they are obtained. In other words, both sides of the breaker can be grounded throughout the test. This is the renowned Megger DualGround™ technique, which is universally accepted as offering substantial safety benefits compared with techniques that require ground connections to be lifted during a test.

A further important benefit is that the high frequencies used in DCM testing have no effect on CTs, so the problem of magnetisation is entirely eliminated. This makes DCM ideally suited for use in GIS.

In fact, the use of high frequencies has even more benefits. The impedance of the external circuits at these frequencies effectively isolates them from the contacts under test, so it is never necessary to disconnect the breaker’s main circuits. This is a big advantage where bolted busbar connections are used, as these are difficult to disassemble, and major problems can ensue if the right torque is not used for each bolt during reassembly.

Over the last decade, DCM testing has established itself as being effective, reliable and convenient. And for those familiar with DRM testing, moving to DCM testing is very straightforward. The test connections required for DCM testing are exactly the same as those used for DRM testing, and the results from a DCM circuit breaker test set are presented in exactly the same way as those from traditional circuit breaker test sets. Another bonus is that DCM testing is carried out with low currents, so the test sets are more compact than the DRM equivalents, as well as being lighter and more readily portable.

As we have seen, DCM provides a complete solution to the challenges of testing GIS power circuit breakers, but it’s important to emphasise that the benefits of this proven technique are not limited to GIS breakers. DCM test sets are the most convenient solution for assessing contact condition in any type of power breaker and, because they incorporate DualGround™ technology, they are also the safest solution. What better arguments could there be for investing in a DCM test set?
Effective earthing is essential for the safe operation of wind farms, but accurately measuring earth resistance at these locations presents multiple challenges. When they are operating normally, the hazards wind farms pose to the general public are minuscule. But, like any other type of electrical installation, wind turbines can develop faults and these can, albeit very rarely, lead to large currents flowing in their earthing system. This will have been designed to take into account the local earth resistance at the site and can be expected to handle the fault currents safely provided that this resistance has not changed significantly.

If the earth resistance has significantly increased however, possibly due to a long spell of dry weather, faults can lead to hazards that could imperil members of the general public who happen to be in the vicinity. This is a particular concern in Scotland where “Right to Roam” legislation means that the public has almost unrestricted access to all areas of the countryside.

Two key issues related to wind farm faults are step voltage and touch voltage. Current flowing in the earth leads to a potential gradient at the surface of the earth. Because of this, anyone walking in the area affected will experience a potential difference – the step voltage – between their feet. A combination of high earth current due to a fault and unexpectedly high earth resistance can produce a step voltage large enough to cause a dangerous electric shock. Touch voltage is similar, but relates to the voltage between an earthed object – for example, a metal fence surrounding a wind farm – and a person who touches it. Once again, this voltage results from current flow in the earth and its magnitude depends to a large extent on earth resistance.

Wind farm operators go to great lengths to eliminate these hazards. Before a wind farm is constructed, detailed earth resistance surveys are carried out and the earthing systems are designed, with the results of these surveys in mind, to deal with worst-case fault conditions. However, as has been mentioned, earth resistance can change over time. To ensure that wind farm earthing systems remain safe and effective it is therefore, highly desirable to make regular measurements to confirm that the earth resistance has not increased significantly.

Unfortunately, such measurements are far from easy to make. While the wind turbines are operating, they produce electrical noise in the earth surrounding them, and this makes accurate earth resistance measurement difficult. The seemingly obvious solution of stopping the turbines while the measurements are being made is impractical, for operational reasons and also because of the high costs associated with shutting down a complete site.

Another problem relates to lead length. To deliver accurate results in wind farm applications, the fall-of-potential method of determining earth resistance must be used. This is a three-pole test – one connection is made to the earth bar of the turbine whose earth system is being tested, and a second to a temporary earth spike outside the sphere of influence of the earth system. In practice, this means at least 500 m away from the first connection. The third connection is made to another temporary earth spike, which is moved between the other two connections in 10% distance increments, with readings taken at each increment. In order to make it easy to handle, the lead for the moveable spike is accommodated on a cable drum but, particularly when the spike is close to the turbine, the coil of the wire round the drum adds a considerable amount of inductance to the test circuit. Practical experience has shown that this can lead to measurements indicating that the earth resistance is lower than its true value – a situation that is potentially dangerous.

With all of these issues in mind, Megger and SSE, one of the UK’s largest energy companies, have been carrying out trials with the primary aim of determining whether it is possible to make reliable earth resistance measurements on wind farm sites without taking the site out of service. The trials were performed on a site in Scotland where 16 wind turbines are in operation. Measurements were made using Megger instruments and, for comparison purposes, non-Megger instruments. The first step was to make measurements of the electrical noise present in the earthing systems at various locations around the site. As expected, these tests revealed the presence of significant levels of noise, much of it concentrated around harmonics of the supply frequency. The Megger engineers were confident, however, that the noise would not affect the results delivered by the high-end earth resistance test sets in the Megger range, which are designed to provide accurate and repeatable measurements even in difficult conditions. The results of the tests were illuminating. The measurements made with Megger’s DET4 were unstable and consistently lower than those produced by the other Megger instruments used in the trial. This was not altogether unexpected. The DET4 is a cost-effective instrument that has proven itself to consistently meet the needs of users in “standard” applications. It was never intended for use in challenging locations such as in-service wind farms. In contrast, the Megger DET2/2, a high performance instrument developed for use in even the most demanding conditions, delivered consistent and credible results in all of the tests. It was, in fact, the only instrument to do so – the non-Megger instruments in the trial performed no better than the DET4.

As further validation of the results produced by the DET2/2, these were compared with the historical earth resistance measurements made when the wind farm site was initially surveyed. Excellent agreement was found in every case, confirming that the DET2/2 can be relied upon for measuring earth resistance in wind farm installations, even while the turbines are in service.

There is, however, one caveat. For this initial trial, SSE and Megger elected to carry out measurements on the earth systems associated with turbines around the edge of the site, largely because of the difficulty in achieving sufficient spacing for the test electrodes at the centre of the site, where the turbines are closer together. Work is ongoing to address this limitation.

In the meantime, both SSE and Megger consider the results produced to date to be of great value and significance, not least because it is unlikely that the centre of a wind farm site would be affected by conditions so localised that they would materially change its earth resistance without this change being reflected, to some extent at least, by a change in the earth resistance of the peripheral areas of the site. The joint trials carried out by Megger and SSE have shown that earth resistance measurement on an in-service wind farm is every bit as challenging as had been expected. Nevertheless, with commercial equipment that’s readily available right now, it is possible to obtain accurate, reliable results, making routine periodic testing a realistic and financially viable option. Such testing has a major role to play in helping operators keep their wind farms safe, and to minimise risk to the public, even under fault conditions.

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Keeping wind farms safe

Dr. Ahmed El-Rasheed - Megger Product Management

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BRing the mid-frequency range (12 kHz to 20 kHz), the response is most influenced by the coupling between the windings, so the shape of the curve and resonant points will vary depending on the type of connection and arrangement of the windings. As the sweep progresses into the high frequency range of 20 kHz to 1 MHz the leakage inductances, along with the series and ground capacitances of the winding determine the overall shape. For both mid and high frequency ranges, the curves for all three phases almost exactly overlay since the response depends on the winding and, in general, all three windings will be nearly identical.

Once the sweep extends above 1 MHz for transformers greater than 72.5 kV, or above 2 MHz for transformers 72.5 kV and below, the response depends more on the test setup and connections than on the transformer itself, although the internal tap leads will have some influence. At this point the response for the phases will start to diverge. These comments describe typical results; the actual frequency ranges and the effects of the various components on the sweeps will vary from transformer to transformer.

### Recommendations for consistent measurements

IEEE C57.149 states “the test configuration can have an impact on the test results. It may be difficult to determine if these minor variations are due to differences in test configuration or some other physical change. Therefore, it is important to document the test configuration and connections for future test repeatability.” It also states “grounding techniques will have a significant effect on test results. Grounding techniques, including selection of ground conductors as well as their routings, should therefore be precise, repeatable, and documented.”

The presence of residual magnetism in the core can influence results in the low frequency range. Residual magnetism may be the result of performing a winding resistance test. For such a test, direct current is injected into the winding, the core is magnetized and saturated so that the voltage drop due to the inductance of the winding is excluded from the measurement. If the core is not demagnetized after this test, significant differences could show up on open-circuit SFRA measurements in the low frequency range.

To demonstrate the effect of core magnetization, an open-circuit SFRA sweep was carried out on the phase B of the LV winding of the transformer with the core in the demagnetized state. Winding resistance tests were then performed at 10 A, 25 A, and 50 A. After each of these tests, an open-circuit SFRA sweep was carried out. The SFRA sweeps done after the resistance tests produced the same curve, irrespective of the DC current used for the test. There was, however, a noticeable difference between the pre-magnetization and post-magnetization curves, as shown in Figure 3 and 4.

In the low frequency area, the curve shifts upwards and to the right after magnetization. A shift in the first resonant frequency is observed at approximately 500 Hz. A difference curve was plotted to highlight the difference between the pre-magnetization curve and post-magnetization curve.

As can be seen from the difference curve in Figure 5, there is a considerable difference in the low frequency range of 10 Hz – 3 kHz. Minor differences are also observed at higher frequencies. Based on these observations, it is clear that care should be taken to ensure the core is not in a magnetized state during SFRA testing. Ideally, winding resistance tests should not be conducted prior to SFRA tests but if this is unavoidable – or if core demagnetization is suspected – the core should be demagnetized before starting the SFRA test.

### Effect of removing the core ground

Often, the core-ground insulation resistance measurement is the first electrical test done on a transformer. If the technician forgets to ground the core terminal after the test and begins SFRA testing, the ungrounded core terminal may lead to a deviation in the curve. To simulate this condition, the core was disconnected from the ground, as shown in Figure 6.
The curves in Figures 7 and 8 were obtained with open-circuit sweeps performed on the HV phase A of the transformer. The magnitude difference between the curves shown in Figures 7 and 8 was plotted separately, and is shown as Figure 9.

As can be seen from Figure 9, differences are noticeable up to 9 kHz but then the curves essentially overlay up to 900 kHz, after which there are further noticeable differences. For valid fingerprints and comparisons, the core should therefore be kept grounded during the SFRA test.

**Effect of the grounding braid length**

Since SFRA measurements are sensitive, grounding plays an important role. The grounding loop must be as short as possible and the grounding should be connected using braids at the flange of the bushing where the signal leads are connected. To demonstrate the effect of the length of the grounding connections, two measurements were made. The shortest possible length was used for one measurement, as shown in Figure 10. The whole length of the grounding braid was used for the other measurement, as shown in Figure 11.

The curves shown in Figures 12 and 13 were obtained. The difference curve is shown in Figure 14.

There are essentially no differences in the two curves until frequencies of 900 kHz and higher are reached.

In the next set of open-circuit measurements, shown in Figures 15 and 16, the grounding braids were removed altogether. The difference curve is shown in Figure 17.

Once again, there was no change in the low and mid frequencies but the deviation increased dramatically in the high-frequency range. There was a small difference between the two curves at 100 kHz, which is lower than the frequency where differences produced by long and short grounding braids were noted. Above 200 kHz, the differences increased significantly.

The grounding arrangements for the instrument were also changed. But no differences were observed whether the instrument was grounded to the transformer, to the substation grid, or even not grounded at all. The magnitude and phase responses are shown in Figures 18 and 19. Note that even though the grounding of the instrument does not affect the measurements, it must nevertheless be grounded at all times to ensure safe operation.

Based on these observations, the grounding of the instrument may not affect measurements, but the position and effective length of the grounding braids does have an effect on the high frequency range. Standard grounding procedures should therefore be followed to allow accurate comparisons of SFRA results.

The second part of this article, which will appear in a future issue of Electrical Tester, will look at the effect of tap position, reversing switches, length of shorting leads and the influence of the test voltage used on SFRA testing. It will also cover delta stabilizing windings and how to verify the correct functioning of the test instrument before concluding with a summary of the main recommendations for dependable and repeatable SFRA testing.
The many facets of loop testing

Introduction
Electrical installations must be designed to make sure that, in the event of a fault, the resulting short circuit current (prospective short circuit current or PSCC) does not exceed the maximum breaking capacity of the circuit breaker. Otherwise the fault current might destroy the circuit breaker and could lead to catastrophic failure of the installation resulting in damage, injury or even death of personnel.

In addition, even a well-designed installation must be properly implemented with, for example, correctly rated protection devices, conductors of the right cross-sectional area and so on. And it is essential that all of the important parameters that could affect the safety and performance of the installation are verified before it is put into service.

The amplitude of a short circuit current in a circuit is dictated by the vector sum of the internal impedance of the voltage source and the impedance of the protection devices: live, protective earth and, if present, neutral. The impedance of the short circuit itself is assumed to be zero.

The simplified circuit illustrating this relationship resembles a loop (Fig. 1) so the measurement used to determine the PSCC is referred to as “loop impedance testing” or, in electrician’s jargon, “loop testing”.

The no-load voltage can be easily measured by any voltmeter, but the impedance of the conductors and the voltage source are more difficult to measure. There are further complications resulting from the types of protection devices used in the network. For these reasons, a variety of different test methods are used, depending on requirements and the configuration of the installation.

Two-wire high-current method
This method relies on connecting a sizeable current load, \( I_{L} \), directly between the L and PE conductors. This method is referred to as “high current”. The same test can be carried out between L or L-N conductors.

This test is easy to use and it gives very reliable results. It should therefore always be used when possible. Instruments like MFT1710 and MFT1800 series provide this type of test with a nominal resolution of 0.001 Ω (Fig. 3). Instruments like MFT425 can measure with an even higher resolution of 0.0001 Ω.

When using this test method, it is always a good idea to check the current load applied by the test instrument to ensure that the circuit breaker protecting the installation will not be tripped. For instance, some instruments apply a load exceeding 15 A, which in the worst case could trip a circuit breaker rated at 6 A.

On the one hand a higher current gives more stable readings, but on the other hand there is an increased risk of unwanted tripping of protective devices. Therefore it is not necessarily “better” to use testers with a higher load current.

Four-wire high-current method
The two-wire method just discussed can achieve the very high resolution of 0.001 Ω, but with very low values of loop impedance the connection between the probe tips and the components of the installation (for example, the screws in the terminals) becomes significant. The pressure exerted by the operator on the probes can change during the test and thus seemingly irrelevant results can be produced. This is normal behaviour and it is not caused by shortcomings in the instrument, but rather by the limitations Mother Nature puts on the physics of surface contact between two metal parts.

Using four-contact voltage sensing instruments can eliminate this problem. The load current is applied in the usual way, but the effect of the variable resistance of the probe tips is eliminated (Fig. 4). This method should be used when the highest possible precision is needed in the measurement.

Four-wire sensing instruments are, however, typically more complex and more expensive than their two-wire equivalents.

Three-wire low-current method
A high-current load cannot be used to carry out tests when an RCD (residual-current device) is present in the system. After all, it is the main job of an RCD to trip as soon as a significant current passes between the L and PE conductors. Therefore the test must be carried out in such a way that the test current is below about 50% of the RCD rating. A typical RCD is rated at 30 mA so, in order not to trip it, the test current must not exceed 15 mA. This is around 1000 times smaller than the load current used in the high-current two-wire test. This means that the measurement is around 1000 times more difficult for the instrument to perform, and averaging over longer test time needs to be used to minimise the influence of noise.

The low-current method most often uses requires three connections, because a high current can be still drawn between the live and neutral conductors, so some parts of the impedance can be measured with better resolution, the low current being used only where it is essential. The neutral conductor can be thought of as an auxiliary aid during the three-wire test (Fig. 5). The neutral is required for the test, but its impedance is not included in the final value. The test sequence is performed automatically, and it is normal to hear relays clicking inside the tester when a three-wire test is being performed.

Typically, the tester first applies a high-current load between the L and N conductors and measures their combined impedance \( Z_{L-N} \). Then it applies another high-current load between L and N, but senses the voltage drop between the N and PE conductor. This allows it to measure the impedance of the N conductor alone, \( Z_{N} \).

When the test is performed, it is very important to ensure that the load current is applied in the proper way. Typically (below 15 mA) is applied either from L to PE or from N to PE, and the voltage drop is sensed between N and PE, which allows the instrument to measure either \( Z_{L-N} \) or \( Z_{N} \). Since it now knows \( Z_{L-N} \) and \( Z_{N} \) it can calculate \( Z_{N} \), which is the value it displays at the end of the test. This whole process is automatic and various manufacturers use different test sequences. The operator does not have to worry about the details, however, because the final displayed value is always \( Z_{N} \).

It can be seen that the instrument has to work quite hard to derive these values automatically and, because the test has multiple stages, there is considerable scope for noise to affect the measurement, especially when a very low load current is used. An additional problem is caused by some RCDs, the construction of which introduces a small, but noticeable additional impedance in the loop. In some circumstances, the instrument includes this in the loop impedance measurement. This is in fact correct, but the extra impedance is genuinely present when only a small current load is applied. However, because the extra impedance causes an unwanted increase in the total measured loop impedance value, which should not include the RCD impedance, users often consider the measurement to be incorrect and question the performance of the instrument they are using.

This conundrum is solved in Megger’s new MFT1741 multifunction installation tester, which adopts an innovative measuring technique that is insensitive to the additional impedance of RCDs.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Method</th>
<th>Load current</th>
<th>Measurement errors can be caused by</th>
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<tr>
<td>Best</td>
<td>Four-wire high-current</td>
<td>Very high</td>
<td>Test lead resistance Contact resistance</td>
</tr>
<tr>
<td>Very good</td>
<td>Two-wire high current</td>
<td>High</td>
<td>Test lead resistance Contact resistance</td>
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<tr>
<td>Good</td>
<td>Three-wire low-current</td>
<td>Combination of high and very low</td>
<td>Test lead resistance Contact resistance Noise in PE conductor</td>
</tr>
<tr>
<td>Acceptable</td>
<td>Two-wire low-current</td>
<td>Very low</td>
<td>Test lead resistance Contact resistance Noise in PE conductor</td>
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Dr Stan Zurek - Manager of Magnetic Development, Megger UK

Fig. 1. Concept of loop impedance
Fig. 2. Two-wire high-current method
Fig. 3. MFT1730 in two-wire high-current mode (a) and MFT425 in high-resolution mode (b)
Fig. 4. NIM1000 utilises the four-wire method with load currents up to 1000 A
Fig. 5. Three-wire low-current method
The do’s and don’ts of insulation power factor testing – part 2

Jill Duplessis - Global technical marketing manager and Editor

Power factor (PF) / dissipation factor (DF) tests are widely used to assess the condition of the insulation in transformers and other electrical assets. The first article in this series will take a look at the theoretical background for these tests. This instalment moves on to look at practical aspects, using an easily accessible Do’s and Don’ts format.

Safety Do’s

- DO hold an informal meeting before each test job
  Talk to your colleagues before starting work. Discussing and talking about the task from a safety perspective will naturally raise safety awareness. These informal meetings challenge those involved to think about hazards that have not previously been identified. Colleagues may point out a risk they are aware of through personal experience, but isn’t familiar to other team members.

- DO check grounding
  The asset under test must be correctly and securely grounded. With modern test equipment, the test instrument’s ground lead connects to the asset’s ground connection. The test instrument’s supply voltage ground will automatically be compared with the asset ground by a comparative ground circuit relay to make sure that the resistance between the two is sufficiently low. If the resistance is not low enough, the relay will inhibit testing.

- DO inspect test equipment and leads before use
  If there are any signs of damage or if indications of excessive wear, do not use the affected equipment and/or leads.

- DO connect the instrument ground lead first
  Always connect the ground lead to the test instrument first, before making any other connections, and remove it last, after testing is complete.

- DO use a grounding stick
  Develop the good habit of touching each terminal with a grounding stick before moving or disconnecting test leads. This will ensure that any stored charge that may be present is discharged safely.

Safety Don’ts

- DON’T ever take safety for granted
  It’s easy to become complacent about safety, especially when carrying out familiar tasks. But taking safety for granted is a swift route to accidents.

- DON’T forget that only qualified persons can perform testing
  Only qualified persons are permitted to perform tests such as testing. This is for the good reason that, in becoming qualified, they will have undergone extensive safety training.

- DON’T forget that improper use of test equipment can create electrocution and arc flash hazards
  No matter how well designed and constructed the test equipment is, if it is used incorrectly, there will be a risk of shock, electrocution and arc flash. Modern test equipment is designed to promote safety – there’s never been a fatal accident associated with a Megger PF test set, for example – but no one should ever cut corners and hope for “get away with it.”

- DON’T cheat the comparative ground circuit relay
  The comparative ground circuit relay, the operation of which was described earlier, is there for a reason – to help make sure you stay safe. If it inhibits testing, don’t cheat it, however great the temptation. Instead, investigate the problem with the ground connections and fix it properly.

- DON’T get distracted
  It only takes a moment or two’s distraction for an accident to happen. Stay focussed on the job in hand.

General Insulation Knowledge

When insulation is the patient undergoing diagnostic tests, there are a few things it’s good to know!

General Insulation Knowledge Do’s

- DO memorise the state in which insulation performs best
  It’s worthwhile remembering that insulation performs best when it’s clean, dry and relatively void-free. Insulation must also be used only within its designed temperature range – if it isn’t, early failure is almost inevitable.

- DO be wary of the enemies of insulation
  The principal enemies of insulation are heat, moisture and oxygen. They often arise from external sources, but remember that they can also be produced as natural by-products of the insulation ageing process. In addition, remember that losses produce heat and heat can increase losses, producing even more heat in a process that can ultimately lead to thermal runaway and dielectric failure.

- DO remember insulation fails when stresses exceed withstand capability

As the diagram shows, manufacturers design insulation systems so that there is a very comfortable margin between anticipated stresses and the insulation’s withstand capabilities. But many insulating materials, particularly those used in transformers, are organic – paper, oil and pressboard – so they will inevitably deteriorate over time and eventually reach the end of their lives. This means that the withstand capability of the insulation fails as it ages. Stress on the insulation, however, may well increase over time. An unexpected increase in loading, for example, may lead to more heating. In such circumstances, it is possible that a point will be reached where the stresses exceed the insulation's withstand capability, leading to dielectric failure. This point is shown as an explosion on the diagram, and this is not accidental. Dielectric failures can result in explosions and fires – the impressive ones that find their way onto social media for all the wrong reasons.
Q: Many high voltage insulation test sets offer polarisation index (PI) and dielectric absorption ratio (DAR) tests as well as straightforward insulation resistance tests. Are there any benefits in using PI and DAR tests on motors?

A: In a word, yes! The results of straightforward insulation resistance tests depend to some extent on temperature, so if you want to compare measurements, you have to make sure that the motor is always at the same temperature when you make the tests. PI and DAR test results, in contrast, are largely unaffected by temperature, which means that these tests can be carried out without waiting for the motor to cool down – or heat up – to a specific temperature. Motor size also has little effect on PI and DAR test results, so measurements can easily be compared with published results to provide a rapid and dependable indication of the condition of the motor insulation.

Q: Some instruments also have a ramp test option. What does this do, and what is it useful for?

A: As the name suggests, a ramp test applies a continuously increasing insulation test voltage, up to a preselected maximum, to the motor. This allows the response of the insulation to be assessed in detail. Small defects are readily detected and the test can be terminated at the first sign of breakdown, before serious damage occurs. Ramp tests are particularly useful for detecting defects like cracks, voids, delamination, moisture ingress and surface contamination.

Q: When I’m choosing an insulation resistance test set for use on motors, what should its maximum test voltage be?

A: That very much depends on your requirements and the types of motors you’ll be testing. For most applications, 5 kV test sets will provide good results, but users are increasingly finding that tests at higher voltages, usually up to 10 kV, are more revealing, especially when the results are trended over a period of time to aid the detection of incipient faults. Recently, 15 kV test sets have become available, and these are useful where compliance is required with certain standards, such as NETA MTS-1997 Table 10.1, applicable to the maximum voltage rating of equipment, and NETA ATS 2007 Section 7.15.1 for medium voltage motors. It’s also worth remembering that the maximum test voltage is usually related to the maximum insulation resistance the instrument can measure. ForMegger insulation test sets, 5 kV models measure up to 10 TΩ, 10 kV models up to 20 TΩ and 15 kV models up to 30 TΩ. The extended measuring ranges provided by instruments with higher test voltage capabilities are particularly useful when trending results over time, as it’s not possible to trend an “infinity” reading!

POWERED BY

... Niclas Wetterstrand

Keith Wilson - Electrical engineer

Megger is powered by its people, and it’s our people that make possible the exceptional innovations, great products and outstanding customer service for which the company is renowned worldwide. With this in mind, for the next few issues of Electrical Tester, we plan to interview some of the key people who power Megger so that you can find out a little more about them.

We’re starting with Niclas Wetterstrand.

Hi Niclas! Please start by telling us a little about your role at Megger.

I’m Program Manager for Megger Sweden and my responsibilities cover all of our products except transformer products. My main function is business development.

What do you most enjoy about your job?

I really like being the link between our customers, our development team and our manufacturing operations. The link between the customers and Megger works in both directions. I start by finding out and understanding what our customers need, I collate and formulate these requirements and feed them back to our development and manufacturing teams. Then comes the part I enjoy the most – I go back to our customers with effective and often novel solutions for their problems.

Not long ago, the need to measure earth resistivity or the resistance of an earth electrode was, for most engineers, a rare occurrence. With the advent of small generating schemes and, in particular, solar and wind energy schemes, this situation has changed. Most of these schemes have their own existing earthings and, to ensure safe operation, these need to be checked. This has led to a large increase in the number of questions our helpline receives about earth testing; here is a selection of the most common.

Q&A

What’s been your biggest work-related challenge to date?

In recent times, I would say that its been keeping our product portfolio, which is the broadest in the industry, up to date and attractive to our customers. This is made even more difficult because we operate in a sector where competition is continually increasing. When you’re a leader in your field, those behind you are always trying very hard to catch up! We constantly need not only to enhance our existing product range, but also to develop new and innovative solutions that meet the ever-changing needs of customers. Believe me, all of this adds up to a very substantial challenge.

What do you like to do in your spare time?

There are three things I enjoy and all of them involve my family. In summer, we like to spend weekends and vacations on our boat. In winter, I am a coach for Bele Barkabyl, our local floorball team. My youngest son plays for them. My older son also plays floorball and I try to go to as many of his games as possible. Otherwise, I like to spend time with my extended family and friends, ideally enjoying home-cooked food together!

Tell us something about you that not many people know

The first boat I ever owned came from the Mosel Valley in Germany. I brought it all the way back to Sweden, passing through many canals and crossing the Baltic Sea. It was a journey of 1,000 nautical miles and it took me two weeks. Looking back on it, that was quite a tough challenge given the limited experience I had with boats at that time. On the other hand, I did make many useful additions to my boating experience during the journey!

If you were President of the World, what would be your first executive order?

To make affordable, environmentally friendly electricity available to everyone in the world. That would be great for the environment and for all the people who are still without electricity today. And it would, of course, be absolutely awesome for Megger!

The world’s first integrated circuit may be older than you think!

For many of us, the history of the integrated circuit starts one hot July day in 1958 when Jack Kilby was sitting alone at his desk in Texas Instruments. Having been employed by the company for only a couple of months, he couldn’t take holiday like the rest of his co-workers so remained at work in the deserted factory halls. And as he had ample time to think, he figured out that all parts of a circuit, not just the transistors, could be made out of silicon – at a time when nobody was making capacitors or resistors out of semiconductor materials. By September 12, Kilby had built a working model, and on February 6, Texas Instruments filed a patent. The company’s “solid circuit”, the size of a pencil point, was shown to the public for the first time in March of the next year.

Of course, depending on which version of history you choose to side with, you might prefer to believe that Westinghouse Electric of Youngwood, Pennsylvania was responsible for the first silicon IC, having produced one at roughly the same time as Texas Instruments. But what if I told you that the first device with good claims to be an integrated circuit went into production as early as 1926? Even though the world’s first IC looked quite different from the ones we know today, the basic concept was developed by Dr Siegfried Loewe, founder of the Opta Electronics company in Berlin.

Loewe’s device, for which he was granted a patent in 1924, used vacuum tube technology and consisted of three triodes and a number of resistors and capacitors encapsulated in an overall glass envelope. The external connections were brought out to pins, and the device could be plugged into a socket in the same way as an ordinary vacuum tube. The design was slightly improved over the next couple of years and, by 1926, it was put into production with the designation 3NF.

The 3NF was used as the basis of the Loewe OE333 AM radio receiver and contained most of this receiver’s components. The only external devices were a tuning coil, a swinging aerial coupling coil, a tuning capacitor, a loudspeaker and the high tension and low tension (A and B) batteries which supplied the anode and the filament power.

The cost of this new technological wonder was 39.50 Marks and it must have been seen as offering good value for money, as it became the first ever radio receiver to sell in excess of one million units – a tremendous achievement for the inter-war period.

The discovery and successful production of the first IC are events that most engineers would firmly place in the 1950s but, as we have seen, there was a spectacularly prescient invention thirty years earlier that paved the way for modern electronics.

Keith Wilson - Electrical engineer