Electrical Energetics

Application catalogue

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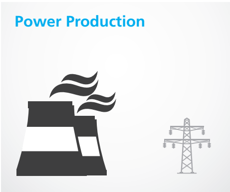
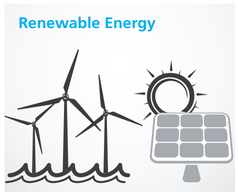
Introduction of covered fields

Electrical Energetics

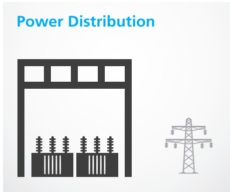


Electrical Power Plants - require professional approach to design, maintenance, and testing. Regular testing and maintenance is necessary to minimize potential outage periods, optimize power quality and ensure the safety of the surroundings. The goal is to maintain long-term operation without accidents or incidents. The test equipment needs to be robust with high immunity to electromagnetic field and noise. Test current and voltage sources must be powerful enough while meters need to be synchronized and filtered to achieve satisfactory results. Generators and primary transformers need to be tested with high voltage DC yet exclude the effects of capacitance in the insulation and inductance in the windings.

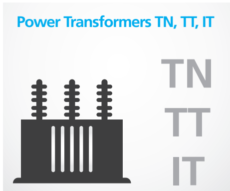


Renewable Energy Power Plants - in combination with existing power network platforms open new challenges. They need thorough safety procedures and advanced test approach like any other high-powered infrastructure while considering their specific properties. Several interesting testing cases present themselves in the field: trip-out ability on live circuits at higher voltage levels, AC and DC sources, batteries, solar panels and strings, inverters and others. Ground impedances, lightning protection, equipotential bonding, insulation quality, voltage, current and power quality testing are expanding to new dimensions. A specific problem is the length of the wires used for bonding.

Power distribution - the system ranks among the largest structures constructed by man. Thousands of kilometres of conductors carry extremely high voltages from the generator to the final step-down transformer and the consumer. The

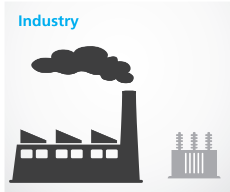


whole system needs the electrical safety and functionality at the heart of considerations both during design and later maintenance. Insulators protect from leakage to the ground, equipotential bonding, and connectivity to earth to protect against dangerously high potential differences between exposed surfaces, and earthing system designed with the high voltages in mind to prevent dangerous surface potentials.



Substations and transformers - need to be designed, installed and maintained appropriately to keep the environment safe in terms of operational and functional safety. Functionality may be compromised to prevent injury or damage. The grounding systems under substations and surroundings are large and complex, which makes them hard to test. The type of system installed is the main consideration in choosing the correct measuring method and test equipment. The strength of connections and earth bonding need to be checked with adequate test currents to assure safety even in case of an overload. The transformers need a specific set of measurements to ensure their continued safety. The methodologies should work under power to simplify the process and avoid down time. However, some measurements cannot be done without disconnecting the unit under test, particularly insulation. The equipment needs to be immune to parasitic effects and noise. Particular care is taken about their cooling and working temperature. Thermal camera inspections are particularly valuable.

Installations exceeding 1 kV industrial and other medium voltage platforms, where the safety features are dictated by powerful transformers and loads, regular testing of safety and functionality



features is of paramount importance for continued operation. Measuring equipment and methods should be capable of managing the higher cross sections, corrosion due to industrial pollutants, leakage and noise currents, harmonics, and other disturbances from the surroundings. Complex test equipment needs to be highly protected and cleverly designed to operate without interruptions for a long period. More frequent periodical testing is strongly recommended for environments with vibration caused by constantly changing high currents or mechanical work.

Contents

Electrical Energetics

Electric Safety and Quality Bundles

Solutions@Metrel®

INNOVATIVE APPROACH

Adaptable bundles are combination sets of test tools for each application, location or pre-defined set of measuring methods. They can be tailored perfectly to customer requirements or selected from the Metrel pre-prepared ones. Licences on the instruments, PC and Android software, cus-tomization and appropriate accessories are included. Part of each solution is the provision of literature and posters both in printed and electronic versions, and the organization of training for future users. Pre-made sets cover the expected locations, special installations and use cases, and can be further customized on request.

AUTO SEQUENCE®

AUTO SEQUENCE®s are testing procedures prepared in advance for a specific application. They consist of a pattern of single tests with limits and parameters prescribed. In context of the Solutions@Metrel, test procedures can be designed as required as part of the set. The operator can follow local rules easily and safely, never missing the goal.

Power generation

Solutions by the Field of Use

The modern world runs on electrical power. It is efficient to generate it industrially and at large scale, using easily accessible resources. Using electrical induction to generate three-phase alternating current is the strongly prevalent method. Electrical generators are essentially motors in reverse: they transform external mechanical power to electrical energy. Traditionally, steam or water is used to drive a turbine that turns the rotor.

Heat for thermal plants can be produced using any number of fuels, from fossil fuels like natural gas or coal, renewables like biomass, side products like waste, or from nuclear reaction. In every case, a thermal plant is a steam engine, and therefore the efficiency is low, no more than 45% at most.

The waste heat can be reused for heating nearby buildings. Depending on the energy source, the thermal plants can be extremely environmentally damaging. Fossil fuels lead to high carbon footprints and waste causes pollution with nitrous and other gasses. Nuclear plants have a lower immediate environmental footprint, but the problem of storing their highly radioactive waste has not yet been solved satisfactorily.

Hydro plants have much higher efficiency, between 80% and 90%. The potential energy that is stored in the water as its weight and elevation is relatively low. Plants on largest rivers can achieve similar output to largest thermal plants. But such rivers are relatively few and transferring power over long distances from them to where they will be used is not efficient. In many parts of the world, hydro plants can only achieve a fraction of power generation of their thermal-powered counterparts. The water itself is renewable resource but damming necessary for operation of a hydroelectric plant has powerful environmental and social impact. The electrical part of the plant operates at high, alternating voltage. This means electrical safety must be at a commensurately high level to protect workers. Any bystanders are discouraged by fences and other physical barriers.

The grounding system is the most important safety component of a high voltage installation. Methods for testing it will be considered in more detail in the application notes following this introduction.

Apart from voltage generation, the plant also contains the primary transformers and switchyards necessary to transferring the power to transmission and distribution. In the case that it is connected to high voltage DC network, the DC conversion will also be part of the same facility.

Measuring continuity in vicinity of a power plant.

Thermal energy power plants

Power generation

Traditional fuels for generation of electrical energy include burning of fossil fuels, waste, biomass, and nuclear energy. Their obvious problem is environmental cost. The footprint is high for fossil fuels, mainly as carbon releases into the atmosphere. There are also issues with releases of heavy metals and toxicity of ashes. Waste and biomass are considered renewable sources, but come with higher content of toxic gasses, mainly NOx in the exhaust. Nuclear fuel does not normally have issues with atmospheric discharges and its energy density is incomparably higher than other fuels, but waste storage is not an easily solved problem due to both technological and social circumstances.

Their strong point is availability: they can work exactly as much as the network needs to up to the top power availability, and do not depend on current weather conditions or time of day. Geographical location is of low importance, as both fossil fuels and uranium are relatively easily transported and comparatively little demineralised water is needed for steam as it is constantly recycled.

THERMOELECTRIC POWER

Generating plants powered by burning the fuel or nuclear reaction use the resulting heat to boil water. Steam then powers the turbines. For this reason, they can be classified together as thermal plants. This expression includes other types of plant such as geothermal and sun concentration. These are not considered here but work in a similar way with a different energy source. Thermal plants work as steam engines. By the second law of thermodynamics, all the produced heat cannot be converted into mechanical energy, there is always some lost to environment. This waste heat can be recovered by using it for communal heating, desalination of water or industrial processes; plants used this way are referred to as cogeneration plants. The second option is to recycle heat for more steam generation. This is considered a second thermodynamic cycle, and the plant is then called combined cycle plant.

Efficiency in electricity generation typically reaches about 40%. Technologically, it depends on steam temperature. Modern plants can use supercritical water at temperature and pressure where liquid or gas phases no longer exist to boost efficiency. Combined cycle plants improve it even further. Nuclear powered plants operate with wider safety margins and reach about 30-32% efficiency for thermal energy conversion. It depends on work regime as well: the plants under constant operation are more efficient that the intermittently used. The closer the constant operation at the full power is the better. This is the reason (primarily thermal, but also other) plants can be classified by duty: baseline plants are kept on always and forms the backbone of the system; the peak plants only come online during the highest consumption, maybe for a couple hours a day; and the load following plants maintain the balance between the two, more flexible than baseline, but more constant than peak. Thermal energy is extremely versatile in this aspect.

Waste heat needs to be disposed of through environment. Condensers and cooling towers are used for safety and lowered impact.

Generator is run by a series of turbines with a common shaft. The first is run by steam at highest pressure and temperature, followed by an intermediate one and lastly one, two or three low pressure and temperature types. The system is so large and heavy that it needs to keep turning even when off to prevent it from deforming. Stand-by batteries are in place for this. The generator itself uses a wound rotor with no permanent magnets. It is synchronized to local grid, running at 3000 or 3600 rpm. A single generator in operation creates currents in range of 20 kA and voltages in range of 24 kV. The generated electricity is immediately passed through a step-up transformer that changes the values to high voltage for energy transmission.

Using disconnected transmission lines In measurements

Power generation

Measuring a large earthing system is difficult. It takes extremely long wires, possibly multiple kilometres long, and repetition of the measurement at different locations to validate the result. Some of these problems can be eased by using the existing transmission lines as measurement wires, but this idea comes with several issues of its own.

In theory, the method is quite elegant. Particularly large complexes like power stations need to have the earthing measured at a great distance, however, there are wires already available in the form of transmission lines. Being a power station also eases the bureaucracy necessary for disconnection of a section needed for measurement. At both ends of the section, the line wires are connected together and grounded. On the measurement side, the instrument is connected between the line and the ground. A powerful surge protection is installed parallel to the instrument. Only then can the grounding wire be removed. A loop is created between the line wires and returning underground, and the grounding resistance can be calculated by the instrument. See the image below.

An important advantage of this method is easy estimation of the current in the loop. The resistances in the loop are the wires, the earth resistance at the far point and the measured earth resistance. They are all generally low, so the method can make the most of the instrument's power.

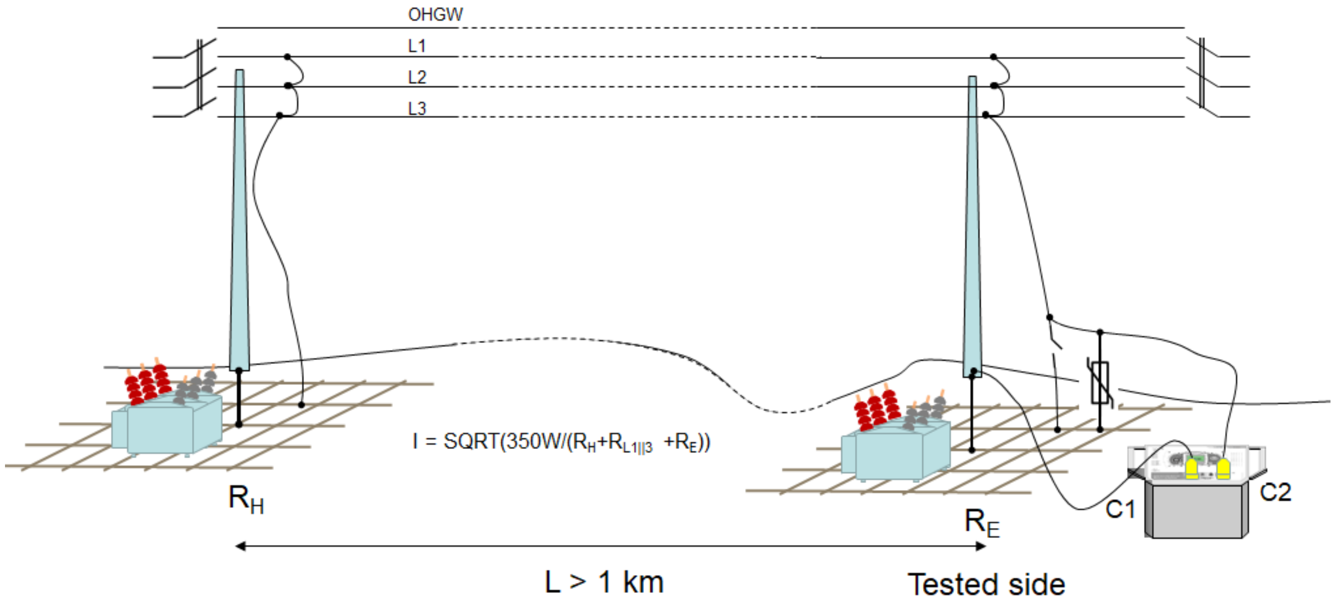
While elegant, the method is very dangerous in most locations. Pylons that only carry a single transmission line are rare. There is no bureaucratic reason to disconnect the other line on the pylons used. A second parallel line can induce very high currents in the measuring loop, some tens of amperes. For this reason the surge protection is absolutely necessary.

The Metrel solution for this method is the Step Contact Voltage Measurement system MI 3295 of base station and autonomous meter. The station provides 350W of power for earth measurement, which gives an estimated current of 20-30 A for this method. The current in the loop can be estimated with the equation:

$$I = \sqrt{2}\, 350\ W / R_H + R_{l1} \,||\, R_{l2} \,||\, R_{l3} + RE$$

Power and resistances are easier to find or estimate than the voltage in this loop would be.

Connect the E and ES cables to the electrode under test. Connect the surge protection in parallel to the instrument, between the measuring cables and the ground. Only when protection is installed, the grounding on the line wires can be open. S and H contacts are connected to the line wires. This is an extremely important safety precaution. Only then, connect the measuring contacts S and H to the line wires. From the function selector choose EARTH, and EARTH RE from subfunction selection. Press TEST to perform measurement. Store the result with MEM key.



Schematic of using the disconnected lines for measurement. The potential parallel lines that could cause dangerous inducted currents are not pictured.

Insulation of generator windings and primary transformers

Power generation

Windings in medium voltage generators are insulated using resin, cellulose, and polymer laminates, sometimes using special methods of application to keep it in place. Transformers on the other hand often use impregnated paper and oil. Choice of material depends on the required thermal, mechanical, and electrical properties.

The materials used on wound-wire components are covered by three comprehensive standards: NEMA, UL and IEC. Each defines different classes, but the intentions are similar. The principal class rating is by temperature resistance. Classification is by the maximum hot spot temperature permissible. Hot spot temperature is calculated from ambient temperature plus the maximum permissible equipment operating temperature plus a further 10°C for a hot spot. Insulation does not fail immediately at the hot spot temperature, but expected lifetime is halved for every 10°C above it.

Lifetime can be increased by lowering exposure to moisture. Primarily this is achieved by proper atmosphere control. Larger complexes take no risks in this regard, since reliability is a high priority. Moisture-damaged material can usually be dried to some degree and used for a bit longer, but its lifetime is very limited.

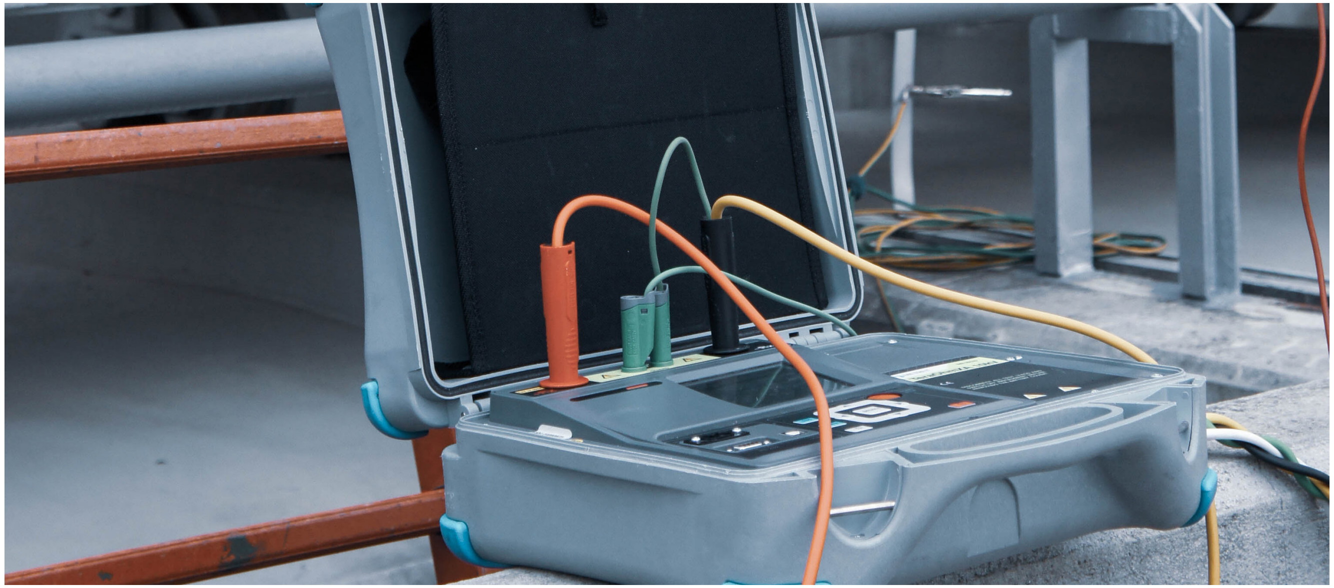
Testing the insulation on generators or transformers during commissioning is exhaustive. It can cover several power quality features as well as pure insulation resistance and diagnostic factors over a large frequency spectrum. This creates the baseline specifications to compare with future periodic tests. Power quality parameters are easy to monitor long-term with a dedicated instrument and can serve as an early indicator of insulation health.

Periodic tests are ideally done quickly, but measuring insulations always takes time.

The capacitance of the insulation of these large devices that needs to be charged and discharged is not trivial. Diagnostic tests can take half an hour each. It is good practice to schedule the periodic testing for times of low consumption so the load can be passed around the equipment in turn.

Metrel solutions with MI 3210 cover DC insulation measurements, diagnostic factors and withstanding tests with up to 10 kV test voltage.

The capacitance loading is fast at 3s/μF and discharge at the end of the test is automatic. These methods can cover most power generators and transformers as long as the records were kept. Smaller instruments like MI 3205, MI 3201 or multifunctional installation testers can be used for smaller facilities or secondary generators.



MI 3210 during transformer measurement

Renewable energy sources

Solutions by the Field of Use

Renewable energy means harvesting energy from sources that regenerate fully on a human timescale or harvesting it from continuous processes that cannot be halted. These include using visible light and heat from the sun, wind, water potential or tidal energy, biomass (plant growth) and geothermal heat. Apart from electricity generation, these energy sources can also be used for heating, cooling, direct mechanical energy, and transportation.

The use of renewable sources of energy is generally considered environmentally friendlier than the use of fossil fuels and is therefore rapidly gaining popularity. In 2020, about 25% of generated and about 19% of consumed energy came from renewable sources, while two thirds of newly constructed plants use renewable sources. With popularity, prices are decreasing and intense research is focused on improving the technologies. Generally, the renewable sources have high efficiency, but quite poor energy availability and tend to use up a lot of land. Energy storing and transportation technologies can alleviate trouble with availability while efficiency improvements will alleviate the land use issue.

Mainstream technologies for energy generation include hydro plants, wind plants and solar or photovoltaic plants. Less well-known technologies that are limited to a limited number of locations around the world are geothermal and tidal plants. Biomass is a type of thermal plant: it depends on burning only so much plant mass as can be restored in human timescale.

Power from water is very widely available; access to river flow and tides and wave force of the sea is available in most countries. Typical technologies use damming the river to control the flow through the turbines, small systems that still use a dam, but keep very little water in it, and run-of-the-river type that does not use a reservoir. Dams can be environmentally extremely damaging, but they significantly increase the availability of power.

Plants using tides or waves to generate energy are much fewer

A hydroelectric dam.

and generate less overall power. They are considered a future potential more than already developed technology.

Available wind power depends on location and weather. Some of the areas in the world with greatest potential for wind use are very remote and therefore unsuitable – the transmission costs would be too high. Another factor is that wind plants use a lot of land. Best locations are offshore or at high altitudes, where winds are more constant. These locations also do not compete for land that could be used for building or farming. Wind power installed capacity in 2018 was about 564 GW, which is the least of mainstream technologies. Solar power uses a specific type of diode that generates voltage from energy in photons of light. The current technology depends on locations with a lot of sunlight but only reasonable heat – semiconductors do not react well to high temperatures. This limits appropriate locations for large-scale facilities or their efficiency may suffer. Small-scale, single consumer type that can be supplemented with energy from other sources when necessary can however be a good investment. The solar panels are already reasonably cheap. This opens a consideration of a new concept for energy generation and distribution with distributed generators.

Renewable sources, while still plagued by a number of issues, are already a major player in the field and still have large amounts of untapped potential.

Hydroelectric power

Renewable energy sources

Hydroelectric plants are powered by gravitational pull on water. Their power depends on the volume of water available and its drop. They can only exist on the rivers and at the coast, where they can use the power of the tide. In many parts of the world, the rivers' potential energy is insufficient to match the power of thermal plants, but the most powerful power plants in the world are run by hydro power.

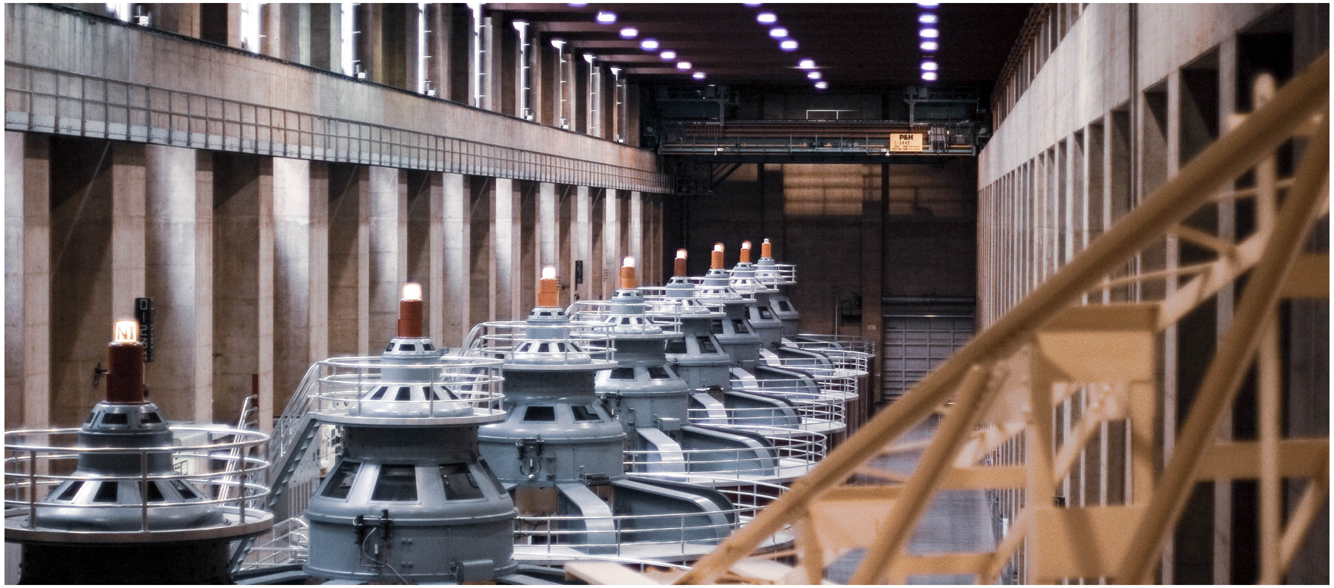
Water is considered a renewable energy since the water is not consumed when energy is extracted. It produces no waste once constructed. Particularly in temperate regions, it has the lowest carbon footprint of all energy sources. The plant needs a dam to control the water flow. But the dam comes with high environmental cost. It creates an artificial lake that destroys local communities and significantly changes flora and fauna. There are solutions available for fish migration upstream. Another problem is siltation – its prevention requires the water that enters the turbines to be filtered of any particles it carries, and siltation can even fill the dammed area, rendering the plant useless.

Solutions without a dam are possible at cost of reduced power flexibility or efficiency. Run of the river plants only use the water that runs past, with no control over it. They are appropriate to rivers with little variability in the amount of water available or locations with natural reservoirs. Pumped storage facilities use excess power in the network when demand is low to pump water and then using this water to expand capability when the demand is high. Pumped storage is the simplest and most common way of storing large amounts of energy on the grid. Tidal plants use changes in tide changes of the sea to generate electricity. There are relatively few locations available where the tide changes are large enough.

Water flow regulation by damming makes it an extremely flexible source of energy. It works at constant efficiency regardless of output power. A water turbine can be easily turned off and brought from a cold start to full power in about a minute, much faster than a thermal turbine could. Hydro power is therefore rarely used as base power in the grid, mainly serving the fluctuating part of the consumption.

Two types of water turbines are used for electricity generation: reaction turbine and impulse turbine. Reaction type is directly acted on by water and need to be encased to keep the water pressure. It is useful where ‘head’ of the water is low. A head means available energy in water in terms of velocity and drop. The impulse type uses a change in velocity of a water jet to run. It does not need encasing. It is mainly useful for locations with high head, but larger variations are possible than with reactive turbines.

Since there is no inefficient energy transformation like thermal or chemical, extraction of energy from water is highly efficient. Efficiency depends on size and amount of water flow available and ranges in about 80-95%. It is more difficult to extract energy from low flow. Betz law for extracting energy from a fluid does not apply due to the ability to control the water flow. Efficiency doesn’t depend on type of turbine, both can achieve similar values. Generator losses are low. Overall about 90% of available energy in the water can be transformed into electrical energy.



Hydro-Electric Generators.

Photovoltaic installations

Renewable energy sources

The sun is an important source of renewable energy with a low environmental impact, except for the manufacture and land use. Its main problem is that as a source of energy it is not available everywhere or all of the time. In parts of the world where the sun is plentiful it can make a reasonable impact in its role of a non-dispatchable supply. This means while its output is predictable in the long term, it is not on an hourly or even daily basis.

Energy from the sun can be used in two ways: as heat source for thermal turbines, or directly through use of photovoltaic cells. As a heat source, it works in a very similar way to any thermal plant. Photovoltaic cells are a type of semiconductor that creates direct current when illuminated. The current fluctuates with intensity of light.

Photovoltaic system is composed of solar cell arrays and its concomitant support system that is commonly referred to as Balance of System, or BOS. The BOS contains supportive structures, wiring, overvoltage protection, an inverter to change produced DC to more commonly used AC voltage, and optionally a battery system, charge controller, a metering solution for feeding power to the grid, maximum power point tracker, and other equipment for improving efficiency. All of these components need testing after installation and then periodically. Generally, photovoltaic system needs little maintenance, but as with any electrical installation it is better to be on the safe side. It is particularly hard to locate the fault once it happens in large systems, so it is important to prevent them.

Each individual PV cell produces too low a voltage to be useful, therefore they are connected in series to form a string or array. Multiple strings are then connected in parallel to achieve desired power. This is a solar panel. Its power can be measured under STC (standard test conditions) or PTC (PVUSA test conditions).

Panels are typically designed to output 100 – 400 W. Together with wiring between the modules and arrays, they are Assembled into protective housings which allow for the best possible cooling and easy handling while protecting against the weather. High temperature and mechanical stress lower the panel efficiency and longevity. The cost of a solar cell is nearly all due to materials and construction. It is estimated that about 9% of the cost comes from operation and maintenance over the 25 - 40 years of lifetime of the system.

The efficiency of commercial solar panels is about 17% in 2019 but expected to rise. There are however a large number of effects at work that can lower it. The most obvious is shading. In the shaded cell, the electrons reverse direction through the p-n junction, while using the voltage from illuminated ones to break it down. This effect can suck up the voltage from a number of neighbouring cells. Most panels come with a diode to bypass the shaded current, restricting the losses to only the shaded portion. For tilted arrays, rainwater is generally sufficient to keep them clean, but in dry and windy areas extra effort to keep them clean may be needed. The absorption of energy is best when the panel is perpendicular to the sun's rays. Tracking systems can be installed to boost energy absorption, but they add cost and require maintenance, and are therefore not common. Usually the fixed tilt is set for the rays to be perpendicular at noon. A number of other efficiency boosting techniques can be used, including tracking system control and cooling. Part of successful energy transformation is also management of surplus energy on sunny days normally using software.

Inverters have to take the DC input from the solar panels and transform it to a sine wave, with frequency synchronized to the grid frequency and an amplitude limited to the grid value. Disconnection from the grid in case of an outage, to prevent islanding, is also managed in the inverter. Grid-connected inverters will use a technique to extract maximum power from the cells, called maximum power point tracking (MPPT). It comprises of digital sampling of the solar output and applying optimal resistance to the output. The algorithm and exact execution are usually proprietary. Typically inverters achieve 98% power efficiency.

Solar panels in a private building can be used to directly power devices that already use DC, or in combination with an inverter for AC power.

MEASUREMENTS

MI 3108 is a combination tester for photovoltaics and installations safety. The installation part covers the requirements of standard IEC/EN 61557. The photovoltaic part covers requirements of the standard IEC/EN 62446 plus – I-U characteristic, STC values as required by IEC 61829 and power measurements on AC and DC sides. These measurements give indication of panel health, its efficiency at the prevailing conditions, and (depending on the connections) locate any fault. You are advised to use safety probes for testing the high-voltage parts. High-quality thermal camera is a must for regular maintenance of solar panels.

Thermal imaging camera MD 9930 can be used to locate power losses due to overheating, weakened contacts and hot spots due to parasitic currents, and other faults on wiring and supporting systems for PV installations. The images can also lead to a new cooling design and other improvements.

Wind power generation

Renewable energy sources

The use of wind as power source is ancient. The first use of wind to mill grain is documented as long ago as 1700 BC in Iran. The technology matured and today it no longer provides mechanical power but generates electricity. The wind drives giant blades up to 90m long to rotate a shaft that is connected to a turbine that can generate megawatts of power.

There are two options for design: the more common type with horizontal axis and vertical blades that provides higher efficiency, and the type with vertical axis, that provides higher reliability, easier maintenance as access to vital parts is at ground level.

Design with horizontal axis puts the main components, rotor with blades and the generator, high in the air. A sensor array turns the blades towards the wind. It is common to use a gearbox, a continuously variable transmission or adjustable speed drive, to change the slow rotation of the blades to higher speeds more suited to driving a generator than using a generator suited to slower speeds. Commercial variants usually have a rotor with three blades, which offers low torque ripple and good reliability.

Vertical axis designs are more suited to smaller or private ventures. The rotor does not have to point into the wind to be effective and the shaft can be brought to the ground before entering the generator, easing the maintenance. However, lower energy yield over time is a major drawback, along with some mechanical considerations. This is to some degree alleviated if the turbine is placed on a roof, where it can redirect the wind from the roof and even double the rotation speed.

The turbines have to be designed for expected wind speeds to optimise efficiency. Theoretical limit is given by Betz's law, which states that no turbine can extract more than 59.3% of wind power. Commercial variants achieve about 80% of this limit after losses from gearbox, drag, friction, generator and converter. It can decrease over time due to wear and remains of insects stuck to the blades that change the surface properties, but this is not always the case. Efficiency is better in stable weather conditions with no rain and most importantly no ice.

Electrical power generated depends on gearing and its ability to change the speed of rotor in the generator.

Fixed-speed type uses and asynchronous generator. When the rotor is spinning faster than network frequency, the slip is termed positive, and it generates real power. It is directly connected to a step-up transformer. The drawback is the high reactive power it takes to start. A soft starter is used to ease this.

Machines with limited variable drive include variable resistors in the rotor circuit that can control the current flow in it. This arrangement can compensate for example gusts of wind that speed the rotor briefly. Real power can be stretched to higher slips than with the fixed speed design.

Variable speed machines with partial electronic conversion or double-fed asynchronous generators add variable frequency excitation instead of a variable resistance. Small amount of power injected into the rotor can create large control over the output power of the generator. When slip is positive, both the main generator and the variable frequency excitation generator emit power into the network. When slip is negative, the variable frequency generator consumes power.

Variable speed machines with full electronic conversion does not control the rotation speed of the generator, but rather uses a frequency converter after the generator. The turbine is allowed to rotate at its optimal aerodynamic speed, often without a gearbox. The generator can be any type, synchronous or asynchronous. Final type of a wind turbine uses variable speed drive train before the generator to adjust the speed of the rotor in it. It commonly uses a synchronous machine. Regardless of the turbine type, the created power is passed through.

Maintenance on top of the wind wheel.

Power distribution

Solutions by the Field of Use

Practical energy sources for electricity generation are often remote from the consumers they serve. Large rivers, geothermal locations, even coal mines and the thermal plants they serve can be located far away from industrial centres that use the generated energy. This is where the transmission and distribution system comes in. The energy is transmitted at very high voltage AC or DC. DC system is more appropriate for very long distances as it reduces losses and can connect incompatible AC systems, but uses more hardware. An AC system is simpler in terms of equipment and the best option for shorter links. The limit where DC becomes more cost-effective is at about 600 km.

Regardless of functional voltage used in the system, voltage amplitude is chosen also based on amount of energy transported. The higher the energy, the higher the voltage. Energy levels are designated also voltage classes. Low voltage systems up to 1000 VAC/1500 VDC are used very locally, from the final step-down transformer to the consumer. Medium voltage systems are still often called 'distribution', even though with up to 36 kV they mostly serve local communities. High voltage has the range between 36 kV and 300 kV is already used to transmit energy for some distance. Extra high voltage (above 300 kV) and ultra-high voltage (800 kV) are used for energy transport between countries. In 2020 the longest unbroken link is Changji-to-Guquan in China, spanning about 3300 km at 1100 kV DC, which is also considered the most powerful with capacity of 66 billion kWh of energy transmitted per year.

The conductors themselves differ depending on when they were constructed. Traditionally copper was used for all wires, but in modern construction it is limited to smaller projects. More modern cables are an aluminium alloy with steel core or all-aluminium alloy. Other materials can be used or added to existing cables to reduce thermal sag.

An important part of the system is the insulators: the elements

Surveying the distribution substation before starting measurements.

that hold the cables on the pylon. They have to withstand normal operating voltage over long term, but also surges due to switching or lightning. They are broadly divided as pin type (supporting the conductor above them) or suspension type (the conductor is hanging below them). The usual materials are porcelain, toughened glass or special polymers for the extremely high voltages.

Components of the system are step-up transformers, cumulative or divisive substations, the transmission with pylons and conductors, and step-down transformers at the destination. At each point, preventative measures have to be taken: the buildings or structures are bonded and grounded, surge protection, fuses or other automatic trip-out devices are in place, equipment for monitoring functionality is set, possibly also insulation monitoring or other protective equipment.

Preventative maintenance differs according to the component. Long lines can be most easily checked using aerial thermography. There are specific methods for measuring ground resistance at pylons, transformer stations and objects with specific power supply like antenna stations. Insulation and continuity measurements are always part of programme. This chapter will mainly deal with actual lines and special structures in terms of safety and functionality.

Earthing resistance of pylons

Power distribution

Each pylon in the distribution line is grounded and there is an overhead shielding connection between them. This creates a distributed grounding for low frequencies and very low resistance if taken together. Measuring every electrode without disconnecting it will give this low measurement and make it impossible to find a fault in the system. Faults however are often high frequency, particularly lightning. This is why every pylon needs grounding, as high-frequency disruptions see a high impedance from long lines and need to ground as close to the source as possible.

There are appropriate three methods for testing grounding of transmission towers, particularly the steel variant: 4 flex clamps, 25 kHz or fall of potential. The latter is described in detail in previous chapter. The measured electrode needs to be disconnected from the network and the network de-energised, which is often impossible.

25 kHz method is described in the standard IEEE 81-1999, but no longer in the 2012 edition. It benefits from physics of impedance: the impedance of an element is a function of signal frequency. Long overhead cables used for equipotential bonding between pylons have low impedance in forms of resistance, capacitance and inductance at 50 Hz. At 25 kHz, inductance becomes prevalent and high enough to very nearly prevent the current from flowing in the conductor. Therefore, the injected current at 25 kHz will only flow to the grounding electrode under test. It is very simple to execute but comes with a number of conditions before giving accurate results. The next pylons in the line have to be sufficiently far away, 150m to be safe.

4 flex clamps method is type of selective method. It can be used to measure resistance of each grounding electrode in a system with multiple, or ground resistance of a system with no dedicated electrodes, just contact to the ground. A powerful advantage is

that the ground bonding doesn’t have to be disconnected from the measured electrode. Transmission towers are often like that. To find their full ground resistance, results from four contacts in its legs have to be combined.

The setup is similar to fall of potential method: two electrodes for injecting the current and for measuring the voltage are staked into the ground at a distance from the electrode under test. To prevent any disruptions from neighbouring pylons, the electrodes should be set perpendicularly to the line conductors. The current probe is set on one side of the pylon and the voltage probe on the other. Both must be at least 5 times the pylon diagonal away. A flex clamp is applied to every earth electrode in the system. In case of a pylon, there are usually four of them. Each of the clamps measures the amount of the injected current on that electrode. Ratio between the each of the currents and the measured voltage at the removed electrode gives all four ground resistances. The full resistance is calculated from the four partial results. This method is amongst the more universal methods that can give reliable results, but is time consuming to execute.

Multiple turns of the flex clamps around the grounding leg enable sensing lower currents.

Remote antenna tower earthing resistance

Power distribution

An antenna tower has a specific problem with measuring its earth resistance: the transmission antenna always offers a low-impedance path to earth.

Grounding of an antenna fills three roles: performance in RF transmitting and receiving, safety of personnel and lightning protection.

In terms of functionality, some antenna designs contain ground connection as necessary part of the design. It is often constructed as ground plate that is about a quarter of signal wavelength long. Other types of antennas do not need the earth connection to function, but it can help with their performance in lowering some types of disturbances.

Safety of personnel refers to the fact that the antenna is a large metallic object with a potential to become live. It has to be bonded to the earthing system to minimize dangerous voltage differences and their duration.

Antennas are lightning bait. The system needs to be well designed and sturdy as lightning strikes are to be expected. The three systems all depend on sufficiently low resistance to earth, which is achieved mainly by large contact surface between the earth electrode and ground. Antenna towers are more effective if built on hilltops or other elevated areas, so the ground resistivity is not a big consideration in their construction.

The electrodes are designed to achieve a low enough resistance. Measuring such a system can be easily achieved by disconnecting the electrode under test from the rest of it and using some form of fall of potential method. Remote areas are well suited to this method. However, disconnection is only possible if the tower is taken offline for the duration of measurement. This is generally undesirable or sometimes even impossible.
It is possible to use the 2-clamp method, but one needs to be

careful. The link directly to the ground electrodes can be provided at the distribution panel with this method in mind, but the electrical plan or other documentation should be consulted before measuring there. The length of bonding from the panel to the earth electrode should have a very low resistance and make very small difference in the measurement.

Second important method for antennas is the impulse method. It measures the impedance of the system in frequency range typical for a lightning strike, which can be used to gauge the effect of an actual strike. The instrument injects a transient pulse with frequency content up to some hundreds of kHz.

There is a design feature with some of the towers that makes doing the 2-clamp method at the panel inappropriate. The bonding between the earth electrodes can be in a ring. In this case, measurement at the panel will produce resistance of the ring, not earth resistance. See Figure 1. For successful measurement, the clamps have to be applied between the ring and the ground electrodes to force the return path of the loop to go through the ground. The method does not have inbuilt option to check the results like fall of potential method has by moving the electrodes. It is important to keep construction records for reference.

Metrel offers multiple testers that support 2-clamps measurement method. The most basic is the earth resistance tester MI 3123 with optional clamps. Multifunctional testers MI 3155, MI 3152 and MI 3102 all are enabled for it. Clamps are included in some of the standard sets. The method can be also done with the earth analyser MI 3290. It is strongly recommended to transfer the results to MESM software to assist in trending any changes in the result.

The 2-clamp method measures resistance of the whole earthing system and even small changes can mean beginning of corrosion in the system.

Multiple turns of the flex clamps around the grounding leg enable sensing lower currents.

Insulation of long cables

Power distribution

Long cables for power distribution are mostly overhead and do not need to be insulated. However underground or underwater cables do need insulation. Their environment is conductive and leakage would get out of control without it.

Capacitance is a frequency dependent physical property of any conductive body. In overhead power cables where frequency of distributed signal is relatively low, it is only an issue with very long cables or very high voltage. A long cable lying in wet and conductive environment like earth or water is another issue. Insulation is defined, in DC conditions, as resistance. In an AC environment, it becomes defined as impedance, containing capacitive and inductive components. In case of long cables, the capacitance between the cable and its conductive surroundings can become important for signal and power transfer. Charging current for the capacitance can be higher than the rated current of the cable. This depends on cable length and voltage used. Ferranti effect can make the voltage at the end of the cable higher than the input, in extreme cases even exceed the rated voltage. It is caused by the distributed inductance and capacitance acting together on an unloaded or lightly loaded line where mostly only capacitance charging current flows. It causes voltage drop over the cable inductance that is in-phase with supply voltage. The resistance is considered negligible.

In the case of energy transfer underground, this translates into losses, high reactive power and other issues with power quality. There are some techniques that help mitigate the effects. Inductance can be added to the system to lower the reactive power. This is easy to achieve as extra windings on transformers. DC power transfer is preferable where possible, but underground cables tend to be the last stretch from transformer to the consumer where AC is required. Capacitance of the cable can be lowered by using thicker insulation, larger distance between cables in the system, and distancing the cable from conductive surroundings by using a duct.

Insulation of the cables is still extremely important. It protects from DC leakage and from any accidental contact. Underground, this is mainly due to animals, but also important during any construction and maintenance work. Testing can be done with DC as insulation or AC as leakage current.

Measuring the insulation of longer cable takes time. The capacitance needs charging before a meaningful result can be taken. Powerful instrument speed this process and provide high accuracy measurement. Metrel recommends the TeraOhm line which offers test voltages up to 10 kV and can be used for nearly any length of wire. It also offers voltage and frequency measurements in the network. Other important capabilities include measuring with step method and quick rise method that offer a view of AC properties of the insulation, and impulse test that give insight into case of lightning strike.

Leakage current can be measured with a multifunctional tester and a clamp that operates in the milliampere range. MI 3155 standard set contains such clamps.

High voltage testing in a large switching station with MI 3210.

Substations and transformers

Solutions by the Field of Use

A substation is a facility for electrical crossroads. It contains switching gear, step up or stepdown transformers, other power converters, powerful surge protection, optionally also filtering or computers for automatic control of the processes.

Typical construction leads the power through a number of stages of safety gear before being transformed or switched: ground wire connected to low-resistance local electrodes, surge protection, automatic disconnection and circuit breakers, etc. Transformer and switchgear each have their own lightning arrester and connections to the ground. The system must be highly resilient, particularly in the larger facilities that support power distribution for wide areas.

Functions of the substations include disconnection of part of the grid for maintenance (transmission substation), dividing or collecting the power, converting it between different systems, or serve a specific need like railway or industrial power. Voltage transformers are a quintessential component of the electric grid. They can change the nominal voltage in the part of the network by magnetic link. This is useful to lower losses in the grid by using high voltage for long-distance transfer, but still a safe low voltage at the end user. Magnetic link also causes galvanic separation between parts of the grid.

Transformer is a pair of coils on a common core made from laminated iron. In AC conditions, magnetic flux in the core will connect the two coils. Voltage will be changed in the same ratio as the number of turns in the coils. Current changes inversely. Even though there are many sources of loss, a typical transformer can achieve about 98-99% efficiency. Since their power is very high, this is still a lot of energy to lose. Forced circulation of air, water or oil is used for cooling to prolong the life expectancy and limit power hazard. Protective devices used depend on the cooling agent used. Dry transformers are more sensitive to overheating, but a smaller fire hazard. Typical devices include circuit breakers, fuses, shunt breaks, temperature sensors, or combined devices that isolate the transformer in case of unexpected events. Insulation is the most important safety and functionality parameter. It needs to be in good condition between turns, between windings and core, between the windings, and around the windings' terminals. Most commonly used materials are paper soaked in the same oil that is used for cooling wound around the wires in windings. Modern polymers can be used instead of paper. The whole windings can be dipped into resins to encapsulate them, improving rigidity as well as insulation. Converters perform other changes in electrical signal where necessary, particularly between incompatible power systems. Rectifiers turn AC into DC, while inverters do the opposite. Filters change frequency contents. Specialized, even digital tools may read the mains signalling and remove it from the signal to prevent high-frequency damage to transformers.

Connections to different locations over the power lines.

Substation earthing has to have an electrode type earthing installed directly underneath its footprint, regardless of its location. Possible designs include electrode directly under the floor slab within the foundations, pocket design, or a copper strap. The electrodes must be up to 3 metres apart and connected in a cable type grid. The station earthing system must be independent of and separate from other earthing of other building parts and from lightning protection.

Transformer predictive maintenance

Substations and transformers

Damage in transformers can be caused by poor design, poor maintenance, overheating, etc. It can show as shorted turns, changes in turn ratio, loose connections and weakened contacts on tap changers. The measurements look at absolute resistance value of each winding, differences between windings in a transformer and possible open connections.

Transformer ratio is the ratio of voltages and also numbers of turns on each side of it. This is the measuring method: an AC voltage is induced at a bit slightly higher than nominal frequency in primary. It is measured on the secondary. It should be within 0,5% the nameplate value. Reasons for changes in ratio include failures in insulation between turns, turns breaking, and similar occurrences. Main issue that causes the breaks is over-heating due to cooling failure or overcurrent. Higher frequency is used to avoid disruptions at the nominal frequency.

Taps are contacts to the winding in different positions and therefore at different ratios. Tap changer is a mechanical device that moves connections between them. Tap evaluation means testing each tap position for continuity. The contact should be firm, safe and have a low resistance to prevent any chance of overheating. An 'on load' tap changer can change ratio while energised, while 'off load' needs to be disconnected and de-magnetised before changing.

The measurement of winding resistance is simple in the essence: apply a DC current to the windings and measure the voltage to calculate the resistance. The core must saturate and the system must be in balance for a sensible result to emerge. Inductance of the windings causes a transitional effect that can last a couple of minutes for very large transformers. Test results cannot be taken at face value. At the very least, they are compared to the adjacent winding in 3-phase transformer at the same tap that is assumed to have the same temperature. They have to keep within 1% of each other. It is also possible to use the previously measurements if the temperature of the windings during measurement is known for temperature correction of the results. Results can only be compared at the same temperature. Most large transformers have a temperature gauge built-in, or oil temperature can be assumed to be about the same as that of the windings.

To be thorough each tap position should be tested, but during routine maintenance, usually only the currently designated is. This is particularly true if transformer is equipped with ‘off-load’ tap changer. The transformer must then be discharged before changing tap and the measurement takes a very long time. With ‘on-load’ tap changer, the measurement can be left running while changing taps. This tests functionality of the tap changer as well. After measurement the transformer is demagnetised. It ensures smooth restart. Use one of the windings and a demagnetizing current form. Connection of the instrument is generally at each end of the winding under test with Kelvin clamps. Primary and secondary can be tested at the same time if two measuring instruments are available. Three-phase transformers with dual windings are best tested with an extra voltmeter, while there can be only one current source. Care with connections can lower time to core saturation.

Metrel’s Digital Transformer Analyser MI 3280 is a specialised instrument for testing single and three phase transformers. The user interface makes operating easy with references always in reach. Windings resistance can also be measured with the MicroOhm line of tester by Metrel, like MI 3252. With its high current even the largest transformers can be tested safety. It however does not include the smart features of the MI 3280.

The Impedance Meter MI 3144 permits testing of live transformer’s windings with high current. This method also tests the automatic trip-out ability of the installation.

Multifunctional instrument MI 3155 it does not pack enough power for testing large transformers, it can be useful on medium and small sized transformers. It can measure winding resistance while transformer is live.

Comparing measurement result to documentation is part of the procedure.

Installations exceeding 1 kW

Solutions by the Field of Use

There is a number of large installations that do not quite fit the labels considered before in this publication. Industrial locations, medical complexes, shopping centres and other large objects generally have their own step-down transformer and parts of installation at medium voltage. There are therefore also numerous other methods applicable to this voltage range that are not specific to any particular plant. This solution set will deal with such methods and their applications. Most of them can be used previously considered locations and scenarios.

Lightning protection and surge protection devices need to be considered as a whole in the medium voltage range. They, of course, strongly depend on the location's specifics and how the earthing system has been executed. Methods for measuring partial earthing integrity with a single clamp deserves consideration. There is general overview of testing switches, joints, bus bars and other low-resistance elements. Step method for insulation resistance is a generally useful method in cases of very high nominal voltages – it can reveal issues at lower test voltage than the working one.

Industrial locations need to confirm the insulation and bonding of walls and floors. Specific electrodes and methods are necessary. Power quality analysis can save a lot of energy and hence money and is therefore popular in industrial and other professional settings. Asymmetry is amongst the most destructive preventable power quality issues.

Switching events cause considerable disruption of power quality in high voltage installation and the rest of the network. They must be monitored and controlled. Before starting a construction project, the electrical properties of the locality need to be determined.

Specific earth resistance measurement is required for planning the grounding electrodes. Different measurement frequencies are used in the measurements to gain a full understanding of its properties under extreme circumstances such as lightning strikes.

Industrial locations need more powerful protection than standard RCDs allow, called an ELR or earth leakage relay. Its working principle is a bit different and safety can be compromised in certain circumstances, but ability to protect high powered systems is the primary concern. For rapid fault finding thermography is essential. It is a non-contact, non-invasive diagnostic method.

Each of these procedures and methods has wide options of applications in medium voltage range and are important for maintenance personnel to understand. Metrel offers solutions that conform to international standards. Instruments provide elegant testing solutions with seamless connection to PC and automatic report generation.

Partial earth bonding resistance with single flex clamp method

Installations exceeding 1 kW

Earth bonding can be measured as a single system or one electrode at a time. Measuring the system gives good information on safety. Faults can generally find their way to ground as long as the resistance is low enough. Measuring each probe by itself gives better information about necessary maintenance, and also about protection in case of a lightning strike. Paths to ground should be evenly conductive to prevent overheating. Probes in the ground slowly rust and decay. Usually there are many connected in parallel, therefore creating a low-resistance system. To discover failed electrodes, they have to be individually measured using the selective method.

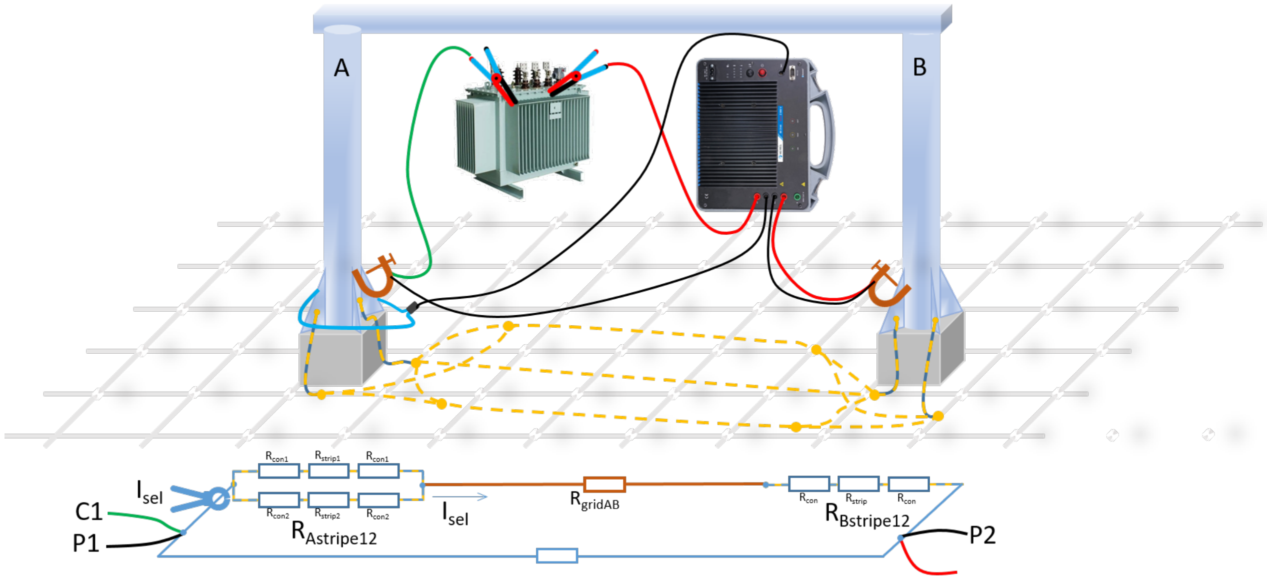
The most obvious way to achieve this is by disconnecting the electrode under test from the system. This is not always possible or a good idea. Possibility of disconnection means an extra switch or other device that needs to be maintained. The second procedure is to use a selective measurement method that enables differentiation between the measured probe and the rest of the system.

Selective method with single flex clamp starts like the 3- wire method for earthing resistance measurement. It uses a current probe at 5 times the object diagonal and the voltage probe at about 62% of this distance. Both should have a very low resistance to avoid impeding the current injected into the further away probe. The current should be as high as possible to lower the effect of spurious earth currents. The flex clamp is wrapped around the connecting wire on the system side while the 3rd wire is connected to the electrode under test. It measures the injected current that flows into the system. From this information and the known injected current, the resistance of the single probe can be calculated.

The most advances Metrel solution for selective method is the

MI 3144. It needs an external power source, but it can develop up to 300 A measurement current, which guarantees stable and repeatable results even in very big systems. The flex clamp comes as part of the standard set and is large enough to envelop almost any conductor to the ground. It is appropriate for both lightning protection measurements and earthing system. The instrument can be controlled by another Metrel instrument like the multifunction tester MI 3155, or by an Android phone. It is possible to synchronize other measuring points to the same current source to test the step and touch voltages during the high-current pulse.

The MI 3290 Earth Analyser supports multiple flex clamps for simultaneous measurement of multiple probes on one object. The primary application of this is measurement of distribution pylon's legs, but can also be used for other objects with 1-4 legs or to speed up the process in a larger object. It allows use of multiple probes in parallel for current injection to lower the common resistance. Instead of high current, it uses different smart techniques to stabilise the measured results. This makes the system light, battery-powered and very portable.



Specific earth resistance measurement methods

Installations exceeding 1 kW

Specific earth resistance or earth resistivity is a property of the material that forms the ground at a location, describing the soil's resistance or conductivity to electrical current. It is generally impossible to determine analytically, since a large number of variables contribute to it. Soil can be composed of different materials. Compactness, humidity and temperature all play a part. Therefore, while it is possible to give an estimation of resistivity based on these features and tables of values, measurement is the only reliable way to determine it.

Specific resistance is generally measured as resistance per unit of the material. In case of soil, a meter (for distance) is an appropriate unit. There are two most commonly used measurement methods: Wenner method and Schlumberger method.

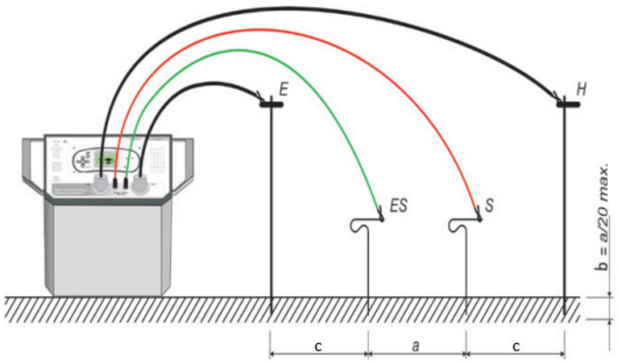
Wenner is possibly the most common. It requires 4 probes or pins set at equal distances, pushed into an equal depth in the soil. This depth should be similar to the expected depth of future grounding system. Outer two probes are connected to current generator while the inner two measure voltage with a high-resistance voltmeter.

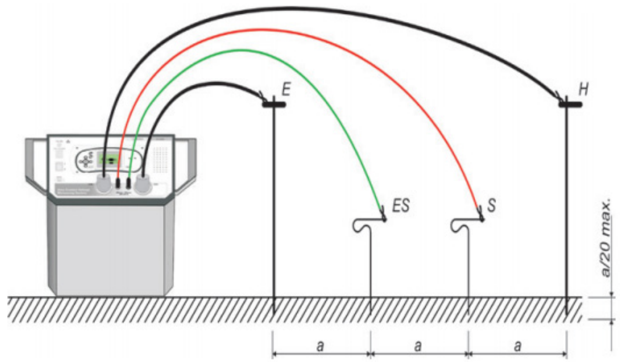
The measured resistance RW is used to calculate the resistivity of soil using distances between probes a and depth of probes b.

If b is small compared to a, it can be reduced to:
Metrel recommends the a to be 20 times higher than b.

Schlumberger method uses uneven distances between the probes: distance between inner voltmeter probes are a, while distance from voltage to current probes is c. Probes' depth is b. Similarly, current is injected and voltage measured. Soil resistivity is calculated from the resistance RS.

Metrel offers a number of instruments that can, amongst other tests, perform specific earth resistance measurements. MI 3290 Earth Analyser supports calculating both Wenner and Schlumberger methods. It is the most comprehensive instrument for measuring earth resistance with IEEE 81-2012 methods and more. MI 3295 Step and touch system only supports the Wenner method. It is the more powerful instrument with fewer functions, applicable to large systems. The installation tester, MI 3155, supports the Wenner method as well. It is amongst the most adaptable of the multifunctional testers in the Metrel portfolio and a great choice for industrial locations.





Recording transients of switching manoeuvers

Installations exceeding 1 kW

Generally speaking, a transient is any short duration electrical event that happens as consequence of a change of the equilibrium in the system. It ranges from inserting a battery into the device or changing the volume of active loudspeaker to the consequences of a lightning strike on a transmission pylon. Changes that cause transients are normally related to sources of energy, but can also be switching manoeuvres or changing the variable resistances, capacitances or inductances. Size and duration of transient response depend on energy present in the system, resistances and type of change.

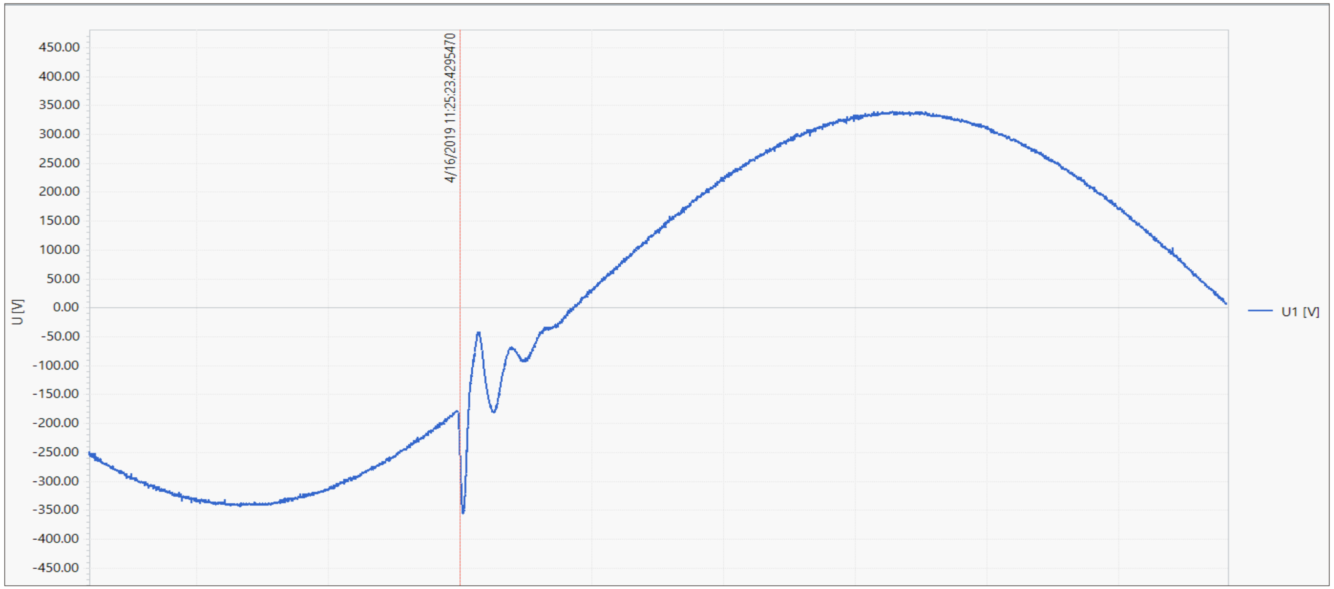
Mathematically speaking transient response can be described as dampened oscillation. Response time is the time from change taking place to the system reaching a steady state. Steady or equilibrium state is the system working with no changes taking place and within tolerances. The transient is damped both by time and by distance from the source. In the grid, it typically manifests as some microseconds to milliseconds long frequency and magnitude change. It can keep one polarity for the whole duration or oscillate between polarities. It can occur in a single line or in multiple at the same time.

Transients in an electric grid that would propagate more than locally must be caused by fairly powerful phenomena. The most obvious is the lightning strike, even though it dampens more rapidly due to its high frequency components experiencing very high inductance in the wires. Man-made transients are most commonly caused by switching manoeuvres in the grid. Very large consumers being added or starting up can also show up as transients. Transients can be highly problematic to the insulation of cables and devices. Even though they are brief, they can go over the rated voltage of the insulation and degrade it, either immediately or over time. The energy from them can also be transformed into vibration or heat, further damaging to their surroundings. More rarely, the insulation can be broken down and arcing may happened. Due to their short duration, they are rarely discovered as culprit for the damage.

The best way of discovering transients is constant logging of power quality. Where this is not an option, a limited-time power quality measurement can be done and its findings extrapolated. However, since transients tend to be random or close to random, a limited-time study may not create a representative report.

With the report and predictions from it, it is possible to design a system with high resistance to transient events. Materials, distances and safety procedures are designed to prevent damage from them in case they cannot be prevented at source.

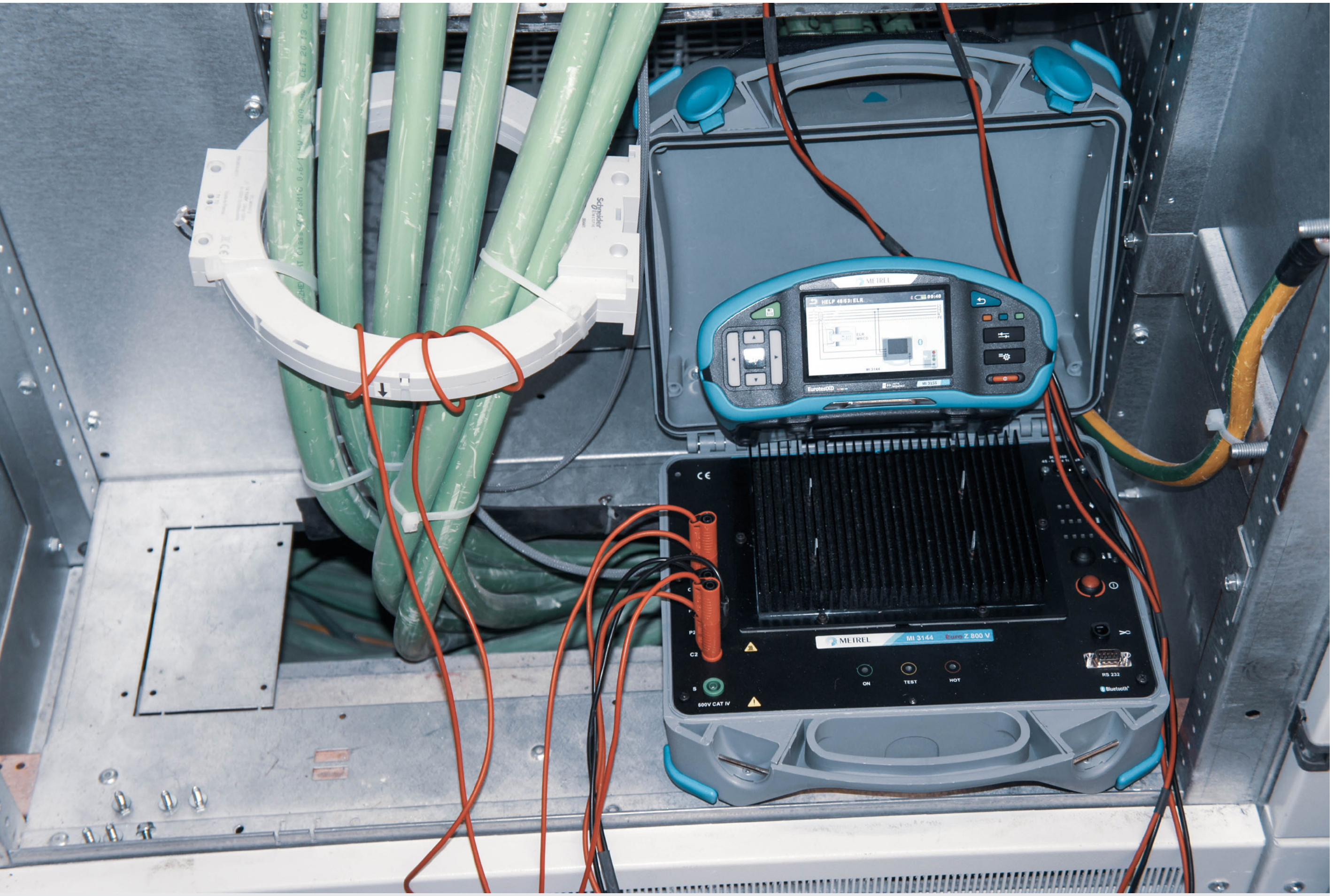
Power quality measurement is a process that should ideally take at least a week. Therefore having to repeat it is expensive and time consuming and should be avoided. Instruments from Metrel PQA line include diagnostic tools to check the connection to the system and prevent faulty measurements. All models support transient recording, but unlike others, the Power Master MI 2893 can operate simultaneously with multiple recorders to capture phenomena like inrush or waveform. The results can be later transferred and further processed in Power View software on PC.



Capturing transient events with MI 2893.

Earth leakage relays and fault currents

Installations exceeding 1 kW



ELR (earth leakage relay) or MRCD (modular residual current device) are industrial protective devices with adjustable leakage current and time to disconnect. In industrial setting, the leakage currents can be considerable even during normal operation. Occasional rises due to a combination of devices or machines working in a specific part of their work cycle are normal as well.

Therefore the protective device should tolerate such rises for a limited period. Industrial settings often require high power availability and unnecessary power outages can be very costly. There must however be a limit how far both magnitude and duration of leakage current will be tolerated.

The principle of operation is reasonably simple: a toroid current transformer with multiple primaries for the phase and neutral lines of the installation and a single secondary, transfers current when there is a current imbalance between phases. The sensed current is electronically is compared to the user adjustable settings. If the limits have been exceeded, a signal is sent to the medium voltage switching device to disconnect the supply.

Testing effectiveness of this type of protective device has two elements: testing disconnection time and disconnection current. To thoroughly test the ELR, it should be set to each combination of its available settings. Regular testing only encompasses the actual setting at the location. Disconnection current test uses linearly rising current until the ELR trips. It can be DC, AC or pulsed, depending on ELR type. In the latter two cases, it is the effective and maximum value that rise.

The current is injected using a flexible clamp with desired properties regarding the current shape that can be rolled into multiple turns to multiply the injected current. Smart instruments can make this part of the processing and present a realistic result. Less smart instruments will require a manual calculation.

Disconnection time tests use the value of current prescribed by the ELR and measure time to disconnection. The test current pulse is injected (as opposed to rising steadily in the current test). Minimum response times are some tens of milliseconds. The desired result is the delay that has been set.

Metrel MI 3144 is the instrument for this measurement. It comes with flex clamp for current injection in standard set. The settable parameters cover test current shape and magnitude and limits for successfully passed test. The instrument provides high performance while keeping high portability. It can be controlled using another Metrel multifunctional tester like MI 3155, or with Android app.

Multiple turns of the cable are necessary to inject the current.

Using thermography in electrical installations

Installations exceeding 1 kW

Thermography is a test that uses a camera operating in the infrared spectrum to record heat patterns. IR spectrum has lower frequency than visible light and transfers heat. It can be absorbed, reflected or transferred though objects. When it is absorbed, the object starts to emit it again as it heats and the camera can pick that up. To accurately calculate the temperature of the object from the IR frequency, additional information is necessary: did the object absorb all the IR waves, or did it reflect any from its surroundings? The factor for absorption is called emissivity and it has to be input by hand. Values for different materials are found in tables, but it can also be reasonably easily measured.

Ability to see in IR spectrum opens a great number of non-invasive diagnostic options. IR partially shows even through the housing. The most obvious application is to search for hot spots that are commonly caused by weakened contacts or mechanical issues in e.g. motors. The bad contacts can be tiresome to find in a large switchboard with electrical measurements alone, however their heat signature will highlight them immediately. This is of course assuming that all are at least approximately equally loaded. Contacts under higher load will always be hotter than those under lower. In thermography context is often the key. It is sensible to create records during commissioning of the facility to be able to compare them with later inspections. Having a reference also means exact temperature measurements are not needed, just comparison of images.

Mechanical issues can be even more difficult to recognise. Motors and generators can regularly operate at quite high temperatures. Unless there is another of the same type and at the same load available, or records of temperatures for the motor under test, the camera cannot determine whether there is a problem at a first sight. The temperature should be measured with higher accuracy then. Emissivity must be set to reasonably accurately too – if possible, measurement is preferred to choosing from tables. The measured temperature is then compared to manufacturer's data on preferred temperatures for the motor under test.

Metrel offers three model of thermographic instruments. They can all boast a very fast thermal refresh rate of 50 Hz, which makes them comfortable to use. MD 9930 is the most powerful with 120x160 pxl thermal resolution, manual zoom and powerful firmware. It offers alarms when temperature in the image goes out of defined limits, which is useful for fever screening, but also for any application with limits on temperature. MD 9910 is a more basic variant, small and portable, it still offers 80x80 resolution and some basic settings and saving up to 20 images. MD 9880 is a combined instrument with multimeter and thermal viewer. It does not save the images, but thermal view on the screen can point to locations that need to be measured electrically.

Differences in the camera's view of different emissivity material and its different temperatures.

Selection guide by application

LOCATION	Application	Earthing & Grounding testers				Photovoltaic testers	Installation testers		
		MI 3295S Step Contact Voltage	MI 3295M Volt-meter	MI 3290 Earth Analyser	MI 3123 Earth / Clamp	MI 3108 EurotestPV	MI 3152 EurotestXC	MI 3155 EurotestXD	MI 3144 Euro Z 800 V
									
EARTH/GROUND NETWORK IMPEDANCE	Use of disconnected power lines			•					
	Single clamp method for lightning system			•					•
	Fall of potential method	•	•	•	•		•	•	
	Two clamps method			•	•		•	•	
	Earthing resistance of pylons			•					
	Partial earth bonding resistance								•
	Remote antenna earthing resistance			•					
	Simulated fault step and contact voltage	•	•	•					•
	Earthing integrity and earth potentials	•	•	•					•
	High and low frequencies for earth testing			•					
	Specific earth resistance	•	•	•			•	•	
CONTINUITY, EQUIPOTENTIAL BONDING AND HIGH VOLTAGE INSULATION	Testing high energy switches								
	Equipotential bonding of a metal construction								•
	Continuity of transformer rails								
	Tesing contacts, joints and switches								
	Generator insulation						•		
	Insulation diagnostic factors PI, DAR and DD						•		
	Insulation resistance of long cables								
	Step method for insulation measurement								
	Insulated or semiconductive walls and floors						•	•	
	Surge protection devices on a solar plant						•		•
TRANSFORMER AND GENERATOR MEASUREMENTS	Insulation of transformer and generator windings								
	Transformer predictive maintenance						•		•
	Automatic trip-out abililty on low-voltage side								•
	Photovoltaic system testing					•			
	Impedance of live transformer and fault currents with hot factor								•
	Wind generator inverter testing								•
	Renewable power and car charging stations						•	•	•
	Earth leakage relays and fault currents								•
POWER QUALITY ANALYSIS THERMOGRAPHY	Power quality analysis in a medium voltage facility								
	Flickers tracking								
	Powerline signaling								
	Asymmetry and overheating predictions								
	Recording transients of switching maneuvres								
	Using thermography in electrical installations								

Conductivity & Equipotential Bonding testers			Insulation & Leakage testers			Transformer ratio & TAP changer testers	Power Quality testers			Thermal cameras
MI 3252 MicroOhm 100A	MI 3250 MicroOhm 10A	MI 3242 MicroOhm 2A	MI 3210 TeraOhmXA 10 kV	MI 3205 TeraOhmXA 5 kV	MI 3201 TeraOhm 5 kV Plus	MI 3280 Digital transformer analyser	MI 2893 Power MasterXT	MI 2892 Power Master	MI 2883 Energy Master	MD 9930 IR thermal camera
										
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MI 3295 Step Contact Voltage Measuring System

Earth analysis

Measurements of different earthing parameters is amongst the most important maintenance actions that ensure safe use of the installation. Typically measurements include earthing impedance, soil resistivity or specific resisntace, analysis of voltage drops around the object, step, contact and mesh voltages, etc. Different methods are used in regard to the measured object. Power plant will not be measured in the same way as distribution pylon.

The MI 3295 Step/Contact Voltage Measuring System is a voltage measuring system intended for testing and verification of protective earthing of power stations, substations and other power systems. It is one of the smallest solutions on the market but cleverly designed to balance safety of use and powerful generator. It includes special technologied for elimination of even very low earth noise currents in range of mA. It utilizes a SELV voltage of only 55 V to perform the tests, reducing the risk of injury to people or livestock when testing in populated area. Test results can be scaled on site to the phase to protective earth fault or lightning strike conditions. The measurement of earth resistance, soil resistivity and the analysis of voltage drop around objects ensure the safety in the surrounding area the earth fault or lightning strike.

The system consists of Station (MI 3295S) for current generation and autonomous Volt-Meter (MI 3295M). Due to high test current (up to 55 A) and effective noise filtering the MI 3295M ensures very accurate and stable measurements (resolution down to 10 μV). Multiple voltmeters can be used simultaneously for faster measurements and analysis of voltage distribution around tested object. Test results and parameters could be saved in the instrument's memory for further downloading, analysis and test report printing with the PC software HVLink PRO.

MEASURING FUNCTIONS

- Step voltage;
- Contact voltage;
- Specific earth resistance;
- Earth resistance.

MI 3290 Earth Analyser

Earth analysis

The measurement of earth resistance, soil resistivity and the analysis of voltage drop around objects ensure the safety in the surrounding area for the event of an earthing fault or lightning strike.

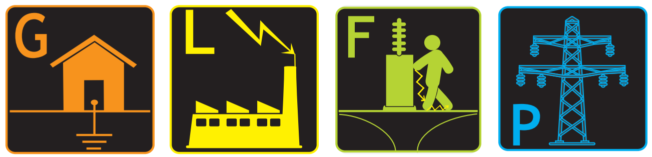
MI 3290 Earth Analyser is a remarkable all in one solution for earthing measurement and analysis. It includes all the measuring methods from standard IEEE-81 in a single easily portable case. The measurement methods included are sweep frequency generator, 25 kHz generator, lightning strike simulator (also called pulse generator), step, contact, touch and GPR voltage research tools, flex clamps method for pylons with singe or multiple legs, classic 2,3 or 4 wire method, selective method with one clamps, and two clamps method. Additionally the instrument supports advanced methods for time savings and for complexity reduction.

- Excellent immunity even against changing earth currents;
- Optional very sensitive autonomous step voltmeter with high resolution and stability down to 10μV;
- Synchronized voltmeter and generator eliminate the need for long wires;
- Multiple voltmeters can operate simultaneously with single generator;
- Low weight;
- High safety due to low output voltage (55 V);
- Downloadable test results and parameters directly to the PC with the help of the professional software MESM for further analysis.

MI 3290 Earth Analyser is a portable, battery or mains powered test instrument with excellent IP protection (IP 54 open case). Battery operation enables testing and analysis without the need for external power. Access to the testing site is made easy without any heavy equipment. High electrical noise immunity makes this instrument best suited for industrial environments. Instrument is available as different set combinations of accessories and measurement functios.

MEASURING FUNCTIONS

- Earth Resistance 2,3,4 -pole (frequency sweep or fixed one: 55 Hz – 15 kHz);
- Selective Earth Resist (1 x iron clamp);
- Earth Resistance (2 x iron clamps);
- Specific Earth Resistance (Wenner and Schlumberger method);
- HF-Earth Resistance (25 kHz, acc. to IEEE 81);
- Earth Resistance of mono pylons with 5 m flex clamp (1 x A 1487);
- Earth Resistance of multi-leg pylons with up to four flex clamps (up to 4 x A 1487);
- Current measurement (Iron, flex clamps);
- Low Ohm measurement 7 mA and 200 mA;
- Earth Potential;
- Step and contact measurements;
- Impulse Earth measurement 10/350 μs.



MI 3252 MicroOhm 100A

Continuity testers

The equipotential bonding and connectivity of conductors with larger cross-section, parallel connected bars and metal strips are hard to prove without a powerful and accurate measuring tool.

The MI 3252 MicroOhm 100A is just what is needed to achieve reliable and stable results with resolution of 1 nΩ. The MI 3252 MicroOhm 100A is portable low resistance ohmmeter used for measuring low contact resistances of circuit breakers, switches and busbar joints using test current from 100 mA to 100 A. 4-wire Kelvin measuring method ensures very high result accuracy (0.25%) and eliminates test leads resistance. MI 3252 can be powered from mains or internal rechargeable battery. PC software HVLink PRO supplied as a standard accessory enables download and analysis of results and test report printing.

MEASURING FUNCTIONS

- Resistance measurement with adjustable test current (100 mA ... 100 A);
- Voltage drop measurement.

MI 3250 MicroOhm 10A

MI 3250 is intended for continuity measurements in industrial applications. Inductive mode of operation enables work with small to medium sized transformer coils, motors and other inductive loads. Other applications include circuit breakers, switches, busbars or cable joints. Measuring current can reach up to 10 A and resolution up to 10 µΩ. 4-wire Kelvin method ensures high accuracy while eliminating test lead resistance. MI 3250 can be powered from internal rechargeable batteries or from mains. Results are stored in the memory and can be later transferred to PC using the included PC software HV Link PRO. The software supports result analysis and printing the reports.

MI 3280 DT Analyser

Transfomer analysis

MEASURING FUNCTIONS

- Turn ratio measurement of single and three phase CT, VT and power transformers;
- Phase deviation between high voltage and low voltage winding;
- Excitation current;
- Winding resistance measurement of single and three phase transformers.

Safe and efficient operation of an electrical system relies on good connectivity between conductors, joints, busbars, switches and components on the way from the power source to the load. Loop impedance testing is one of the best options for finding the source of losses, high voltage drops, faults on live circuits and bad contacts. The MI 3280 Digital Transformer Analyser is powerful single and three phases solution for automatic testing of any vector group of LV and MV transformers. Beside transformer turn ratio test, MI 3280 allows also measurement of transformer winding resistance, which could be periodically performed to inspect the transformer condition.

The MI 3280 Digital Transformer Analyser is a portable, battery (Li-ion) operated test instrument intended for transformers turn ratio diagnosing, phase deviation, excitation current and winding resistance measurements of single and three phase CT, VT transformers and power transformers. It offers excellent IP protection (IP 65 case closed, IP 54 case open) for operation in harsh environments. Colour LCD touchscreen enables straight-forward operation with included help screens and clearly readable results. Test results could be saved to the instrument’s memory and transferred either to PC or Android device with the standardly supplied software via Bluetooth interface or USB cable. PC software offers also creation of test structures, AUTO SEQUENCE® editor and report creation.

MI 3210 TeraOhmXA 10 kV

High voltage insulation measurements

MEASURING FUNCTIONS

- Insulation Measurements up to 20 TΩ;
- Diagnostic Tests (PI, DAR, DD);
- Step Voltage Test;
- Withstanding Voltage Test (DC) up to 10 kV;
- Voltage and frequency measurement up to 550 V TRMS;
- Capacitance.

Characteristics of insulation tend to change through the time, normally getting worse through ageing. Enviromental variables like temperature, dirt, humidity, mechanical and electrical stresses, high-energy radiation etc. have a big influence on insulation characteristics.

Protecting the electrical device or system with insulation ensures its safety for operators, its reliable operation and longevity. Insulation resistance is measured in type testing of the product, during final tests before commissioning each unit and during regular maintenance.

MI 3210 TeraOhm XA 10 kV is a portable, battery or mains powered test instrument with excellent IP protection (IP65), intended for diagnosing of Insulation Resistance by using high DC test voltages of up to 10 kV. Because of its robustness (CAT IV/600 V protection) and high immunity to radiated RF fields it is well suited for industrial or other noisy environment. The voltage can be adjusted in 50 V or 100 V steps and timers for measurements are programmable. The charging rate for capacitive load is < 3 s / μF at 10 kV, discharge is automatically performed after every test.. Results can be viewed on the instrument in numeric or graphical form or transferred to a PC using PC software. Available interfaces are USB, RS232 and Bluetooth.

MI 3108 EurotestPV

Photovoltaic and electrical installations tester

Photovoltaic installation consists of an arrangement of several components, including solar panels, a AC/DC inverter, cabling and other electrical accessories to set up a working system. To ensure calculated reimbursement of investment (ROI), a photovoltaic system should operate on the maximum efficiency and whole system should be maintained appropriately to create safe environment and proper operation.

Systematic and constant approach of the photovoltaic parameters include:
- Easy identification and problem elimination within the PV installation;
- Preventative maintenance by the early location of potential sources of disturbances or failures;
- Optimization of the power network based on power quality parameters.

It is possible to test complete electrical installation in accordance with IEC/EN 61557 standard group and perform all the tests required ny IEC/EN 62446 for one- or three-phase PV installation. Additionally the instrument supports measurement of I-U characteristic and calculation of STC values required by EN 61829. Metrel recommends using the PQA line for measurements of the inverter's DC and AC sides.

MI 3108 includes the complex disconnection in case od failure while within its working conditions (up to 1000 V/15 A DC). Photovoltaic safety probe A 1385 that ensures safe disconnection and improves operator safety is part of hte standard set.

MEASURING FUNCTIONS

Photovoltaic installations:

Measurements on the DC side of PV inverter:
- Voltage, current, power;
- Uoc (Open Circuit Voltage) and Isc (Short Circuit Current);
- I - U curve of PV modules and strings;
- Irradiance;
- Module temperature.

Measurements on AC side of PV inverter:
- Voltage, current, power;
- Efficiency of PV module, inverter, PV system calculation.

Electrical installations:
- Insulation resistance;
- Continuity of PE conductors;
- Line impedance;
- Loop impedance (sub-functions with high current and without RCD tripping);
- RCD testing (type AC, A and B);
- Earth resistance;
- AC current (load and leakage);
- TRMS voltage, frequency, phase sequence;
- Power, energy, harmonics.

MI 3155 EurotestXD and MI 3144 Euro Z 800 V

Electrical Installation Safety Testing

- 3-wire test of PE (RPE function) without extension lead conductor;
- Autotest insulation function between L-N, N-PE and L-PE (R ISO ALL function);
- 4-wire continuity test;
- Insulation resistance with DC voltage from 50 V to 2500 V and PI, DAR calculation;
- Varistor test;
- Continuity of PE conductors with 200 mA DC test current with polarity change;
- Continuity of PE conductors with 7 mA test current without RCD tripping;
- 2-wire and 3-wire loop impedance (L-PE) measurement with Trip Lock RCD function;
- Touch/contact voltage measurement withexternal P/S probe.
- 2-wire and 3-wire line impedance (L-L, L-N) measurement;
- 1-phase/3-phase TRMS voltage and frequency measurements;
- Line, loop and RCD measurements at frequency range 16 … 400 Hz;
- Phase sequence;
- Power and THD measurement (up to the 12th harmonic);

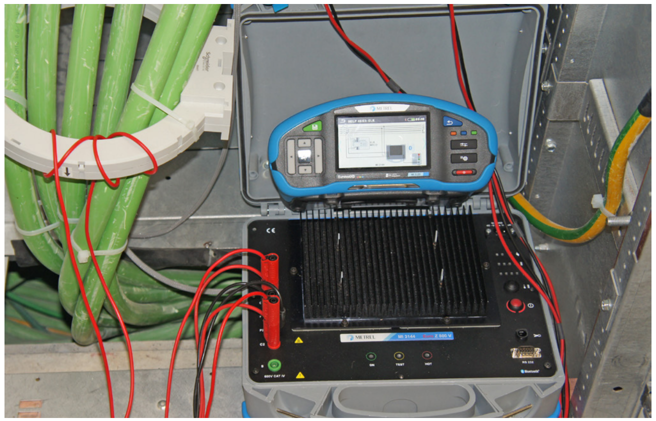
The MI 3155 EurotestXD is the flagship of Metrel Electrical Installation Safety portfolio. It is a most versatile installation tester, designed specifically for testing in industry, offering every test from basic insulation, line/loop impedance and continuity to multiple options for earth analysis and various additional measurements. Its ergonomic design, an intuitive colour user interface and advanced software features like predefined AUTO SEQUENCE®s, customized AUTO SEQUENCE®s, multilevel programmable location structure and complementary PC software allows easy and reliable instrument use.

MI 3144 Euro Z 800 V is an adapter for impedance measurement for installation and machine testers. It can also be used as an independent instrument, controlled by an Android app. It can supply up to 300 A test current. It is mainly applicable in industrial setting, close to the source of supply, where a particularly high accuracy of line or loop impedance measurements is necessary. Other notable features are ELR switch measurement, partial voltage drops and current path resistance measurement, ground fault analysis, floating voltmeter, and ground fault measurement with a clamp. It can also help analyse lightning protection system by measuring step, touch and contact voltages.

MEASURING FUNCTIONS

- Live Transformer’s Impedance Measurement with 4-Wire Test;
- High precision Short Circuit Current evaluation with Calculated Hot factor;

- RCD testing (general and selective, type AC, A, F, B, B+, MI RCD, EV RCD, PRCD, PRCD-K, PRCD-S);
- Earth resistance (3-wire and 2-clamps method);
- Specific earth resistance with Ro-adapter (option);
- TRMS leakage and load currents (option);
- First fault leakage current (ISFL);
- Testing of Insulation Monitoring Devices (IMDs);
- Machine mode support with time discharge;
- Illumination (option);
- High resolution Loop impedance (mΩ) (option);
- EVSE (Electrical Vehicle Supply Equipment) support (option);
- Determining location of cables (option);
- QR and/or barcode scanner support (option).



MI 2893 Power Master XT

Power Quality Analysis

Power quality analysis refers to monitoring the deviations of delivered power factors from the required. There are multiple standards regulating it that depends mainly on region and governing body. Both standard requirements and the providers' conformation to them are major strategic issues in the open electricity market. Power quality issues include:

- Harmonics influences;
- Low power factor;
- Voltage instability and;
- Imbalance impact on the efficiency of electrical equipment.

Systematic and constant approach to the power quality monitoring issues include:

- Easy identification and elimination of problems on the utilities or customer's installation;
- Preventative action by early location of potential sources of disturbances or failures;
- Optimization of the power network based on measured Power Quality parameters.

Including consequences:

- Higher enegy usage and cost;
- Higher maintenance costs;
- Lower reliability or frequent failures in the equipment.

Energy management is an and a critical consideration for any business. With the proper energy management it is possible to achieve better business results through:

- Reducing namesto reduce;
- Shifting your energy use to time of lower tariff or rate;
- Improving the bussiness result by keepng track of you energy use.

Power quality is considered a part of any energy management strategy.

The MI 2893 is the top of the line Class A power quality analyzers intended for usage in different type of installations. It has a large easy-to-read graphical colour display. Simply by connecting to the system, it detects and graphically displays harmonics, phasors, flickers, waveform and transient anomalies in the installation as well as other recorded data and events. The instrument is designed for long term recording as well as for troubleshooting power quality problems. The handy Quick Set buttons allow faster data overview for troubleshooting. Advanced PC software package Power View 3 enables detailed analysis of recorded data, direct local or remote reading from the micro SD memory card, analysis of long term records and automatic creation of professional test reports according national and international standards, like EN 50160, IEEE 519 etc.

MEASURING FUNCTIONS

- Voltage: TRMS, peak, crest factor (4-channel);
- Current: TRMS, peak, crest factor (4-channel);
- Power (active, reactive, apparent);
- Power measurements fully compliant with IEEE 1459 (active, non-active, fundamental, harmonics, inter-harmonics, load unbalance) and classic (vector or arithmetic) method;
- VFD (Variable Frequency Drives),
- Measurements at 400 Hz;
- Flickers measurement;
- Harmonic and inter-harmonic analysis up to 50th harmonic, THD, TID & TDD measurement;
- Energy (active, apparent, reactive, generated, consumed);
- Capturing and recording of power supply events (shutdowns, interruptions, swells, dips);
- Inrush currents monitoring and recording;
- Waveform/inrush displaying, snapshot and recording;
- Transients recording with the 1 MHz sampling frequency;
- Efficiency measurements for PV installations;
- Power quality analysis according to EN 50160, IEEE 519;
- Recording up to 7 adjustable alarms;
- Temperature measurement;
- Power factor/tan phi.

Accessories

Featured accessories

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	MI 3295M	Volt-meter for measuring Step & Contact voltages with resolution of 10 μV	•	•									
	A 1587	Flex current clamp 3000/300/30 A	•	•									
	S 2053	Step voltage test plates	•	•							•		
	A 1353	Step voltage probes (25 kg)	•	•									
	A 1529	Current earth spike (90 cm)	•	•									
	A 1528	Potential earth spoike (42 cm)	•	•							•		
	A 1629	Potential earth spike (60 cm)	•	•									
	A 1325	Current test lead (shielded), 50 m, black, 10 mm², with crocodile clip, on wheel	•										

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1392	Current test lead, 10 m, black, 10 mm², with crocodile clip	•										
	A 1508	Shielded test lead 75 m on reel		•									
	A 1530	G clamp	•	•							•		
	A 1487	Flexible current clamp, 50 A, 5 m		•									
	A 1509 A 1510 A 1525	Test lead 50 m on cable real; black green blue	•	•							•		
	A 1526 A 1527	Test leed 5 m on holder; blue red	•	•									
	A 1595	Large test crocodile, black									•		
	A 1596	Large test crocodile, red									•		

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1620	Test lead 5 m, black									•		
	A 1621	Test lead 20 m, black									•		
	A 1640	Test lead 20 m, red ,1.5 mm2									•		
	A 1608	Test lead 20 m , green									•		
	A 1654	Test lead on cable reel, 50 m, red, 1.5 mm2, extendable									•		
	A 1660	Extension test leads on reel, 75 m, red, green, 2.5 mm2		•							•		
	A 1661	Jumbo case mount for A 1660		•							•		
	A 1597	Human body resistance probe									•		
	A 1022	Earth test rod, 2 pcs		•					•	•	•		
	S 1072	Continuity test lead with crocodile clip		•			•						

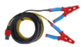
Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1615	Pair of red and black Kelvin test leads. Jaw width 35mm. 2,5m yellow and black cable					•						
	A 1616	Pair of red and black Kelvin test leads. Jaw width 35mm. 2,5m green and white cable					•						
	A 1617	Pair of gray and black Kelvin test leads. Jaw width 35mm. 2,5m black and yellow cable					•						
	A 1618	Pair of gray and black Kelvin test leads. Jaw width 35mm. 2,5m green and white cable					•						
	S 2046	100A Current test leads with insulated crocodiles, 5 m, 25 mm²			•								

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1314	Plug commander							•	•			
	A 1172 A 1173	Luxmeter sensor, type B (A 1172) type C, PS/2 (A 1173)							•	•			
	A 1199	Ro-adapter							•	•			
	A 1201	Insulated rod for continuity measurement							•	•			
	A 1198	Magnetic contact probe							•	•			•
	S 2058	Insulation test plates							•	•		•	
	S 2029	10 kV shielded test lead, 8m										•	
	S 2030	10 kV shielded test lead, 15m										•	
	S 2036	HV crocodile clip										•	
	A 1532	EVSE adapter							•	•			

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1333	Resistor Shunt, 750 Ω			•	•							
	S 2052	100 A test leads with crocodile clip			•								
	A 1383	Temperature probe with 3 m cable				•							
	A 1169	Fast battery charger				•				•			•
	A 1160	Fast battery charger				•				•			•
	A 1110	Three phase adapter							•	•			
	A 1111	Three phase adapter with switch							•	•			
	A 1391	AC/DC current clamp							•	•			
	A 1105	Barcode scanner							•	•			
	A 1653	QR / Barcode scanner (Bluetooth)							•				

Photo	Part number	Description	MI 3295S	MI 3290	MI 3252	MI 3250	MI 3280	MI 3108	MI 3155	MI 3152	MI 3144	MI 3210	MI 2893
	A 1567 A 1568	4400 mAh battery pack 8800 mAh battery pack							•				
	A 1593	Large Kelvin test crocodile									•		
	A 1597	Human body resistance probe									•		
	A 1609	Flex clamp, 30/300/3000A, fi=54 cm, 5 m cable lengt									•		•
	A 1281	Iron current clamp 0,5/5/100/1000 A/ 1 V, with jaw opening: 5.2 cm;Max. conductor size < 50 mm, 1.5m cable length									•		•
	A 1227	Flex clamp, 30/300/3000A, fi=14 cm, 1.5m cable length									•		•
	A 1501 A 1502 A 1445	1-phase flexibile smart current clamps 30/300/3000A/1V phi 7cm/14cm/19cm											•
	A 1503 A 1446	1-phase flexibile smart current clamps 60/600/6000A/1V phi 27cm"											•
	A 1588	1-phase iron smart current clamps 0.5/5/50A jaw opening 4 cm; max. conductor size < 5 cm / 5 cm											•
	A 1648	Current clamp A 1281 extension cable, 5m									•		
	A 1019	1000 A/1 V current clamp		•					•	•			
	A 1018	1000 A/1 V low range, leakage current clamp, 3.5 m length		•					•	•			
	A 1391 PQA A 1636	AC/DC iron current clamp 40/300A/1V // DC 2000A AC 1000A jaw opening 2.5cm // 7.3 cm; max. conductor size < 2.2 cm // 6.8 cm"											•
	A 1355	GPS synchronization unit											•
	A 1622	3G/Wi-Fi router											•
	S 2014	Safety fuse adapter, 3 pcs											•
	S 2015	Safety flat clamp, 4 pcs											•
	A 1500 A 1565	Watterproof, IP 65 rated plastic carrying case (A1500); outdoor application - pillar mounted (A 1565)											•
	A 1577	Watterproof, IP65 rated plastic carrying case with telescopic handle and smooth running wheels											•
	A 1658	Jumbo case		•			•		•	•	•	•	

Literature and education

Academy@Metrel®

A key part of any solution is education on it, its usage do the user can gain maximum benefit. Metrel offers integrated training programmes that cover every aspect of the solution set. The training consists of theoretical lectures and practical work with the instruments. Both are given and overseen by the product managers. The literature for lectures and exercises for practical work are provided as part of the training. It can be kept for later reference. Theoretical part covers the standards used, reasoning behind them, advice on safe measurements, measurement methods and instrument properties.

Theoretical part covers the standards used, reasoning behind them, advice on safe measurements, measurement methods and instrument properties.

Practical part is work with instruments in real-world scenarios.

RELEVANT STANDARDS FOR ELECTRICAL ENERGETIC INSTALLATIONS

- IEC 61936: covers requirements for design, construction and maintenance of installations with nominal voltage exceeding 1 kV and nominal frequency not exceeding 60 Hz to provide safety and functionality for the intended use. It is applicable to substations, distribution towers, switchgears, generators, industrial locations, equipment, and others.
- IEEE 80-2013: grounding theory and design for large systems.
- IEEE 81-2012: methods for measuring the grounding resistivity, impedance, earth surface potentials. Instruments that measure any of the mentioned need to support the methods it contains while complying to the IEC 61557-4.
- IEC 60076: applicable to most one- or three-phase transformers with power above 1 kVA with some exceptions. It covers properties and maintenace to some degree. It often emphasises an agreement between purchaser and constructor about additional or particular technical solutions.
- IEC 62271: requirements for high voltage switchgear and controlgear for system operating at above 1 kV and up to 60 Hz.
- IEC 51557-2: Part of the standard that covers measurement equipment for installation safety specifically dealing with insulation resistance measurements.
- IEC 61140: Common aspects of protection from electric shock for installations and equipment. Contains requirements about permissible touch voltage, relations between touch voltage and time, and other easily measurable evaluations of safety from shock.

WARNINGS AND PRECAUTIONS

Safety precautions must be respected for any project. Safety warnings and precautions before, during and after testing procedure allow high level of protection. Regular warnings and precautions as well as standardized rules must be implemented during operation in the field to automatically control the work process.

Example of safety precautions and warnings included in Metrel Earth Analyser MI 3290:

Before test:
- Wearing dielectrically rated gloves and footwear.
- Exposed test leads and electrodes are isolated from workers and public.
- Remote probes and test leads are under continuous observation.

During test:
- Surge arrester can approach line potential.
- Never disconnect the ground.
- Lightning or switching currents can be discharged into the ground.
- A system fault can occur if a surge arrester fails during testing.
- Hazard can occur when disconnecting neutral and shield wires.
- Hazard can occur due to current flow through the interconnected shield wires.
- High voltages can occur if neutrals are disconnected from energized equipment.

After test:
- All test leads promptly removed after the test is completed.

Safety precautions are standardised in IEEE 81-2012. See examples below.

Ground electrode tests precautions:
- Reduce the hazards asociated with handling test leads by wearing gloves and dielectrically rated footwear.
- Isolate exposed test leads and electrodes from workers and general public.
- Use short test periods and promptly remove all test leads after the test is completed.
- Continiously monitor remote probes and test leads.
- Lower risks of ungrounded ends of test leads in parallel to an energized line by their physical orientation, grounding or both.

Surge arrester ground continuity tests precautions:

- The base of the surge arrester can approach line potential. Never disconnect the ground of a surge arrester.
- Extremely high, short-duration lightning or switching currents can be discharged into the ground.
- A system fault can occur if a surge arrester fails during testing.

Neutral and shield wire ground tests procedures:

- Disconnected neutral and shield wires can generate hazardous voltages.
- Current flowing through interconnected shield wires can cause hazard regardless of energising the line.

Equipment neutral ground test precautions:

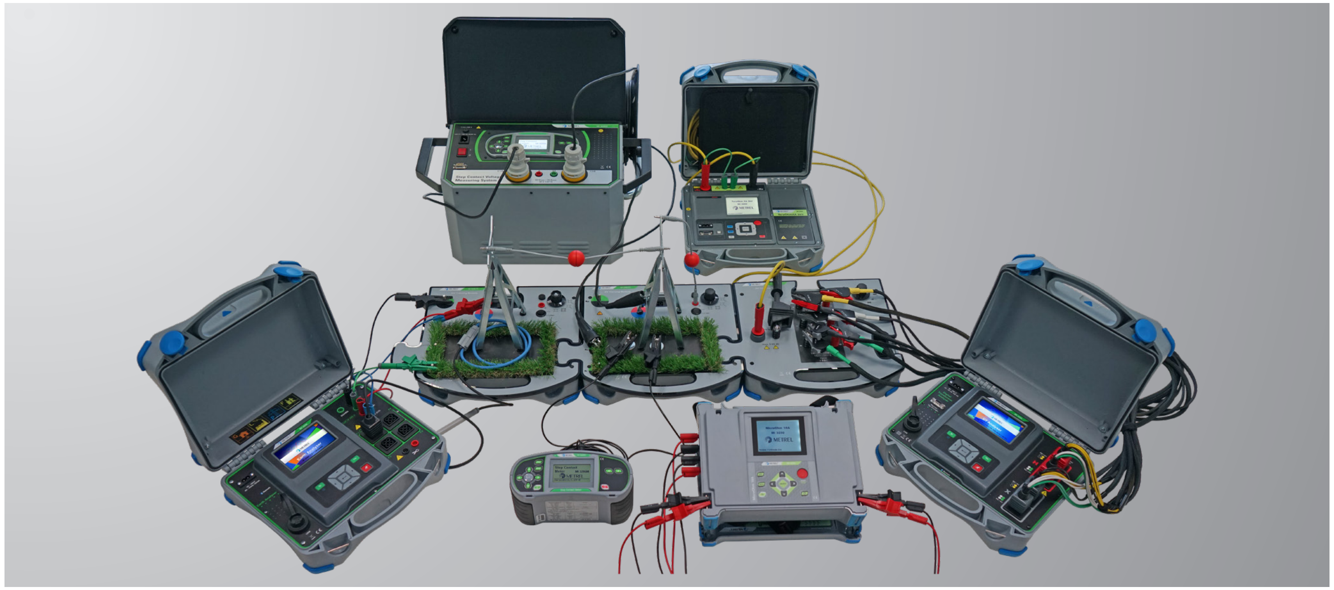
- High voltages can occur if neutrals are disconnected from energized equipment.

MEASURING METHODS AND INSTRUMENTS

Measuring methods cover the necessary techniques that provide most accurate results under the given circumstances. There is a lot of fascinating engineering behind each of them and each has its strong and weak points that prospective users need to know. Examples are covered in application notes in this catalogue. Instrument properties make the chosen methods possible.The lectures include presentation of each instrument in the chosen set.

Metrel instruments are very feature-rich, and each feature deserves to be addressed. This gives users the option to solve measurement problems in multiple ways, either through different parts of user interface, using different accessories, or with different levels of automation.

Use of both standard and advanced accessories in any instrument combination is an important theme. Adaptors expand an instrument's use to new areas or new accuracy levels, while accessories ease the use or allow more focused approach to the problem.



The other face of the instruments is making the user's life easier. The procedures are kept as simple as possible. Data is transparently collected into a memory structure and prepared to be inserted into the reports. High level of automation can prevent human errors and make the measurement possible even for less educated users.

THE LITERATURE

Each course is completed by chosen literature to help the users along. Specially prepared guidebooks, application notes, exercises, and posters come in any desired quantity.
Strategically positioned posters can become cheat-sheets for everyday use. Warnings, precautions and safety measures are prepared for each project separately, covering whole procedure from preparing the test site to leaving it. Extensive materials are provided to cover every aspect of operator's and user's safety.

PRACTICAL AND PRESENTATION WORK

Practical part covers pre-defined exercises with instruments and software that prepare users for real-life challenges. The exercises are prepared to cover the themes from the lectures in practice. The users are familiarized with workflow on the instrument like they were in the field. Most of the exercises can be presented while still in the classroom, using one of Metrel didactic tools. For case of power networks, there is a modular trainer MI 3298 available.

Demonstration equipment

Academy@Metrel®

MI 3298 TRAINER MODULES

MI 3298 is a collection of pieces that can be connected into a simulation of distribution system. There are two different pieces available:

- MI 3298 P1 Earth/Ground module. It allows practicing measuring ground network impedance, earth surface potentials, HF method for earth impedance, measurements on a pylon (selective legs). It can induce fault in simulated step and contact voltages.
- MI 3298 T Transformer/Insulation module can be used for measuring cable impedance, resistance and insulation, HV insulation resistance parameters, transformer impedance, winding resistance and transformer turn ratios.

The modules can be operated independently and used with any instruments. Each can be used to demonstrate a number of measurements and simulate faults. But their strongest point is in ability to connect and form systems to simulate many more real-life scenarios than a single one could. They can be used together to demonstrate the instruments abilites, teach dangerous situations, or let people practice in a safe and practical environment compared to the outdoors.

MI 2891 POWER SIMULATOR

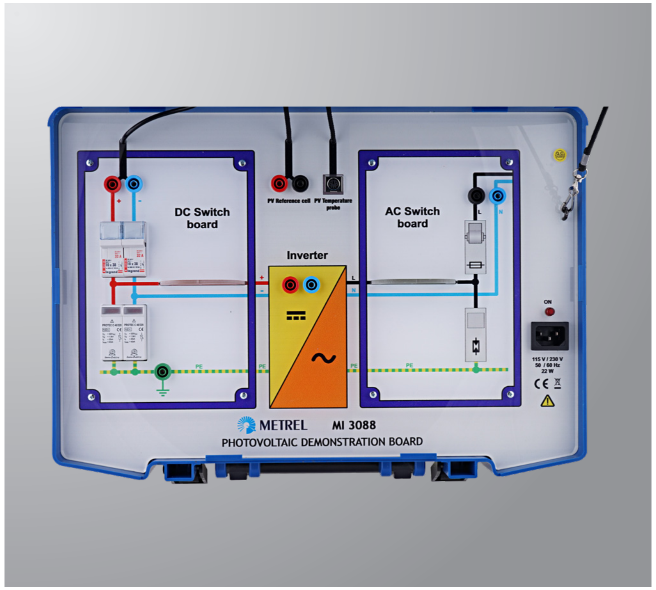
The MI 2891 Power Simulator is a multi-purpose three phase power simulator for simulating typical situations in low voltage power supply systems. It is an excellent tool for training, demonstration purposes, or as an electrical didactic tool. The simulator has some pre-programmed scenarios, and also the option of complete manual mode. The user can decide between different load character adjustments, adjustable current and voltage level with a simulation of various fault conditions.

Key features:

- Simple and powerful waveform generator with various settings;
- 4 voltage channels with wide simulation range: up to 350 Vrms;
- 4 current channels with current clamps simulation up to 2 kA;
- Simultaneous voltage and current (8 channels) simulation;
- 16 bit DA conversion for accurate signal generation;

- Dip, swell, interrupt, signalling, transient and inrush events simulation;
- Voltage and current harmonics waveform simulation;
- Unbalanced voltage and current waveform simulation;
- Square flicker simulation;
- Various character load/character type combination simulation;
- Thorough signal parameters settings;
- Saving current system settings on power off;
- 4.3'' TFT colour display.

Measuring functions:
- Voltage / Current / Frequency;
- Harmonics (U,I) / Phase angle (U,I) / Phase sequence (U,I);
- Flicker.



MI 3088 PV DEMONSTRATION BOARD

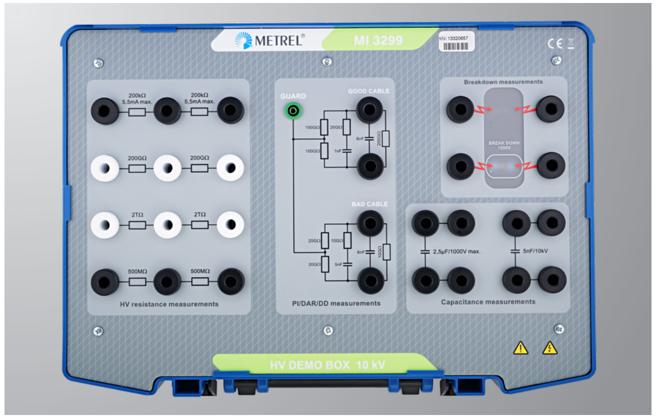
Demonstration board MI 3088 simulates typical photovoltaic (PV) system with one PV module and DC/AC inverter. It represents a typical installation that consist of PV string, DC switch box, DC/AC inverter and one phase connection to the power grid. It is intended for use preferably by sales personnel for demonstration of the measuring methods and procedures on DC and partially on AC side of a PV system.

Key features:
- With this demo board all electrical tests according to EN 62446 can be demonstrated: continuity, isolation, open circuit voltage Uoc, short circuit current Isc and polarity.
- It simulates an I/V characteristic of a PV module/string.
- Simulated output of the irradiance and temperature sensor.
- Simulation of a DC/AC inverter with one DC input and 1-phase output.

MI 3299 HV DEMONSTRATION BOX 10 KV

The MI 3299 High voltage Demonstration Box 10 kV has been developed for demonstration purposes at high voltage insulation diagnostics. It simulates typical electrical insulation usually met in the industrial environment. It is equipped with high quality resistors in different ranges, high voltage capacitors and a discharge chamber to simulate a breakdown phenomenon in gases. Additionally measurements of polarization index (PI), dielectric discharge (DD) and dielectric absorption ratio (DAR) can be demonstrated. Packed with all these features the demonstration box is also well suited for basic calibration of DC high voltage insulation resistance measuring instruments.

Measuring functions:
- 10 kV rated resistors with very low voltage coefficient.
- Resistive decade with 200 kΩ, 500 MΩ, 200 GΩ and 2 TΩ resistors.
- HV capacitors in 2.5 µF and 5 nF range.
- Built-in spark gap and gas discharge tube.
- Demonstration of insulation breakdown in gases is possible.
- Two models of insulation material (good and bad cables) enable the demonstration of real insulation behavior under high DC voltage.
- Demonstration box is put in the strong rugged case with handle for comfortable carrying.



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Note! Photographs in this catalogue may slightly differ from the instruments at the time of delivery.
Subject to technical change without notice.

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