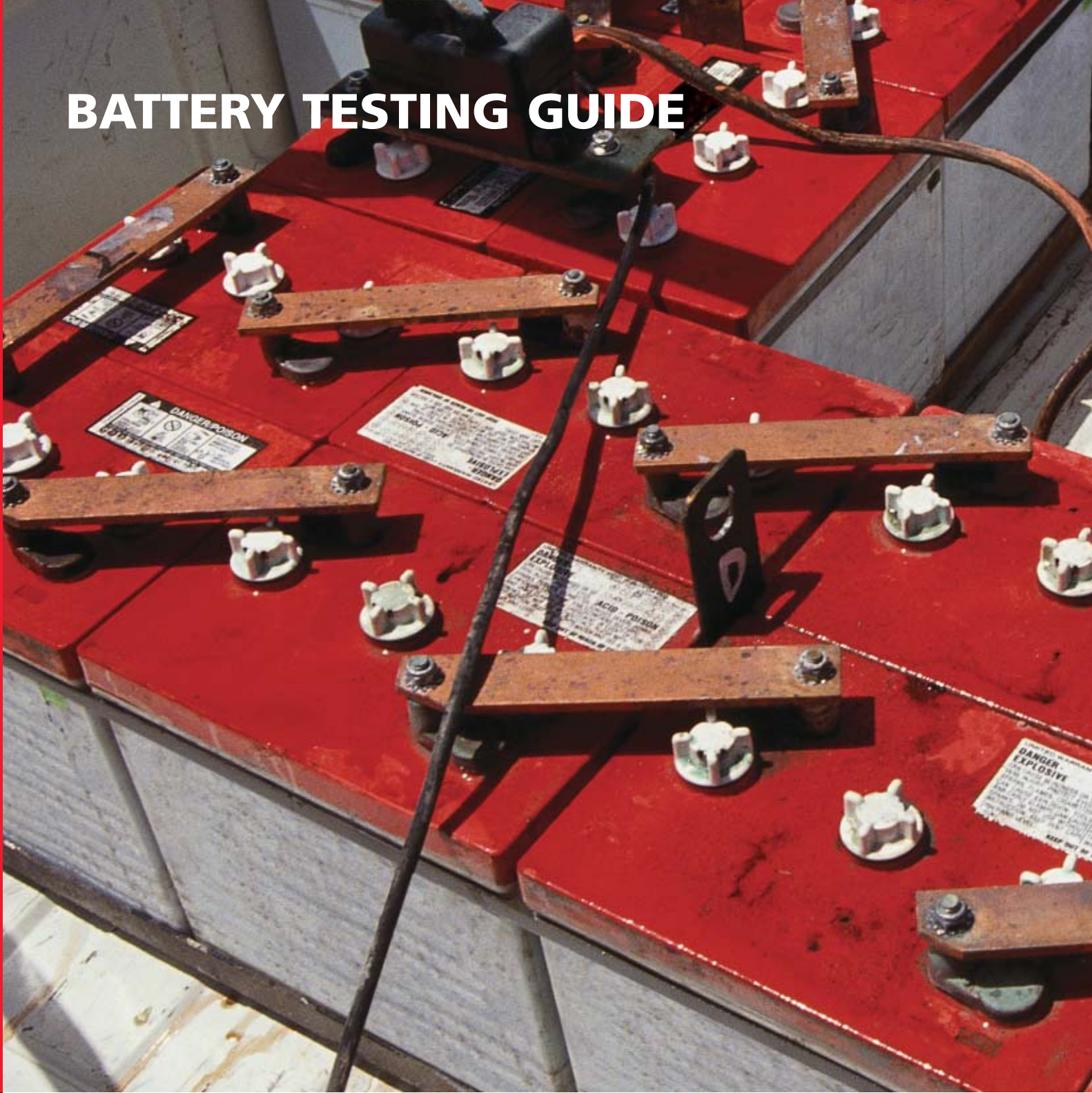


# BATTERY TESTING GUIDE



**Megger** 

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## WHY BATTERIES ARE NEEDED

Batteries are used to ensure that critical electrical equipment is always on. There are so many places that batteries are used it is nearly impossible to list them all. Some of the applications for batteries include:

- Electric generating stations and substations for protection and control of switches and relays
- Telephone systems to support phone service, especially emergency services
- Industrial applications for protection and control
- Back up of computers, especially financial data and information
- "Less critical" business information systems

Without battery back-up hospitals would have to close their doors until power is restored. But even so, there are patients on life support systems that require absolute 100% electric power. For those patients, as it was once said, "failure is not an option."

Just look around to see how much electricity we use and then to see how important batteries have become in our everyday lives. The many blackouts of 2003 around the world show how critical electrical systems have become to sustain our basic needs. Batteries are used extensively and without them many of the services that we take for granted would fail and cause innumerable problems.

## WHY TEST BATTERY SYSTEMS

There are three main reasons to test battery systems:

- To insure the supported equipment is adequately backed-up
- To prevent unexpected failures
- To forewarn/predict death

And, there are three basic questions that battery users ask:

- What are the capacity and the condition of the battery now?
- When will it need to be replaced?
- What can be done to improve / not reduce its life?

Batteries are complex chemical mechanisms. They have numerous components from grids, active material, posts, jar and cover, etc. — any one of which can fail. As with all manufacturing processes, no matter how well they are made, there is still some amount of black art to batteries (and all chemical processes).

A battery is two dissimilar metallic materials in an electrolyte. In fact, you can put a penny and a nickel in half of a grapefruit and you now have a battery. Obviously, an industrial battery is more sophisticated than a grapefruit battery. Nonetheless, a battery, to work the way it is supposed to work must be maintained properly. A good battery maintenance program may prevent, or at least, reduce the costs and damage to critical equipment due to an ac mains outage.

Even though there are many applications for batteries, they are installed for only two reasons:

- To protect and support critical equipment during an ac outage
- To protect revenue streams due to the loss of service

The following discussion about failure modes focuses on the mechanisms and types of failure and why impedance works so well at finding weak cells. Below is a section containing a more detailed discussion about testing methods and their pros and cons.

## WHY BATTERIES FAIL

In order for us to understand why batteries fail, unfortunately a little bit of chemistry is needed. There are two main battery chemistries used today — lead-acid and nickel-cadmium. Other chemistries are coming, like lithium, which is prevalent in portable battery systems, but not stationary, yet.

Volta invented the primary (non-rechargeable) battery in 1800. Planté invented the lead-acid battery in 1859 and in 1881 Faure first pasted lead-acid plates. With refinements over the decades, it has become a critically important back-up power source. The refinements include improved alloys, grid designs, jar and cover materials and improved jar-to-cover and post seals. Arguably, the most revolutionary development was the valve-regulated development. Many similar improvements in nickel-cadmium chemistry have been developed over the years.

## BATTERY TYPES

There are several main types of battery technologies with subtypes:

- Lead-acid
  - Flooded (wet): lead-calcium, lead-antimony
  - Valve Regulated Lead-acid, VRLA (sealed): lead-calcium, lead-antimony-selenium
    - Absorbed Glass Matte (AGM)
    - Gel
  - Flat plate
  - Tubular plate

- Nickel-cadmium
  - Flooded
  - Sealed
  - Pocket plate
  - Flat plate

## Lead-acid Overview

The basic lead-acid chemical reaction in a sulphuric acid electrolyte, where the sulphate of the acid is part of the reaction, is:



The acid is depleted upon discharge and regenerated upon recharge. Hydrogen and oxygen form during discharge and float charging (because float charging is counteracting self-discharge). In flooded batteries, they escape and water must be periodically added. In valve-regulated, lead-acid (sealed) batteries, the hydrogen and oxygen gases recombine to form water. Additionally, in VRLA batteries, the acid is immobilized by an absorbed glass mat (AGM) or in a gel. The mat is much like the fibre-glass insulation used in houses. It traps the hydrogen and oxygen formed during discharge and allows them to migrate so that they react back to form water. This is why VRLA never need water added compared to flooded (wet, vented) lead-acid batteries.

A battery has alternating positive and negative plates separated by micro-porous rubber in flooded lead-acid, absorbed glass mat in VRLA, gelled acid in VRLA gel batteries or plastic sheeting in NiCd. All of the like-polarity plates are welded together and to the appropriate post. In the case of VRLA cells, some compression of the plate-mat-plate sandwich is exerted to maintain good contact between them. There is also a self-sealing, pressure relief valve (PRV) to vent gases when over-pressurization occurs.

## Nickel-Cadmium Overview

Nickel-Cadmium chemistry is similar in some respects to lead-acid in that there are two dissimilar metals in an electrolyte. The basic reaction in a potassium hydroxide (alkaline) electrolyte is:



However, in NiCd batteries the potassium hydroxide (KOH) does not enter the reaction like sulphuric acid does in lead-acid batteries. The construction is similar to lead-acid in that there are alternating positive and negative plates submerged in an electrolyte. Rarely seen, but available, are sealed NiCd batteries.

## BATTERY CONSTRUCTION AND NOMENCLATURE

Now that we know everything there is to know about battery chemistry, except for Tafel curves, ion diffusion, Randles equivalent cells, etc., let's move on to battery construction. A battery must have several components to work properly: a jar to hold everything and a cover, electrolyte (sulphuric acid or potassium hydroxide solution), negative and positive plates, top connections welding all like-polarity plates together and then posts that are also connected to the top connections of the like-polarity plates.

All batteries have one more negative plate than positive plate. That is because the positive plate is the working plate and if there isn't a negative plate on the outside of the last positive plate, the whole outer side of last positive plate will not have anything with which to react and create electricity. Hence, there is always an odd number of plates in a battery, e.g., a 100A33 battery is comprised of 33 plates with 16 positive plates and 17 negative plates. In this example, each positive plate is rated at 100 Ah. Multiply 16 by 100 and the capacity at the 8-hour rate is found, namely, 1600 Ah. Europe uses a little different calculation than the US standards.

In batteries that have higher capacities, there are frequently four or six posts. This is to avoid overheating of the current-carrying components of the battery during high current draws or lengthy discharges. A lead-acid battery is a series of plates connected to top lead connected to posts. If the top lead, posts and intercell connectors are not sufficiently large enough to safely carry the electrons, then overheating may occur ( $i^2R$  heating) and damage the battery or in the worst cases, damage installed electronics due to smoke or fire.

To prevent plates from touching each other and shorting the battery, there is a separator between each of the plates. Figure 1 is a diagram of a four-post battery from the top looking through the cover. It does not show the separators.

## FAILURE MODES

### Lead-acid (flooded) Failure Modes

- Positive grid corrosion
- Sediment (shedding) build-up
- Top lead corrosion
- Plate sulphation
- Hard shorts (paste lumps)

Each battery type has many failure modes, some of which are more prevalent than others. In flooded lead-acid batteries, the predominant failure modes are listed above. Some of them manifest themselves with use such as sediment build-

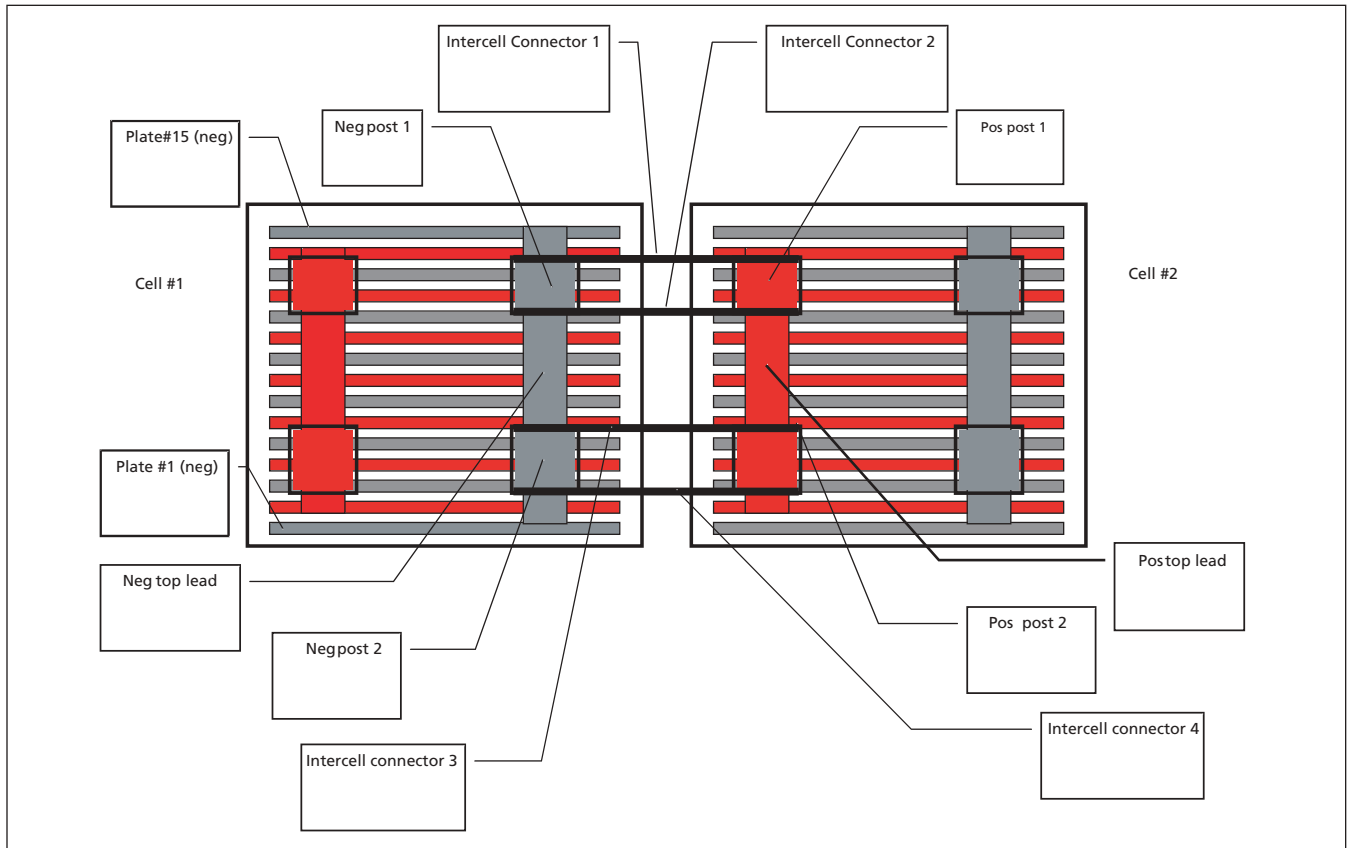


Figure 1: Battery Construction Diagram

up due to excessive cycling. Others occur naturally such as positive grid growth (oxidation). It is just a matter of time before the battery fails. Maintenance and environmental conditions can increase or decrease the risks of premature battery failure.

The expected failure mode of flooded lead-acid batteries is positive grid corrosion. The grids are lead alloys (lead-calcium, lead-antimony, lead-antimony-selenium) that convert to lead oxide over time. Since the lead oxide is a bigger crystal than lead metal alloy, the plate grows. The growth rate has been well characterized and is taken into account when designing batteries. In many battery data sheets, there is a specification for clearance at the bottom of the jar to allow for plate growth in accordance with its rated lifetime, for example, 20 years.

At the designed end-of-life, the plates will have grown sufficiently to pop the tops off of the batteries. But excessive cycling, temperature and over-charging can also increase the speed of positive grid corrosion. Impedance will increase over time corresponding to the increase in electrical resistance of the grids to carry the current. Impedance will also increase as

capacity decreases as depicted in the graph in Figure 2.

Sediment build-up (shedding) is a function of the amount of cycling a battery endures. This is more often seen in UPS batteries but can be seen elsewhere. Shedding is the sloughing off of active material from the plates, converting to white lead sulphate. Sediment build-up is the second reason battery manufacturers have space at the bottom of the jars to allow for a certain amount of sediment before it builds-up to the point of shorting across the bottom of the plates rendering the battery useless. The float voltage will drop and the amount of the voltage drop depends upon how hard the short is. Shedding, in reasonable amounts, is normal.

Some battery designs have wrapped plates such that the sediment is held against the plate and is not allowed to drop to the bottom. Therefore, sediment does not build-up in wrapped plate designs. The most common application of wrapped plates is UPS batteries.

Corrosion of the top lead, which is the connection between the plates and the posts is hard to detect even with a visual inspection since it occurs near the top of the battery and is

hidden by the cover. The battery will surely fail due to the high current draw when the AC mains drop off. The heat build-up when discharging will most likely melt the crack open and then the entire string drops off-line, resulting in a catastrophic failure.

Plate sulphation is one of the easiest failure modes to find with impedance. A thorough visual inspection can sometimes find traces of plate sulphation. Sulphation is the process of converting active plate material to inactive white lead sulphate. Since impedance finds electrical path failures very well, sulphation, as one of the electrical path problems, is easily found.

Sulphation is due to low charger voltage settings or incomplete recharge after an outage. Sulphates form when the voltage is not set high enough.

### Lead-acid (VRLA) Failure Modes

- Dry-out (Loss-of-Compression)
- Plate Sulphation (see above)
- Soft and Hard Shorts
- Post leakage
- Thermal run-away
- Positive grid corrosion (see above)

Dry-out is a phenomenon that occurs due to excessive heat (lack of proper ventilation), over charging, which can cause elevated internal temperatures, high ambient (room) temperatures, etc. At elevated internal temperatures, the sealed cells will vent through the PRV. When sufficient electrolyte is vented, the glass matte no longer is in contact with the plates, thus increasing the internal impedance and reducing battery capacity. In some cases, the PRV can be removed and distilled water added (but only in worst case scenarios and by an authorized service company since removing the PRV may void the warranty). This failure mode

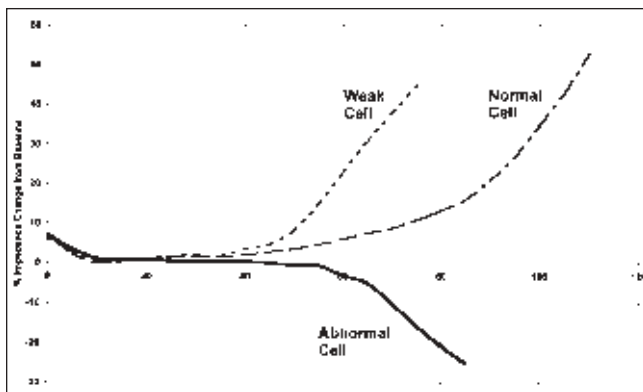


Figure 2: Changes in impedance as a result of battery capacity

is easily detected by impedance and is one of the more common failure modes of VRLA batteries.

Soft (a.k.a. dendritic shorts) and Hard shorts occur for a number of reasons. Hard sorts are typically caused by paste lumps pushing through the matte and shorting out to the adjacent (opposite polarity) plate. Soft shorts, on the other hand, are caused by deep discharges. When the specific gravity of the acid gets too low, the lead will dissolve into it. Since the liquid (and the dissolved lead) are immobilized by the glass matte, when the battery is recharged, the lead comes out of solution forming threads of thin lead metal, known as dendrites inside the matte. In some cases, the lead dendrites short through the matte to the other plate. The float voltage may drop slightly but impedance can find this failure mode easily but is a decrease in impedance, not the typical increase as in dry-out. See Figure 2, Abnormal Cell.

Thermal run-away occurs when a battery's internal components melt-down in a self-sustaining reaction. Normally, this phenomenon can be predicted by as much as four months or in as little as two weeks (which is one of the reasons why Megger recommends quarterly VRLA impedance testing versus the normal 6-month period.) The impedance will increase in advance of thermal run-away as does float current. Thermal run-away is relatively easy to avoid, simply by using temperature-compensated chargers and properly ventilating the battery room/cabinet. Temperature-compensated chargers reduce the charge current as the temperature increases. Remember that heating is a function of the square of the current. Even though thermal run-away may be avoided by temperature-compensation chargers, the underlying cause is still present.

### Nickel-Cadmium Failure Modes

NiCd batteries seem to be more robust than lead-acid. They are more expensive to purchase but the cost of ownership is similar to lead-acid, especially if maintenance costs are used in the cost equation. Also, the risks of catastrophic failure are considerably lower than for VRLAs.

The failure modes of NiCd are much more limited than lead-acid. Some of the more important modes are:

- Gradual loss of capacity
- Carbonation
- Floating Effects
- Cycling
- Iron poisoning of positive plates

Gradual loss of capacity occurs from the normal aging

process. It is irreversible but is not catastrophic, not unlike grid growth in lead-acid.

Carbonation is gradual and is reversible. Carbonation is caused by the absorption of carbon dioxide from the air into the potassium hydroxide electrolyte which is why it is a gradual process. Without proper maintenance, carbonation can cause the load to not be supported, which can be catastrophic to supported equipment. It can be reversed by exchanging the electrolyte.

Floating effects are the gradual loss of capacity due to long periods on float without being cycled. This can also cause a catastrophic failure of the supported load. However, through routine maintenance, this can be avoided and is easily found by impedance testing. Floating Effects are reversible by deep-cycling the battery once or twice.

NiCd batteries, with their thicker plates, are not well-suited for cycling applications. Shorter duration batteries generally have thinner plates to discharge faster due to a higher surface area. Thinner plates means more plates for a given jar size and capacity, and more surface area. Thicker plates (in the same jar size) have less surface area.

Iron poisoning is caused by corroding plates and is irreversible.

## **ELECTRICAL PRACTICES AND IEEE TESTING PRACTICES**

With so many options for testing batteries, from not testing them at all to annual load tests and everything in between, how is one to know what the best testing scheme is? There are several considerations that must be evaluated to determine the best testing scheme and they have to deal with cost versus risk.

Obviously, not testing them at all is the least costly with considering only maintenance costs but the risks are great and so the overall costs are extremely high. These costs must be considered when evaluating the cost-risk analysis since the risks are associated with the equipment being supported. The best testing scheme is the balance between maintenance costs and risks of losing the battery and the supported equipment. For example, in some transmission substations, there is upwards of \$10 million per hour flowing through them. What is the cost of not maintaining battery systems in those substations? A \$3000 battery is fairly insignificant compared to the millions of dollars in lost revenues. Each company is different and must individually weigh the cost-risk of battery maintenance.

Following is a guide to the testing methods to help determine the best testing scheme. This section is designed to be in concert with the appropriate IEEE Recommended Practices

and also to help to understand why the various tests are performed and how to interpret the data.

Even though a battery is considered only as a source of dc voltage, it is much more than that. From the previous discussion, it is obvious that batteries are much more complex than mere voltage sources. There are many parameters to test to verify the condition of a battery. The Institute of Electrical and Electronics Engineers (IEEE) is responsible for promulgating battery testing practices. These practices are only recommendations; they are required to be followed by battery manufacturers in the event of a warranty claim. They also make good sense to follow in order to get the most from your battery assets.

### **IEEE Recommended Practices**

IEEE has split stationary battery testing into three groups:

- IEEE 450 for flooded lead-acid
- IEEE 1188 for sealed lead-acid
- IEEE 1106 for nickel-cadmium

IEEE 450-2002, "IEEE Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-acid Batteries for Stationary Applications" describes the frequency and type of measurements that need to be taken to validate the condition of the battery. The frequency of tests ranges from monthly to annually. Some of the monthly tests include string voltage, appearance, ambient temperature, float current, etc. Quarterly tests include specific gravity, cell voltage and temperature ( $\geq 10\%$  of cells). Annual tests are performed on the entire string. Additionally, the resistance to ground of the battery rack and intercell connection resistance need to be measured. Other tests may need to be performed based on the values measured during periodic tests and battery usage (cycling history).

IEEE 1188-1996, "IEEE Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated Lead-Acid Batteries for Stationary Applications" defines the recommended tests and frequency. VRLA cells have been classified into tiers of criticality of the installation. The frequency and type of tests vary based on the battery's tier.

IEEE 1106-1995, "IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications" has similar recommended practices as IEEE 450.

The Battery Testing Matrix on the following page may help guide even the most skilled battery testing technician and will help simplify the recommended practices.

**Battery Testing Matrix — IEEE Recommended Practices**

INSTRUMENT TYPE	BITE3	BITE2P	BITE2	DLRO	DLRO10/10X	DCM24R	DCM2000P	BMM80	M5091	BGFT	BGL	Digital Hydrometer	Visual
Impedance	■	■	■										
Micro-Ohmmeters				■	■								
Float/Ripple Current						■	■						
Insulation Resistance								■					
Multimeter									■				
Ground Fault Locators										■	■		
Miscellaneous												■	■
PARAMETERS													
String Voltage									■				
Visual													■
Voltage of Each Cell	■	■	■						■				
Charger Output Current and Voltage						■	■		■				
Corrosion at Terminals				■	■								■
Ambient Temperature													
Pilot Cells' Voltage and Temperature	■	■	■						■			■	
Float Current	■					■	■						
Check for Unintentional Battery Grounds								■		■	■		
Specific Gravity and Temperature of Each Cell												■	
Intercell Connection Resistance	■	■	■	■	■								
Structural Integrity of the Rack or Cabinet													■
Internal Ohmic Test	■	■	■										
Temperature of the Negative Terminal													
Voltage of Each Cell/Unit	■	■	■						■				
AC Ripple Current and Voltage	■					■	■		■				



The following is a description of each test parameter:

## Impedance

Impedance, an internal ohmic test, is resistance in ac terms. With regard to dc battery systems, impedance indicates the condition of batteries without harming or stressing them in any way. Since it tests the condition of the entire electrical path of a battery from terminal plate to terminal plate, impedance can find weaknesses in cells and intercell connectors easily and reliably.

Basically, impedance is determined by applying an ac current signal, measuring the ac voltage drop across the cell or intercell connector and calculating impedance using Ohm's Law. In practice, not only is the ac voltage drop measured but so is the ac current. The ac current is measured because of other ac currents in a battery that are additive (subtractive). Other ac currents are present from the charger system. (See Battery Testing Methods.) The test is performed by applying an ac test signal to the terminal plates. Then measure both the total ac current in the string and the voltage drop of each unit in the string by measuring each cell and intercell connector consecutively until the entire string is measured. Impedance is calculated, displayed and stored. As cells age, the internal impedance increases as depicted in Figure 2. By measuring impedance, the condition of each cell in the string can be measured and trended to determine when to replace a cell or the string which helps in planning for budgetary needs.

The impedance test is a true four-wire, Kelvin-type measurement that provides excellent reliability and highly reproducible data on which to base sound decisions with regard to battery maintenance and replacement. Impedance is able to find weak cells so that proactive maintenance can be performed. After all, the battery is a cost but it is supporting a critical load or revenue stream. If a single cell goes open then the entire string goes off line and the load is no longer supported. Therefore, it is important to find the weak cells before they cause a major failure.

The graph in Figure 3 shows the effect of decreasing capacity on impedance. There is a strong correlation

between impedance and capacity so that weak cells are ably and reliably found in sufficient time to take remedial action. The graph shows the reorganized impedance data in ascending order with each cell's corresponding load test end voltage. (Impedance in milliohms coincidentally is the same scale as the voltage, 0 to 2.5). This view, that is ascending impedance/descending voltage, groups the weak cells on the right side of the graph to find them easily.

## Impedance Theory

A battery is not simply resistive. There is also a capacitive term. After all, a battery is a capacitor, a storage device, and resistors cannot store electricity. Figure 4 shows an electrical circuit, known as the Randles Equivalent Circuit, that depicts a battery in simple terms. There are those who would have people believe that the capacitive term is not necessary and that the resistance is the only part that needs measuring.

Impedance measures both the dc resistance (the real component in impedance) and the reactance (the imaginary components in impedance). Only by measuring both can the capacitive term start to be understood. The other argument used against impedance is that frequency is a variable in the reactance part of the impedance equation. That is true except that since Megger uses a fixed frequency, namely 50 or 60 Hz depending upon geography, it is always the same. This variable,  $2\pi\omega$ , now becomes a constant and, therefore, frequency does not affect the final result in any way. The only parts that affect the final result are the parts that vary within the battery, namely resistance and capacitance, which paint the whole capacity/condition picture.

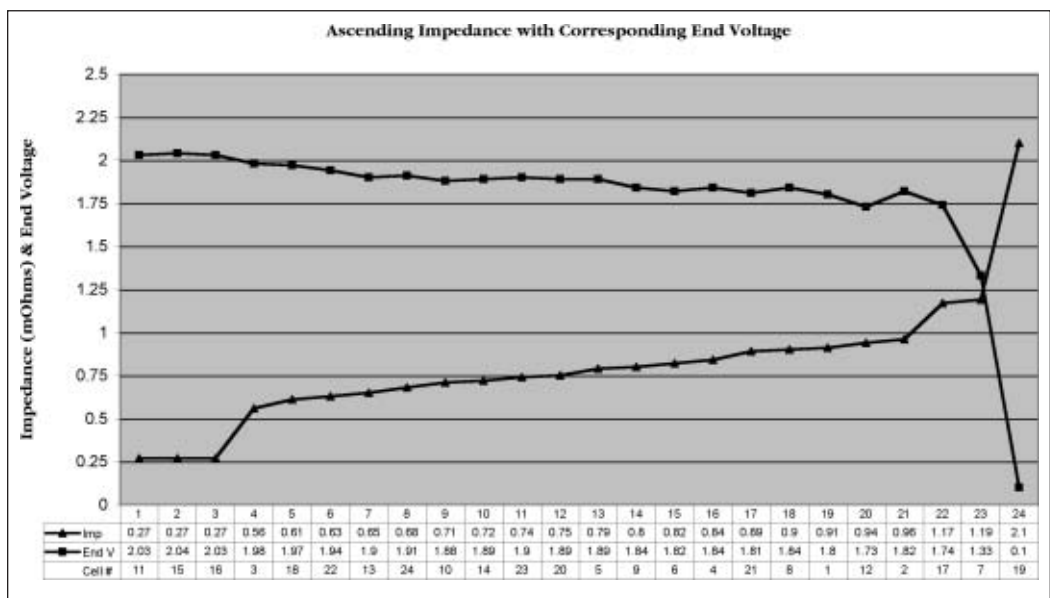


Figure 3: Ascending Impedance with Corresponding End Voltage

In the diagram shown in Figure 4,  $R_m$  is the metallic resistance,  $R_e$  is the electrolyte resistance,  $R_{ct}$  is the charge transfer resistance,  $W_i$  is the Warburg impedance and  $C_{dl}$  is the capacitance of the double layer.  $R_m$  includes all of the metallic components one post to the other post, i.e., post, top lead and grids and to a certain degree, the paste.  $R_e$  is the resistance of the electrolyte which doesn't vary that much on a bulk basis. But at the microscopic level in the pores of the paste, it can be significant.  $R_{ct}$  is the resistance of the exchange of ions from the acid to the paste. If the paste is sulphated, then  $R_{ct}$  increases or if that portion of the paste is not mechanically (electrically) attached to the grid so that electrons cannot flow out of the cell. Warburg impedance is essentially insignificant and is a function of the specific gravity.  $C_{dl}$  is what probably makes the most important contribution to battery capacity. By only measuring dc resistance, capacitance, an important part of the cell, is ignored. Impedance measures both dc resistance and capacitance.

A battery is complex and has more than one electrochemical process occurring at any given time, e.g., ion diffusion, charge transfer, etc. The capacity (capacitor) decreases during a discharge due to the conversion of active material and depletion of the acid. Also, as the plates sulphate, the resistance of the charge transfer increases since the sulphate is less conductive than the active material. (See discussion about the differences between the thickness of the plates in long-duration versus short-duration batteries.)

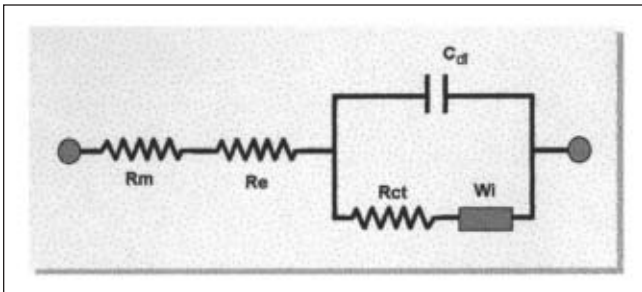


Figure 4: Randles Equivalent Circuit

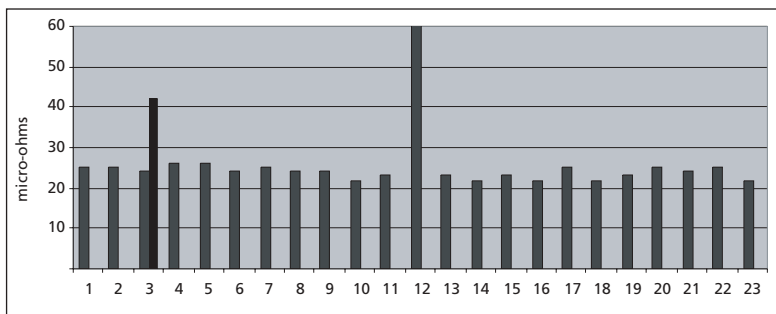


Figure 5: Intercell Connection Resistance Bar Graph

## Intercell Connection Resistance

Intercell connection resistance is the other half of the battery. A battery is comprised of cells connected in a series path. If any one component fails the entire series connection fails. Many times batteries fail, not because of weak cells, but due to weak intercell connections, especially on lead posts which can cold-flow. Generally, hardware should be tightened to the low end of the torque scale that is recommended by the battery manufacturer. But torque wrenches are a mechanical means to verify low electrical resistance. It is far better to actually perform an electrical test using an appropriate instrument. It is a low electrical resistance that is desired. This test should be performed before the battery is commissioned. Proper intercell connections are necessary to ensure that discharge rates can be met. The instrument of choice is the DLRO® which can easily verify that all connections have been made properly. It can even find minor errors before the battery is commissioned, preventing possible causes of failure or damage to supported equipment.

Testing intercell connection resistance performs two functions:

- Validates intercell connection resistance
- Finds possible gross errors with top lead internal to the cell

By following IEEE Recommended Practices, intercell connection resistance can be validated. Those recommended practices specify that the variation of intercell connection resistance be less than ten percent. This translates into 7 micro-ohms on a 70-micro-ohm intercell connection resistance. This method can even find a washer stuck between the post and the intercell connector whereas torquing will not. They also specify that ten percent of the intercell connectors be measured quarterly and all intercell connectors annually.

In multiple post batteries, it is possible to find those rare gross errors in a cell's top lead. (See multiple post battery diagram in Figure 1). On multiple-post cells, measure straight across both connections, then measure diagonally to check for balance in the cell and connections. Measuring only straight across does not adequately test for either intercell connection resistance or for gross top lead defects. This is due to the parallel circuits for the current.

The graph in Figure 5 shows the data obtained from an actual 24-cell telephone (CO) battery. The peak at connector #12 (cell 12 to 13) is an intertier cable connection. Connector #3 was out of specification and it was determined that one of the two bolts was not properly torqued. It was retorqued and retested. It came within ten percent of the string average after retorquing.

The negative plates (odd-numbered plates #1 through 15) are all connected through negative top lead which is connected to both negative posts. Positive plates (even-numbered) are connected to each other through positive top lead which is connected to both positive posts. There are two intercell connectors between neg post 1 and pos post 1 and between neg post 2 and pos post 2.

The higher the current draw the more critical is the proper sizing of current-carrying components both internal to the cell and external. UPS batteries are usually designed for a high rate discharge lasting typically only 15-20 minutes. However, a telecommunications CO battery may have only a 500 Amp draw but can discharge for up to eight hours. So either combination can have disastrous effects due to improperly sized and maintained cells and intercell connectors.

### Testing and Electrical Paths

In order to properly test a multiple post cell, one must understand its construction. Based on the diagram in Figure 1, it can be seen that there are two parallel paths for the test current to travel. If the test leads are placed on neg post 1 and pos post 1, the two parallel paths are 1.) directly from neg post 1 to pos post 1 through their intercell connectors and 2.) neg post 1 down to the top lead, up to neg post 2 and across the intercell connectors to pos post 2 down to the pos top lead and back up to pos post 1. The two paths are parallel circuits and hence indistinguishable. If one bolt is loose, there isn't any way to determine that since the test current will follow the path of least resistance. The better method to measure intercell connection resistance is to measure diagonally from neg post 1 to pos post 2 and again from neg post 2 to pos post 1. Compare the two readings for highest confidence. Admittedly, diagonal measurements are still parallel but the comparison becomes more interesting due to the increased influence of top lead and loose hardware. Diagonal measurements do not allow for a direct connection from post to post. In the case of six-post cells, measure diagonally across the farthest posts in both directions.

### Voltage

Float voltage has traditionally been the mainstay of any testing procedure. What is voltage? Voltage is the difference, electrically speaking, between the lead and the lead oxide on the plates or between the nickel and the cadmium. The charger is the item that keeps them charged. The sum of all of the cell voltages must be equal to the charger setting (except for cable losses.) This implies then that voltage merely indicates the state-of-charge (SOC) of the cells. There is no indication of a cell's state-of-health (SOH). A normal cell voltage doesn't indicate anything except that the cell is fully charged. An abnormal cell voltage, however, does tell you

something about the condition of the cell. A low cell voltage can indicate a shorted cell but only when the voltage finally drops to about 2.03. If a cell is low then other cells must be higher in voltage due to the charger setting. Remember that the sum of all cell voltages must equal the charger setting. Those cells that are higher are counteracting the low cell and generally speaking the higher cells are in better condition because they can tolerate the higher voltage. But those cells are being overcharged which over-heats them and accelerates grid corrosion and water losses.

Let's say for the moment that the low voltage cell is not yet at 2.03, it is at 2.13 V. At 2.13 V it is not low enough to flag a concern but it is degrading. It may or may not be able to support the load when an outage occurs. Impedance is able to find that weak cell sooner than voltage. In this case, impedance will decrease since it is an impending short circuit.

A similar example can be found in VRLA when it comes to dry-out or loss-of-compression. Voltage will not find this condition until it is far later in the battery's life, until it is too late. Impedance finds this condition much earlier so that remedial action can be performed.

So don't confuse fully charged with full capacity.

### Specific Gravity

Specific gravity is the measure of the sulphate in the acid of a lead-acid battery. It is also the measure of the potassium hydroxide electrolyte in nickel-cadmium battery but since the potassium hydroxide electrolyte isn't used in the chemical reaction, it is not necessary to measure it periodically.

Specific gravity traditionally has not provided much value in determining impending battery failure. In fact, it changes very little after the initial 3 to 6 months of a battery's life. This initial change is due to the completion of the formation process, which converts inactive paste material into active material by reacting with the sulphuric acid. A low specific gravity may mean that the charger voltage is set too low causing plate sulphation to occur.

In a lead-acid battery the sulphate is a closed system in that the sulphate must be either on the plates or in the acid. If the battery is fully charged then the sulphate must be in the acid. If the battery is discharged, the sulphate is on the plates. The end result is that specific gravity is a mirror image of voltage and thus state-of-charge. Specific gravity readings should be taken when things are amiss in the battery to obtain as much information about the battery as possible.

Different battery applications and geographies have varying specific gravities to accommodate rates, temperature, etc. Following is a table that describes some applications and their specific gravities.

## Specific Gravities and Their Applications

Specific Gravity	Percent Acid	Application
1.170	25	Tropical stationary
1.215	30	Standard stationary
1.250	35	UPS/high rate
1.280	38	Automotive
1.300	40	VRLA stationary
1.320	42	Motive power
1.400	50	Torpedo

## Currents

### Float Current

Another leg of the Ohm's Law triangle is current. The charger voltage is used to keep a battery charged but voltage is really the vehicle to get current into the battery (or out of it during discharge). It is current that converts the lead sulphate back to active material on the grids.

There are two types of dc current on a battery: recharge current which is the current applied to recharge a battery after a discharge and float current which is the current used to maintain a battery in a fully charged state. If there is a difference between the charger setting and the battery's voltage, that difference will cause a current to flow. When the battery is fully charged<sup>1</sup>, the only current flowing is the float current which counteracts the self-discharge of the battery (<1% per week). Since the voltage differential between the charger and the battery is small, the float current is small. When there is a large voltage difference such as after a discharge the current is high and is limited by the charger until the voltage difference becomes less. When the current is on the plateau in the graph below, this is called current limit. When the voltage differential becomes less, the

charge current is reduced as depicted on the downward sloping charge current line on the graph shown in Figure 6. The charge voltage is the voltage of the battery, not the charger setting which is why it is increasing.

Float current will vary with battery size. The larger the battery is, the more float current it will take to keep it fully charged. Float current can increase for a couple of reasons: ground faults on floating battery systems and internal battery faults. Ground faults are discussed later. As a battery's internal impedance increases, it takes more current to pass through that higher impedance. The increase in float current can be an indicator of battery faults. In lieu of measuring float current, many of the same conditions are found with impedance.

In VRLA batteries, float current<sup>2,3</sup> seems to be an indicator of battery problems, namely thermal runaway. Thermal runaway is the result of a battery problem, not the cause. Some of the causes that can lead to thermal runaway are shorted cells, ground faults, dry-out, excessive charging and insufficient heat removal. This process takes anywhere from two weeks to four months to occur once the float current starts its increase. By measuring float current, it may be possible to avoid catastrophic failure of the battery and damage to connected and nearby equipment. Impedance will find many of these same errors.

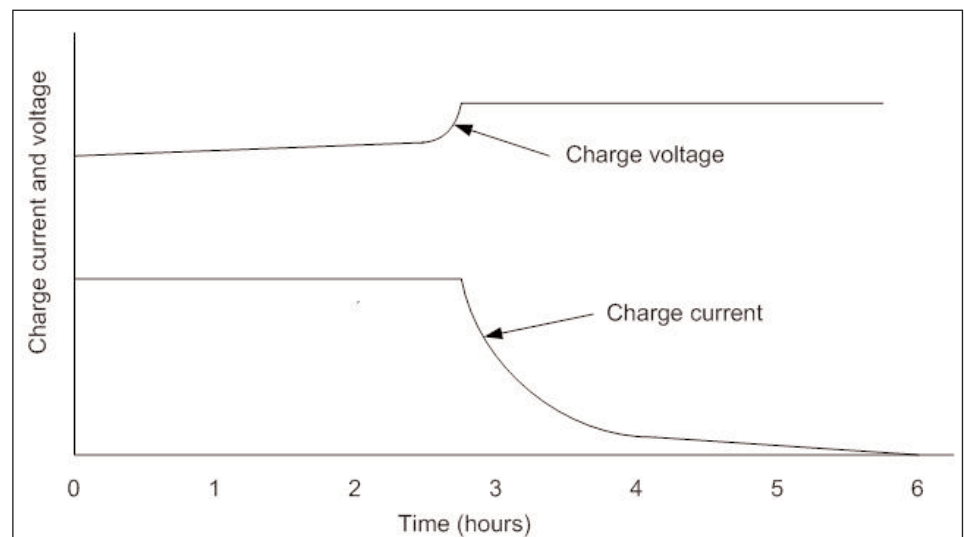


Figure 6: Constant-voltage Constant-current Charge Characteristics

<sup>1</sup> Cole, Bruce, et al., *Operational Characteristics of VRLA Batteries Configured in Parallel Strings*, GNB Technologies

<sup>2</sup> Brown, AJ, *An Innovative Digital Flat Current Measurement Technique - Part Two*, Proceedings of BattConn® 2000

<sup>3</sup> Boisvert, Eric, *Using Float Charging Current Measurements to Prevent Thermal Runaway on VRLA Batteries*, Multitel

## Ripple Current

Batteries, as dc devices, prefer to have only dc imposed on them. The charger's job is to convert ac into dc but no charger is 100% efficient. Frequently, filters are added to chargers to remove the ac current from the dc output. The ac current on the dc is called ripple current. Battery manufacturers have stated that more than about 5 A rms of ripple for every 100 Ah of battery capacity can lead to premature failure due to internal heating. Ripple voltage is not a concern since it is the heating effect of the ripple current that damages batteries. The 5% ripple current figure is a rough estimate and depends also on the ambient temperature. Ripple current can increase slowly as the electronic components in the charger age. Also if a diode goes bad, the ripple current can increase more dramatically leading to heating and premature death without anyone knowing it. Although impedance is not a measure of ripple current, ripple current is measured because of the way Megger designs its impedance instruments.

There is anecdotal evidence<sup>4</sup> that low frequency ripple (<10Hz) may charge and discharge a battery on a micro-scale. More research is necessary to prove this hypothesis. Excessive cycling can lead to premature death of a battery regardless of the reasons for the cycling, be they outages, testing or maybe micro-cycling. One thing is true: the lower the ac is on the battery system, the less the damage is that can occur. VRLA batteries seem to be more sensitive to ripple current than their flooded counterparts. It is then advisable to filter their chargers for ripple current/voltage.

## Temperature

Temperature is the worst culprit of shortened battery life. By applying what Arrhenius learned about chemical reactions, for every 18° F (10° C) increase in battery temperature, battery life is halved, battery life can start to be managed. The increased temperature causes faster positive grid corrosion as well as other failure modes. By holding a lead-acid battery at a temperature of 95° F (35° C) instead of the designed 77° F (25° C), a 20-year battery will last only ten years, a ten-year battery only five years and so on. Increase the temperature by another 18° F to 113° F (45° C), a 20-year battery will last only five years!

A battery is rarely held at a certain temperature for its entire life. A more realistic scenario is for a battery to heat during the day and cool down at night with higher average temperatures in the summer and lower average temperatures in winter. It is unfortunate but cooling the battery off to

below 77° F (25° C) will not gain back the life that was lost. Once the positive grid corrodes, it can not be converted back again. Furthermore, positive grid corrosion occurs at all temperatures, it is merely a matter of speed of the corrosion rate. The end result is to control, as best as possible (back to cost versus risk), the temperature of the batteries in the network.

## Discharge Testing

An analogy that is frequently used when it comes to discharges whether intended or not is the loaf of bread analogy. A loaf of bread has only so many slices in it. The same is true of lead-acid batteries. This is where the alloy of the lead enters the testing picture. There are three main alloys used in lead-acid batteries. Each has its benefits. Lead-calcium (Pb/Ca) uses much less current to keep it charged which also means that there is much less water used. It is designed for float applications. But it can't cycle well at all. In fact, according to various manufacturers' warranty sheets, a Pb/Ca battery can only tolerate about 30 to 50 deep discharges in its lifetime. This means that a Pb/Ca battery can be tested almost to death if it is tested each year for 20 years. Lead-antimony (Pb/Sb) and lead-antimony-selenium (Pb/Sb/Se) can tolerate much higher number of cycles but they also need water more often.

The proper way to discharge test a battery is expensive and time-consuming. Since the main battery will be discharged, a second battery needs to be brought in and connected in the event of an outage during the discharge test. All of the leads from the load bank need to be connected to each cell to measure cell voltages. The load test is run typically for eight hours or longer. Then the battery is recharged for about three days to a full charge. After that the second battery can be removed. The entire process can take four days with overtime and at great expense. The benefit of discharge testing is indeed an accurate measure of the battery's capacity and is the only proven method of measuring a battery's capacity.

Sometimes a quick test is performed to save time and money, but at what current and for how long? If a quick test is performed for 30 minutes but at the eight-hour rate then very little information is obtained as depicted in Figure 7.

But if the 30-minute load test is performed at the 30-minute rate much information is obtained about the battery's capacity. It is not perfect because there are differences in performance at different rates which is why there are short-duration batteries and long-duration batteries. Even though it is not perfect, it is far better than either not testing or full

<sup>4</sup> Ruhlmann, T., *Monitoring of Valve Regulated Lead Acid Batteries*, Proceedings of BattConn® 2000

testing. Much more heat is generated at higher rates than at lower rates, due to  $i^2R$  heating. (Ensure that all intercell connections are properly made so that avoidable problems don't occur causing major malfunctions during the load test.)

InfraRed thermography is an excellent tool to determine if and where weak connections may be. Obviously, IR is only worthwhile under a load that is sufficient to cause heating. IR cameras can be expensive but their uses go far beyond battery testing into many other areas of maintenance. Megger recommends their usage during a load test.

Discharge tests are an important and required part of any battery testing program but the costs must be compared to the risks. The frequency of load testing is usually at issue, not whether to perform load tests. IEEE Recommended Practices specify the frequency but generally, every couple of years (from 3 to 5 years) is a good timeframe. Alloy of the battery comes into play here as well as the criticality of the site. Between load tests, impedance is an excellent tool for assessing the condition of batteries without adding any risk to the testing program. Furthermore, it is recommended that an impedance test be performed just prior to any load test to improve the correlation between capacity and impedance.

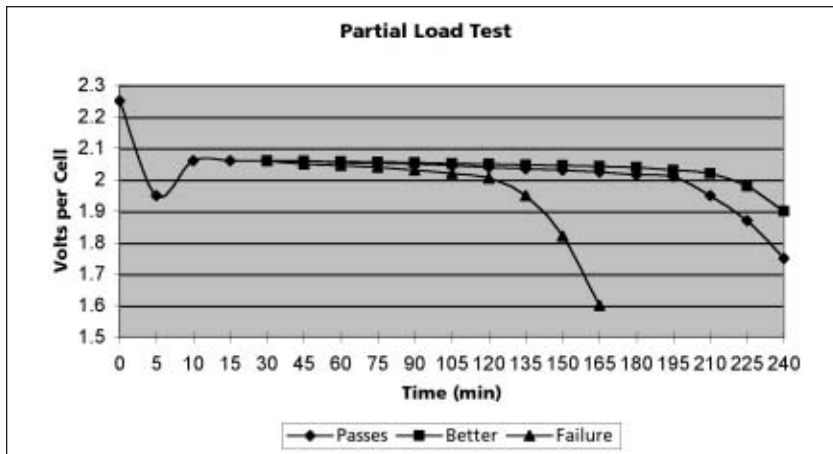


Figure 7: Partial Load Test Graph

	Single Test	Trending	
	% Deviation from String Avg	Cell's % Change from Last Test	Cell's % Change Overall
Lead-acid, Flooded	5	2	20
Lead-acid, VRLA, AGM	10	3	50
Lead-acid, VRLA, Gel	10	3	50
NiCd, Flooded	15	10	100
NiCd, Sealed	15	5	80

## BATTERY CONFIGURATIONS

Batteries come in various configurations themselves. Add to that the many ways that they can be arranged, the number of possible configurations is endless. Of course, voltage plays the biggest part in a battery configuration. Batteries have multiple posts for higher current draws. The more current needed from a battery, the bigger the connections must be. That includes posts, intercell connectors and buss bars and cables.

### Single Post Batteries

Smaller battery systems are usually the simplest battery systems and are the easiest to maintain. They usually have single post batteries connected with solid intercell connectors. Frequently, they are quite accessible but because they are small and can be installed in a cubby hole occasionally, they may be quite inaccessible for testing and maintenance.

### Multiple Post Batteries

Batteries with multiple posts per polarity start to become interesting quickly. They are usually larger and frequently are more critical.

## DATA ANALYSIS

The essence of any testing methodology is how to interpret the data to make some sense of it all. The same is true of battery testing. If the data are to be hand-written and filed or if a printout from an instrument is reviewed then filed, then there is no useful analysis except if there is an emergency at that very moment. The real value in battery testing lies in the trending of data to determine if problems are imminent or a little farther out. Trending of battery data, especially impedance, is an excellent tool for budgetary planning. By watching the batteries degrade over time, a decision can be made as to when to replace a battery. With trending, emergency replacements decrease dramatically.

The first time a battery is tested can cause concern because there is no baseline. In these cases, it is good to compare each cell against every other cell in the string. Weak cells stand out. It is these cells which require further investigation. The table to the left provides a guideline depending upon the length of time batteries have been tested.

## BATTERY TECHNOLOGY SUMMARY

As you can see, there is a lot to a battery. It is a complex electro-chemical device. There is much more information available that goes further into the details of Tafel curves and depolarization but that is beyond this scope. Essentially, batteries need maintenance and care to get the most of them which is the main reason people spend so much on batteries — to support far more expensive equipment and to ensure continuous revenue streams.

## LOCATING GROUND FAULTS ON DC SYSTEMS WITHOUT SECTIONALIZING

### Overview

The main objective of a battery system is to provide standby and emergency power to operate industrial, consumer, commercial or protective devices. Some of these devices include emergency lighting units, uninterruptible power supplies, continuous process systems, operating controls, switchgear components and protective relays.

In emergency situations, it is essential that these devices be in proper operating condition. Failure of a dc system or the battery can result in operational failure of the devices connected to that system. System failure can lead to loss of revenue, damage to equipment and/or injured personnel.

It is a common situation for a floating dc system to develop grounds within it. When a battery system is partially or completely grounded, a short circuit is formed across the battery and consequently may cause the protective device to fail to operate when needed.

### Current Test Methods

Traditionally utilities and industrial complexes have gone to great lengths to find ground faults within their battery systems. However, locating these battery grounds proves to be a very elusive and time-consuming process. The current ground-fault location method involves sectionalizing, or interruption, of dc branches to isolate the ground fault. Sectionalizing disables the system protection and has been known to cause inadvertent line and generator tripping. For this reason, many utilities have banned sectionalizing. Until more recently, though, this had been the only method available to locate ground faults.

## A Better Test Method

Developments have led to a better test method; injecting a low-frequency ac signal and using that ac signal to locate the ground in the dc system. This method can be performed without sectionalizing the dc system and it reduces the fault locating time from days to hours. Furthermore, it allows for system protection to be present at all times.

The ac injection method measures single or multiple ground faults by first injecting a low-frequency, 20 Hz ac signal between the station ground and the battery system. Second, the resulting current is then measured by using a clamp-on sensing current transformer. From this, the resistance value can be calculated using the in-phase component of the circulating current, thus rejecting the effect of capacitive loads. Therefore, if the signal is injected at the battery terminal and the clamp-on CT is connected to the outgoing lead, the instrument will measure the total ground resistance present on the battery system. If the CT is clamped on a feeder, then the instrument will measure the ground resistance on that feeder. Faults can be traced easily regardless of the number of distribution panels or circuits because the “tracer” is merely following the strength of the ac signal. System integrity is maintained because it is an on-line ac test and is designed to prevent system trips.

After injection of a low-frequency ac waveform, a resistive fault on a branch of the battery system will be indicated by a low-resistance value. For example, if the total resistance of a battery system showed 10 k $\Omega$ , this would indicate a resistive fault on the battery system. The resistive fault can be located by clamping on each individual circuit until a resistive value of 10 k $\Omega$  is found.

It is easy to see that this method can be adapted in a straight forward manner to locate multiple faults by using the theory of parallel paths. For example, if the total system resistance indicates 1 k $\Omega$  and an individual branch indicates 10 k $\Omega$  resistive fault, the user would know that the system has a second fault because the total system resistance and the branch resistance do not match. By using the ac injection method, ground faults on ungrounded dc systems is easy, straight-forward and safe.

## FREQUENTLY ASKED QUESTIONS

*What does float voltage of a cell tell me?*

Float voltage indicates that the charger is working, that is, state-of-charge. It does not indicate the state-of-health (condition) of the cell. It indicates that the cell is fully charged, but don't confuse fully charged with full capacity. There have been many times that the float voltage is within acceptable limits and the battery fails. A low float voltage may indicate that there is a short in the cell. This is evident by a float voltage at about 2.06 or below for lead-acid (if the charger is set for 2.17 V per cell)

In some cases, a cell floats considerably higher than the average. This may be caused by the high float voltage cell compensating for another cell that is weak and is floating low. It is possible that one cell floats much higher to compensate for several cells floating a little low. The total of all cells' voltages must equal the charger setting.

*What are the recommended maintenance practices for the different types of batteries?*

IEEE Recommended (Maintenance) Practices cover the three main types of batteries: Flooded Lead-acid (IEEE 450), Valve-Regulated Lead-acid (IEEE 1188) and Nickel-Cadmium (IEEE 1106). Generally speaking, maintenance is essential to ensure adequate back-up time. There are differing levels of maintenance and varying maintenance intervals depending upon the battery type, site criticality and site conditions. For example, if a site has an elevated ambient temperature, then the batteries will age more quickly implying more frequent maintenance visits and more frequent battery replacements.

*How important is intercell connection resistance?*

Our experience has found that many battery failures are due to loose intercell connections that heat up and melt open rather than from cell failure. Whether a cell is weak or an intercell connector is loose, one bad apple does spoil the whole bushel.

When lead acid batteries are frequently cycled, the negative terminal may cold flow, thus loosening the connection.

The proper sequence of measuring multiple post batteries is critical. Not all instruments provide valid intercell connection resistances due to their method of testing. Megger instruments provide valid data.

*What are some common failure modes?*

Failure mode depends upon the type of battery, the site conditions, application and other parameters. Please refer the summary on pages 2-4 or to the "Failure Modes Application Note," which can be found on the Megger website ([www.megger.com](http://www.megger.com)).

*How often should impedance readings be taken?*

The frequency of impedance readings varies with battery type, site conditions and previous maintenance practices. IEEE Recommended Practices suggest semi-annual tests. With that said, Megger recommends that VRLA batteries are measured quarterly due to their unpredictable nature and semi-annually for NiCd and flooded lead-acid.

*At what point should I stop changing cells and replace the entire battery?*

In shorter strings (less than 40 cells/jars), the entire should be replaced when three to five units have been replaced. In longer strings, a similar percentage that is replaced is the criterion.

*How can I predict when I need to change a cell or the entire battery?*

Even though there is not a perfect mathematical correlation between battery capacity and impedance (or any other battery test except a load test), the amount of increase in impedance is a strong indicator of battery health. Megger has found that a 20 percent increase in impedance for flooded lead-acid generally correlates to 80% battery capacity. In VRLA, that increase is closer to 50% from the battery's initial impedance or from the manufacturer's baseline values.

*Do battery manufacturers accept impedance for warranty purposes?*

Many manufacturers now publish impedance values to establish baselines. Several larger organizations who buy many batteries per year have written percent increases of impedance into their battery purchasing specifications for warranty and replacement purposes.



## MEGGER PRODUCTS OVERVIEW

Megger offers solutions to ensure system performance with its comprehensive line of Battery Test Equipment, Low Resistance Ohmmeters and Micro-ohmmeters, Insulation Testers, and Multimeters.

An overview of the various products available is described below. For more information on these and many other Megger products, please contact us at (800) 723-2861, (214) 333-3201. Visit our web site [www.megger.com](http://www.megger.com) for the most up-to-date news, product and service information.

### Battery Test Equipment

Regardless of whether you are testing flooded lead-acid, VRLA or Ni-Cd cells, Megger has the right equipment for your battery maintenance requirements. The products and associated accessories provides meaningful data on battery health without significant expense or any reduction in remaining battery capacity.

Interruption in service can cause disaster to supported equipment and facilities. Consequently, a dependable backup power system is critical so that when AC mains fail, costly service interruptions can be avoided. The battery impedance test helps to identify weak cells before they cause problems.

Taking the battery off-line for testing is time consuming and adds risk to the process. This process is unnecessary with the on-line testing capabilities of the Megger family of battery test products. The highly repeatable instruments help reduce downtime.

#### NEW BITE® 3

- Determines the condition of lead-acid batteries up to 2000 Ah
- On-line testing with Pass/Warning/Fail calculations
- Measures impedance, intercell connection resistance, cell voltage
- Windows CE® Operating System with more than 16 MB of memory
- Measures float and ripple currents



The BITE 3 is a compact, battery-operated, instrument with powerful on-board data analysis tools. It is the first of its kind instrument in that the ProActiv can download all previous data to provide the best in on-site data analysis like no other instrument of its kind. The menus are easy to navigate with a bright, backlit LCD. The data display includes the normal numeric arrangement but adds two graphical displays to help analyze weak cells.

#### BITE® 2 and BITE® 2P

- Determines the condition of lead-acid and nickel-cadmium batteries up to 7000 Ah
- On-board Pass/Warning/Fail indications
- On-line testing
- Robust, reliable instruments
- Built-in printer (BITE 2P)



BITE 2P

The BITE 2 and BITE 2P Battery Impedance Test Equipment work by applying a test current across the battery string while on-line, then measuring the impedance, cell voltage and intercell connection resistance.

They also measure ripple current which indicates the condition of the charger. The instruments help evaluate the condition of the entire string from terminal plate to terminal plate and even the charger.



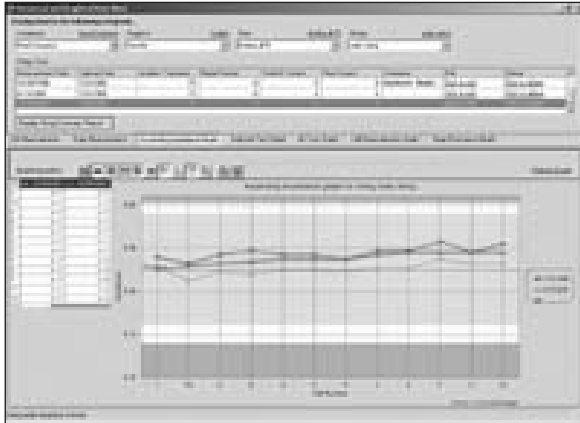
BITE 2

#### NEW ProActiv Battery Database Management Software

- Organizes and manages battery data
- Performs trending analysis
- Assists the user to manage multiple batteries
- Prints basic reports

The first of its kind, ProActiv is a new, powerful, easy to use battery database management software designed to analyze each individual battery in a battery system.

Battery testing is crucial to ensure a battery system provides standby and emergency power to operate devices such as emergency lighting, UPS systems, operating controls, switchgear components, protective relays and continuous process systems. Failure of a battery system within environments such as utilities, hospitals or manufacturing plants can result in operational failure of the devices connected to it. ProActiv assists the user to avoid battery failures, budget for future battery string and cell replacements, and plan battery change outs in an orderly manner.



ProActiv utilizes a standard MS Access database format. It allows the user to organize and manage battery data such as voltages, impedance, intercell connection resistance, ripple current, specific gravity, IR thermographs and more.

### BITE® Accessories

- Enhances the capabilities of the BITE line
- Full line of accessories
- Designed for unique situations
- Great for non-standard installations

Megger offers a complete line of accessories to enhance the capabilities of the BITE product line. Many are shown in the Data Sheet link above, but there are many others including extension cables, calibration shunts, etc. Even though we have many accessories, we are continually evaluating additional products as interest arises.

- RopeCT™ is a flexible, highly accurate current transmitter for measuring current flow in larger battery systems. It comes in two lengths: 24 in. (60 cm) and 36 in. (90 cm) for 8 in. (20 cm) and 12 in. (30 cm) diameters, respectively. It is designed specifically for the BITE 2, BITE 2P and EBITE.



- Mini-CTs are for measuring current in smaller gauge wires and a single cable tied in a bundle.



- Probe Extensions can be mounted on the Receivers and probes of the BITE 3, BITE 2, BITE 2P, MBITE and EBITE. They are ideal for measuring batteries in cabinets and hard-to-reach places. With these probe extensions, batteries needn't be taken off line to measure them — a real time and cost saving device.



- Bar Code Wand is for entering header information such as location, operator's initials and room temperature. This information becomes a permanent part of that string's information and is downloaded with each test.



- Digital Hydrometer measures specific gravity and temperature for each cell and it calculates a temperature-adjusted specific gravity to save time — all in a hand-held device. It can store up to 256 cells per string in up to eight strings. No need to worry about parallax or hand writing data on sheets, etc. It is much safer than bulb hydrometers and without any spilled acid to clean up.



## Ground Fault Tracing Equipment

There are two ground fault locating instruments from which to choose, the Battery Ground Fault Tracer (BGFT) and the Battery Ground-Fault Locator (BGL). The BGFT has superior noise elimination while the BGL has an automatic bridge to differentiate between high capacitance and low resistance. Here is a brief description of each instrument.

### Battery Ground Fault Tracer (BGFT)

- Easily locates ground faults in ungrounded dc battery systems
- Operates in high electrical noise environment
- Simplifies fault tracing by identifying fault characteristic (resistive and capacitive) magnitudes

The Battery Ground-Fault Tracer is an economical, manually balanced instrument that identifies, tracks and locates ground faults in ungrounded dc battery systems - on-line. It is particularly effective in high electrical noise environments, as the strength of the test current can be adjusted up to 80W. The BGFT is particularly useful in any industry where supply of power for operating measurement, communication and control equipment is critical.

The Battery Ground-Fault Tracer accelerates fault location by eliminating trial-and-error procedures and because faults can be located without going off-line. It is line operated and has a manual bridge. The manual bridge is used to differentiate between true, resistive faults and phantom, capacitive faults by using a feedback cable to null the capacitance. But the manual bridge is not required in order to trace faults.

The BGFT works by converting line frequency to 20 Hz. It then pushes the ac signal through some coupling capacitors to prevent transients on the dc buss and applies the ac signal into the dc system while on-line. Using the hand-held tracer, follow the signals with the highest readings until the fault is found.



### Battery Ground-fault Locator (BGL)

- Ground faults in ungrounded dc battery systems are easily located
- Features an automatic bridge
- Battery operated
- Simplifies fault tracing by identifying fault characteristic (resistive and capacitive) magnitudes



The Battery Ground-Fault Locator was developed to detect, track and locate ground faults on battery systems, without resorting to sectionalizing! The BGL tracks and locates

ground faults on live or dead battery systems. To save hours of unnecessary troubleshooting, the BGL readily differentiates between the resistive fault currents and capacitive charging currents. This feature allows the instrument to detect and track leakage paths, even in the presence of surge-suppression capacitors.

The BGL works by filtering and applying an ac signal to the dc buss on-line. The low level output of the BGL allows it to be battery-operated but is more sensitive to system noise. It has a built-in automatic bridge to differentiate between real (resistive) and phantom (capacitive) faults so only the real faults are traced. The BGL is moved from panel to panel to continue the tracing process until the fault is found. Since it has an automatic bridge it is very easy to trace faults and as such is better designed for the novice user.

## Digital Low Resistance Ohmmeters

Many times batteries fail not because of weak cells but due to weak intercell connections. Torquing is a mechanical method to ensure that the electrical path resistances is very low. But it does not truly indicate the quality of the electrical path resistance. The only true method is to measure each intercell connection resistance with a Digital Low Resistance Ohmmeter.

Megger has several DLROs that are appropriate for intercell connection resistance. The portability of the instruments allows effortless mobility around battery strings.

The DLRO instruments are built into strong, lightweight cases that are equally at home in the field or in the laboratory. They are light and small enough to be taken into areas which were previously too small to gain access. All of them have large, easy-to-read LED displays while the DLRO10X has a large, backlit LCD.

### DLRO® 247000 series

- Resolution to  $0.1\mu\Omega$  on  $599.9\mu\Omega$  range
- Standard accuracy of  $\pm 0.25\%$
- Large, digital LED readout



The 247000 Series of DLROs are a family of highly accurate instruments that provide a simple, practical and reliable means of making low-resistance tests in the field. They also are ideal for production quality control. They operate on the four-wire measurement principle, thus eliminating lead

and contact resistances. With basic accuracies of  $\pm 0.25\%$  and resolution down to  $0.1\mu\Omega$ , they are nonetheless designed to be rugged and portable for use at the job site. A variety of optional test leads and calibration resistance standards are offered for use with them.

### DLRO10 and DLRO10X

- Accurate results in under three seconds
- Fuse protected to 600 V
- NiMH battery reduces weight
- Automatically detects continuity in potential and current connections
- Visible warning of high voltages present at the terminals
- Multiple operating modes including fully automatic

- Alpha-numeric keypad for entering test notes (DLRO10X)
- User configurable high and low limits (DLRO10X)
- Printer output and memory (DLRO10X)

The DUCTER® DLRO10 and DUCTER DLRO10X bring new standards to low resistance measurement. Both are fully automatic instruments, selecting the most suitable test current, up to 10 A dc to measure resistance from  $0.1\mu\Omega$  to  $2000\Omega$  on one of seven ranges. For users who desire more control over the measurement process, DLRO10X uses a menu system to allow manual selection of the test current. DLRO10X also adds real-time download of results and on-board storage for later download to a PC.



## Digital Clampmeters

- Autoranging and auto-zeroing features
- Full multimeter functionality
- True RMS for accuracy, even with harmonic loads

Megger offers a family of DCM-R Clampmeters that are ideal for use in the installation, maintenance, monitoring, or checking of battery and other electrical systems or equipment. The three models in this series provide a versatile, safe and accurate solution to non-intrusive current measurements, both ac and dc, to diagnose faults on live battery systems. The series measures ac, dc, pulse and mixed current, and include a diode test.

The analog output of these instruments allows connection to recorders, loggers and oscilloscopes. These multi-purpose instruments offer a range of functions suited to individual applications. Their rugged design is ideal for harsh environments, like battery rooms, and reflects versatility and quality workmanship.



## Insulation Resistance Test Equipment

Batteries are supposed to be well insulated from adjacent equipment and metallic objects. The insulation provides several benefits: 1) keeps the charge in the battery rather than letting it leak, 2) provides for normal float current, and 3) reduces energy losses. If a battery is leaking electrolyte, then there may be a path to ground. When a path exists, the current needed to keep the battery fully charged increases. It also shortens the length of back-up time of the battery depending upon the severity of the leak. An insulation resistance test can identify whether there are leaks. The insulation resistance is measured across one of the terminals of the battery to some ground, presumably the battery rack or tray. It is a very easy test to perform and provides for a lot of confidence in the overall state of electrical insulation.

This test applies a dc voltage, say 500 Vdc, between the buss, off-line and the rack. Then measures the dc leakage current to calculate resistance in  $M\Omega$  or  $G\Omega$ . The higher the resistance is the better. This test is recommended at installation and whenever a leak may be suspected (from tell-tale signs such as salt build-up.)

Meggers offers a variety of hand-held insulation testers. The following instruments are the most economical models, combining simplicity and ease of operation. The hand-held models provide the maintenance man or electrician with multimeter functions across the full spectrum of resistance.

These instruments are available from as low as 50 V to as high as 1 kV. For analytical applications, multiple test voltages are desired.

### BM81/2 Insulation Resistance Tester

- Multiple insulation test voltages from 50 V to 500 V dc
- Designed to IEC1010-1 safety standards
- Functions as a general-purpose ohmmeter and voltmeter
- Measures voltages up to 600 V ac/dc

The preferred insulation and continuity instrument for integrated services digital network (ISDN) testing, the BM81/2 ensures the integrity and reliability of twisted-pair telephone lines used for high speed digital communications over ISDNs. It allows performance of basic service line tests and noise meter readings including reading opens, shorts, grounds and crosses. The user can perform precise insulation resistance readings on sensitive equipment that would otherwise be subject to damage by higher voltages.



### Model BMM80 Insulation Resistance Tester

- High spec low voltage insulation tester
- Includes 50 V and 100 V tests
- Insulation resistance to 200  $G\Omega$

The BMM80 offers a Millivolt Transducer input which accommodates a wide range of probes to allow measurement of additional parameters, such as temperature, current, humidity, pressure, and microwave leakage. Five insulation test voltages, which include 50 V and 100 V tests, combine with capacitance measurement to make the BMM80 fully suited to telecom applications.



### Multimeters

Megger multimeters compliment the solution to measuring and maintaining battery strings and cells. All instruments undergo rigorous testing throughout their design and manufacture and are suitable for use in field service applications. All are CE marked and designed to National and International Safety Standard, EN61010-1. They include such features as large digital displays, automatic power down, water and dust resistance. There are three series of Megger multimeters, the M8000, M7000 and M5000 depending upon needs and features wanted.





**Your “One Stop” Source for all your electrical test equipment needs**

- Battery Test Equipment
- Cable Fault Locating Equipment
- Circuit Breaker Test Equipment
- Data Communications Test Equipment
- Fiber Optic Test Equipment
- Ground Resistance Test Equipment
- Insulation Power Factor (C&DF) Test Equipment
- Insulation Resistance Test Equipment
- Line Testing Equipment
- Low Resistance Ohmmeters
- Motor & Phase Rotation Test Equipment
- Multimeters
- Oil Test Equipment
- Portable Appliance & Tool Testers
- Power Quality Instruments
- Recloser Test Equipment
- Relay Test Equipment
- T1 Network Test Equipment
- Tachometers & Speed Measuring Instruments
- TDR Test Equipment
- Transformer Test Equipment
- Transmission Impairment Test Equipment
- Watthour Meter Test Equipment
- STATES® Terminal Blocks & Test Switches
- Professional Hands-On Technical and Safety Training Programs

Megger is a world leading manufacturer and supplier of test and measurement instruments used within the electric power, building wiring and telecommunication industries.

With research, engineering and manufacturing facilities in the USA and UK, combined with sales and technical support in most countries, Megger is uniquely placed to meet the needs of its customers worldwide.

For more information about Megger and its diversified line of test and measurement instruments:

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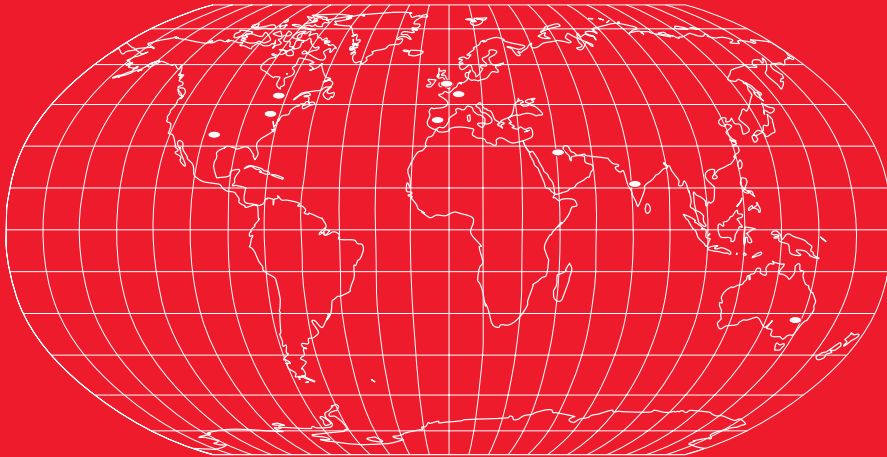
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