AVOID BEING STRAPPED BY STRAP CONNECTION RESISTANCE

Volney Naranjo
Principal Engineer
Technical Support Group
Megger
Dallas, TX

Andrew Sagl
Product Manager
Megger
Phoenixville, PA

David Martinez
Applications Engineer
Megger
Dallas, TX

1 Battery interunit connectors

A fundamental component of a battery string is the interunit connector also known as straps. This is made of a conductive bar or strap and is used to link the different basic battery units to conform a string of a certain voltage. Pending the configuration of the string they can connect posts of opposite polarity to form a series connection, or of the same polarity to set up a parallel connection.

The strap connection resistance is the summation of the contact resistance between the posts and the connector plus the resistance of the connector, which may be just a conductive bar or made of a flexible conductor plus a pair of terminals, a case in which the contact resistance between the conductor and the terminals also adds up to the total connection resistance. The intercell connectors are installed in direct contact to the post of the battery and are bolted with hardware at a certain torque in an attempt to minimize the resistance of the connection without damaging the terminals.

A low resistance connection between the posts and the connector is required to maintain high ampacity, guarantee an efficient transfer of power to the load, and minimize degradation of the container or the internal components of the battery due to hot spots. The connection resistance is also an indication of the tightness, quality, and health of the connection. Loose connections or contaminated contact surfaces can cause higher than desired connection resistance.

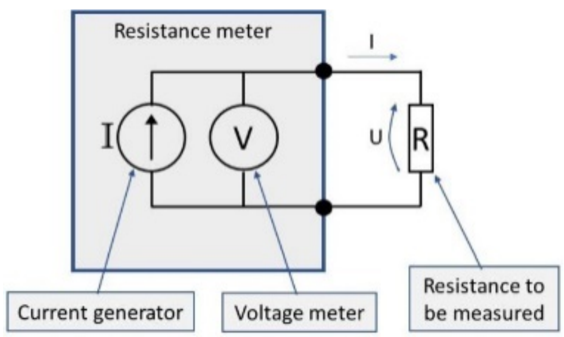
A recommended practice for installation and maintenance of a battery string is the measurement of the strap connection resistance. This resistance is in the order of micro-ohms, and its measurement requires use of the appropriate instrumentation and consistent practices. Being that this is a measurement on a highly conductive circuit, it requires injection (or withdrawal) of current through the circuit and the measurement of the corresponding voltage drop to be able to determine its resistance. How this current is injected (or withdrawn) through the circuit and its magnitude can affect the result and its corresponding trending analysis.

Straps are subjected to vibrations as well as heating and cooling which, over time, will affect their connection. As these connections degrade their resistance increases. This will increase the voltage drop across the strap which can lead to unbalanced strings, low float voltages on some cells, and consequentially partially sulfated plates within the cells.

The following sections discuss the recommended practices for proper measurement of interconnection resistances, the appropriate measurement technique, and the effect of different current magnitudes and type of current signal (dc or ac) on test results. Different instruments, techniques, and current signals were used on the same battery strings to show a practical comparison that will help users improve how they take their measurements and trend data during battery installation and maintenance.

2 Methods for low ohmic resistance measurement

Resistance measurement is based on ohms law. For low ohmic applications, like a strap connection resistance, a known current is circulated from a source through the connection to measure and back to the instrument. The resistance across the connection to be measured causes a difference in potential or voltage drop across its terminals. Using a voltmeter this potential drop can be measured (see Figure 1). This voltage and known current are used to determine the resistance of a connection using ohms law (Eq. 1):



$$R = \frac{V}{I}$$

Eq. 1

Figure 1: Basic concept of resistance measurement
(Source: https://blog.beamex.com/)

2.1 2-Wire method

Figure 1 shows only two wires involved in the measurement setup, and it is clearly seen that the voltage drop is measured at the terminals of the instrument which implies that the resistance of the test leads used to perform the measurement is added to the resistance being measured. This is called the 2-Wire method and a clearer representation is shown in Figure 2.

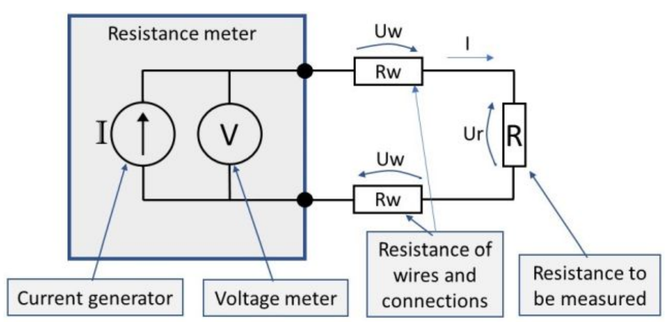


Figure 2: 2-Wire resistance measurement circuit
(Source: https://blog.beamex.com/)

If the resistance R being measured is in the same order of magnitude or lower than the resistance of the test leads, a high error is introduced in the measurement due to the additional voltage drop caused by the resistance of the test leads.

2.2 4-Wire method

Figure 3 shows a method in which 2 wires are used to circulate current through the object to be measured and two separate wires are used to measure the potential drop across the resistance. In this case, due to the high impedance of the voltmeter, there is a negligible current circulation through the measurement leads; hence, there is no potential voltage drop due to the measurement wires which equates as if the voltmeter is connected directly to the object. This method guarantees a measurement without any additional resistance from the test leads and is known as the 4-wire method or Kelvin sensing.

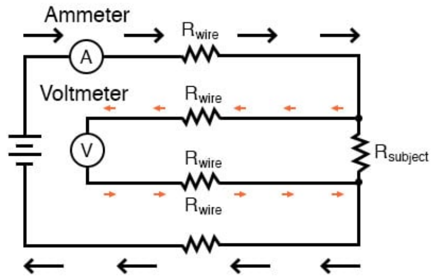


Figure 3: 4-Wire resistance measurement circuit
(Source: https://www.allaboutcircuits.com)

For strap connection resistance measurement, due to the low ohmic nature of the circuit it is preferred to use the 4-wire method. The sole resistance of the measurement wires in a 2-wire method can easily mask any defect or high resistance in a strap connection.

3 Absolute Vs Relative Measurements

The 4-wire measurement method can provide either relative or absolute values depending on how it is performed and what is used as test probes because the current density at the point of connection is higher and not uniform. The current density gets uniformly distributed as it circulates down the conductor (Figure 4). If the potential drop is measured near the current injection point, it gets affected by the higher current density making the measurement a relative measurement rather than an absolute one. The best approach to get absolute values is to have the current leads as separate from the potential drop measurement leads as possible so that the current is applied uniformly at the measurement point.

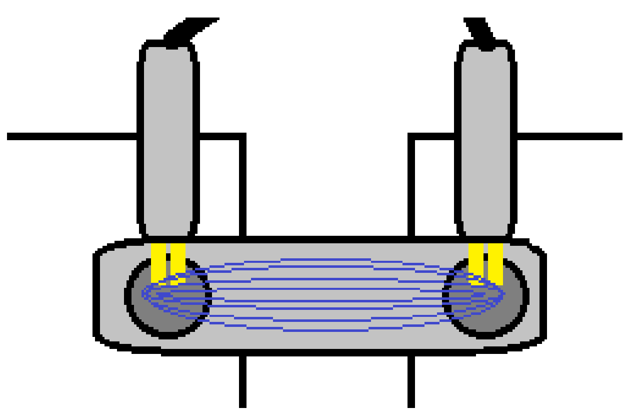


Figure 4: Representation of current density in a strap connection resistance measurement

There needs to be a minimum distance between the pins to achieve a uniform current density. If the current density is not uniform at the point where the potential drop is measured, then the measured resistance value will change if a different model probe that has a different distance between the pins is used, making the result relative to the probes used for the test. However, this does not mean the measurements are not valid. Simply, any comparison of results needs to be made to measurements taken with the same type of probe.

Absolute measurements with a low resistance ohmmeter require a uniform current density through the material under test. For example, to ensure a uniform current density through a wire, the potential leads must be separated from the current leads by at least 1.5 times the sample's circumference being measured, as shown in Figure 5.

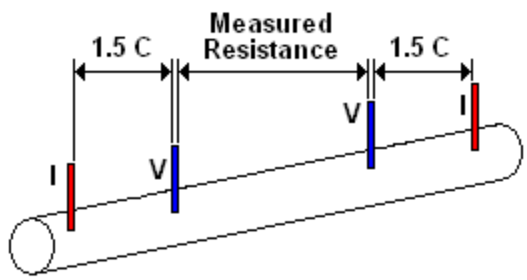


Figure 5: Minimum distance for absolute resistance measurement in a wire

Figure 6 shows the minimum distance to ensure a uniform current density through a bar. The potential leads must be separated from the current leads by at least 3 times the width of the sample being measured.

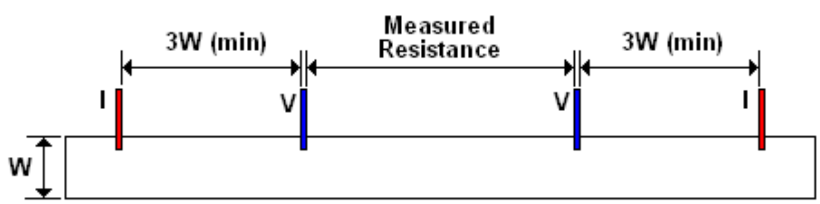


Figure 6: Minimum distance for absolute resistance measurement in a bar

When using duplex leads that have a fixed distance between the current pins and the potential pins, the current density will not be uniform and, therefore, will only provide a relative measurement. Figure 7 and Figure 8 show two distinct types of duplex leads with different pin separation.

Figure 7: Duplex leads (4-wire probes) – 0.23 in (6 mm) pin separation

Figure 8: Duplex leads (4-wire probes) - 0.4in (10 mm) pin separation

For some battery strings the inter-cell connecting straps do not have sufficient length beyond the terminal, to allow for a uniform current density. Therefore, an absolute connection resistance measurement is not possible with duplex probes. As a result, it is normal that strap connection resistance results are relative values. It is then important to document what instrument and probes were used when producing a report for future reference and evaluation.

Finally on this topic of relative and absolute readings, some multifunction battery testers use ac current as it is discussed in the next section, but a characteristic of some of these instruments is that they can inject current through the entire string where potential drop measurements are taken with a separate receiver. In these cases, since the current is circulating through the entire string, the current density is uniform at the straps and the measurements are absolute.

4 Type of current and magnitude

4.1 Using dc current or ac current

As for the current to be used, both dc and ac can be used but it is important to consider the following aspects to use the proper procedure and get appropriate measurements.

For the dc case, the measurement of an unenergized connection is different from an energized connection that represents the measurement of a strap connection resistance in a battery string, where the inter-cell connections already have a dc current running through them. This current comes from the charger and the batteries. Since the charge current is flowing through the string in one direction, the low resistance ohmmeter will get a different measurement depending on the polarity of the test current.

If the test current flows with the same polarity as the current already floating through the battery, they add up and if it is flowing opposite, they subtract. In the end, the current magnitude used for the calculation by the instrument is different from the current causing the potential drop. To get a proper measurement, the low resistance ohmmeter must take the measurement in both directions. Then the average of the two measurements will represent the actual resistance.

Some low resistance ohmmeters do have an option to perform forward and reverse measurements, known as bi-directional mode. If available, this should always be enabled when measuring an intercell strap. If the meter does not have this capability, then the readings must be taken in both directions and averaged together.

Some multifunction battery testers will test using dc current and the same concept applies to them: the measurement needs to be in both directions. The tester may have this function built in and it is recommended to verify it prior to test to avoid comparability issues with future results.

Some battery testers use ac current. The alternance of the signal means that the measurement is made in both directions every cycle, and the measurement is the averaged value. Also, since the strap connection circuit is mainly resistive with negligible capacitance or inductance presence, the measured ohmic value lacks any reactive impedance in the results and can be considered an absolute resistive value.

4.2 Test current magnitude

The connection resistance of a strap is an indication of the quality of the connection and as such the measurement requires a high resolution which is achieved with a high current: In a low impedance circuit, the higher the test current, the higher the voltage drop, leading to an improved resolution in the result.

Multifunction battery test equipment and low resistance ohmmeters have a variety of output currents. These can range from 100µA to over 200A.When using equipment with low current outputs, in the 100mA range or below, the quality of the connection is not tested, only the connection continuity is verified.

When selecting the test current, it is also important to not exceed the ampacity limit of the strap. A current that exceeds the ampacity can lead to heating and the consequent effect of resistance increase due to its temperature dependence.

Another aspect to consider when measuring battery straps is the dc current from the charger as explained before. This can further complicate the ability to take adequate intercell measurements and using a higher current magnitude can improve the chances of getting a good result. In some cases, such as in substation applications, the amount of current can be relatively low, assuming the batteries are in float mode, and this does not interfere with the measurement. However, in other applications, such as UPS (Uninterruptible Power Supply) systems, in which this current can be relatively high, the test current needs to be higher.

For example, IEEE450 recommends reworking an intercell connection if it rises by more than 20% from its baseline. Therefore, if the intercell connection baseline is 50µΩ, a typical value for strap connection resistance, 20% of this is 10µΩ. The potential drop developed across 10µΩ at 100mA of test current is 1µV. Therefore, the difference between a passing and a failing reading is 1µV, a value too low that can fall into the inaccuracy of the instrument. If a current of 1A is used, the voltage drop developed across 10µΩ is 10µV, a value ten times higher which in a deenergized system could easily be measured. In an energized system like a battery string where on top of the floating current there can be ripple current, the Signal-to-Noise Ratio (SNR) can still overwhelm this value, causing fluctuating measurements or unreadable measurements.

Using the appropriate current magnitude guarantees not only good resolution but repeatability despite the surrounding conditions. Below are the results of intercell connection tests that were performed at various test currents and under two different conditions: low levels of noise and with 10A of low frequency noise (approx. 55 Hz). The test results are summarized showing the average deviation in the measurement and were performed on the strap pictured in **Error! Reference source not found.**.

All these measurements were done with low resistance meters that utilize dc current and using bidirectional measurement method to show an averaged result. These were not done with battery testers that may employ different output signals and various filters, which may improve the overall measurement. The results will also be affected by different frequencies of noise, depending on the filters used in the test equipment.

Figure 10: Average deviation of strap connection resistance at different test currents and noise conditionsFigure 10 shows the results of this exercise. At lower currents the measurement repeatability, represented by a low average deviation, was poor, and it can be seen the added current from the low frequency noise improved the repeatability of the measurement. As the test current increased, the repeatability of the measurement improved to about 100A. At this point, heating effects from the high current began to decrease repeatability.

Figure 9: Strap Under Test

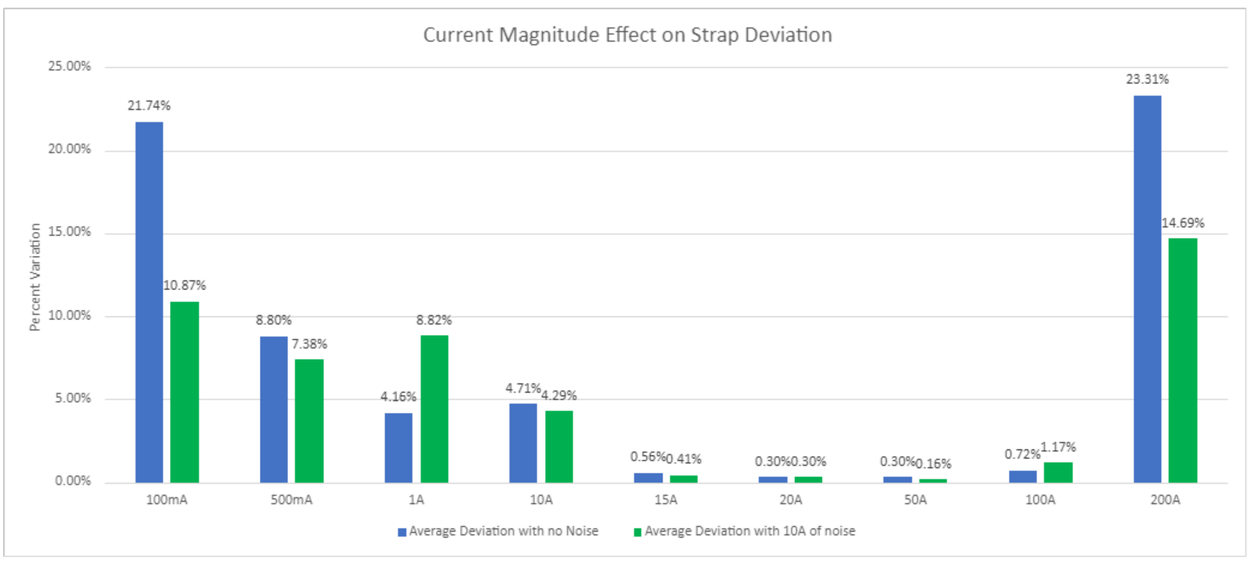


Figure 10: Average deviation of strap connection resistance at different test currents and noise conditions

It is important to note that not all straps are the same size. When smaller straps with smaller cross-sectional areas are used a decrease in repeatability may be seen due to heating effects at lower currents. In general, low magnitude test currents do not provide adequate repeatability. It can also be seen that high magnitude test currents do not provide adequate repeatability as well.

5 Best practices for strap connection resistance measurement

Using the 4-wire method and proper current magnitude is the foundation to a good measurement, however the way the measurement is done in the field can affect the result considerably. Before doing measurements, it is important to understand what type of instrument is being used to know what measurement method, current type and magnitude will be used and if it is suitable for the test. If the measurement range is selectable, it should be set to the lowest scale available, and test results should be displayed in micro-ohms.

Then, the type of post/strap configuration to be tested needs to be checked to determine if the posts are accessible directly or if some barriers need to be removed or if some insulating material is permanently installed to determine if it is possible to run the test, what test probes are required or if the ones that are available are suitable for the test. In some cases, there is a small hole to perform measurements and only concentric probes work on these cases.

Once ready to perform measurements, this is done always between adjacent units, from one post of a unit to the adjacent connected post. When placing the probes for the measurement these should be perpendicular and flush to the post if possible (not always possible, especially for smaller batteries, depending on terminal and hardware design/configuration). The following sections describe the best field practices to achieve reliable results.

5.1 Probe positioning

A duplex probe utilizes two pins. One pin injects current and the other measures voltage potential. Typically, they are labelled as C for the current probe, and P for the potential drop measurement. For proper measurement, they must be positioned so that the current injection pin is located outside of the voltage measurement pin, as shown in Figure 11. This ensures that the voltage pins are in the path of the current flow. Furthermore, if the pins are angled or with the current pins inside the voltage measurement as shown in Figure 12, the current density and the measurement are altered.

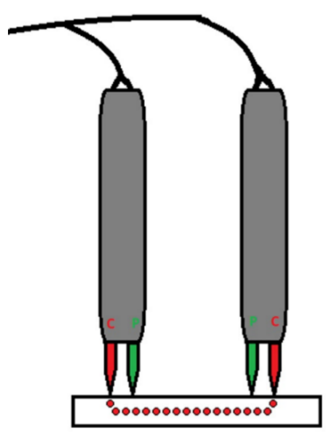


Figure 11: Right positioning of duplex probes

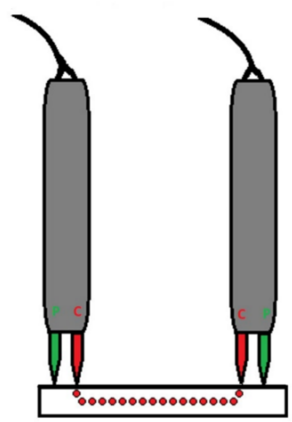


Figure 12: Wrong positioning of duplex probes

Therefore, when using this type of measurement is not only important to take the measurements in the same location, but it is also important to verify the probes are positioned with the current pin to the outside and are parallel to the strap connection being measured.

5.2 Different strap configurations

Battery designs and layouts are diverse, and they may pose challenging situations to measure the strap connection resistance. The following are some common situations and how to perform the measurements. The concepts described for each method can be considered for other situations not described herein to determine the way to perform the measurements.

In cases where the connection resistance is higher than expected, instead of measuring from post to post, it can be measured from the post to the strap on each post as a troubleshooting step. This can help determine if it is only one side introducing the problem or both.

5.2.1 Single post with single or parallel straps

The images below, from IEEE450, depict the case of interconnection of single post batteries with single or parallel straps. Figure 13 shows the case of a single post per battery side and a single strap interconnecting them. The measurement is taken placing the probes at the positive of one unit and the negative of the adjacent unit. It is important to place the probes on the post, not on the hardware or the strap itself.

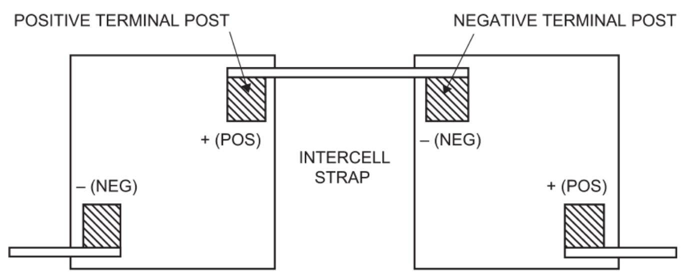


Figure 13: Single post with single strap - Figure from IEEE 450

Figure 14 depicts the case of units with single post and parallel straps. In this case the injected current divides between the straps and the total resistance includes the four contact surfaces plus the resistance of the strap conductors.

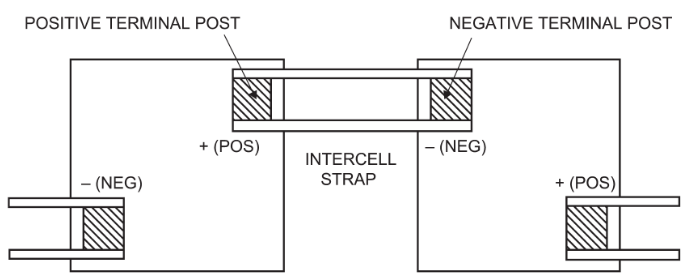


Figure 14: Single post with parallel straps - Figure from IEEE 450

Previously, an AC impedance test set that injects ac current through the string and uses a separate receiver to measure the current and potential drop was mentioned. Since the current is measured with a clamp current transformer (CT) with this unit, it may happen that the CT can only clamp around one of the parallel straps, measuring only a fraction (1/number of parallel straps) of the total current. This is known as split strap measurement method, and it needs to consider a multiplier to calculate the total current. Note also that even though parallel straps of the same size connected by the same bolt and nut assembly have essentially the same resistance in their copper (and tin or lead plating), they may not have the same exact connection resistance due to very slight differences in the contact surfaces. This means that current sharing between parallel straps is not exactly equal, and thus the split strap measurement method has some inherent error introduced due to this phenomenon.

5.2.2 Multiple post – Single or parallel straps

Battery units may have multiple posts for each side, e.g., two positive posts and two negative posts. In these cases, straps may be used to connect all the terminals from one side to all terminals on the adjacent unit. In these cases, it is necessary to take as many measurements as the number of posts on each side. Figure 15 shows the case of units with double posts and parallel straps. The posts are labeled as A and B on one unit and C and D in the adjacent unit. In this case, two measurements need to be taken and reported, from the first post on one unit to the first post on the adjacent unit, and from the second post on the first unit to the second post on the second unit. i.e., from post A to Post C and from post B to post D.

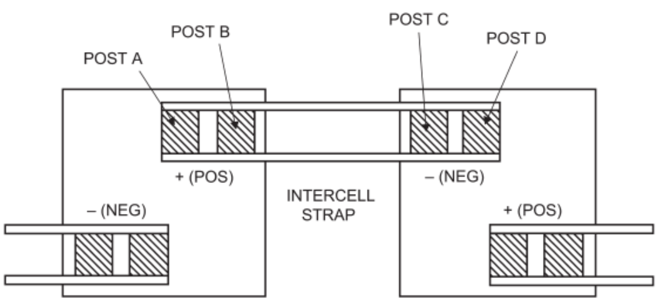


Figure 15: Double post with parallel straps - Figure from IEEE 450

Figure 16, shows the case of three posts per side of the unit and parallel straps. In this case, following the measurement concept described above, the measurements are taken as follows: Post A to Post D, Post B to Post E, Post C to Post F.

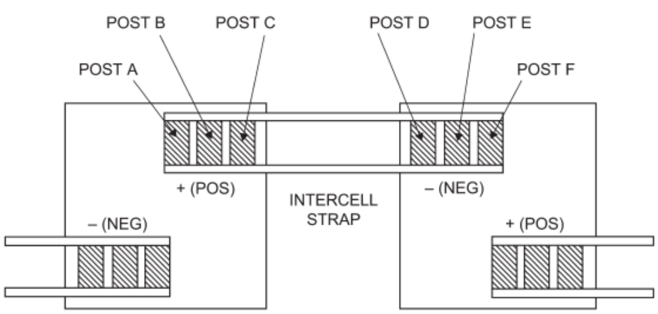


Figure 16: Triple post with parallel straps - Figure from IEEE 450

5.2.3 Battery string terminals

Although not straps, the main positive and negative terminals of a battery string are also connected to conductors that are terminated to lugs. The connection between these lugs and the terminals of the string should also have low resistance connection and should be checked for a good connection quality.

Figure 17 shows the measurement points, from the post to the lug to obtain the connection resistance on each side of the battery string. This can also apply to the inter-tier or inter-rack connections.

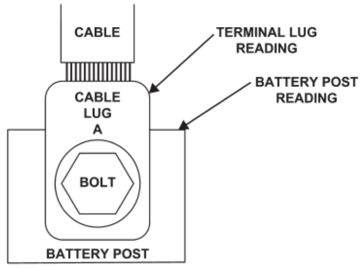


Figure 17: Battery string terminal to cable lug connection - Figure from IEEE 450

5.3 Inaccessible Post Measurements

As explained so far, the measurement of a strap connection resistance requires access to the posts at the ends of the strap. Enough surface is required to be able to place on each post the two probes for current injection and potential drop measurement. In some cases, the posts, straps and hardware are covered with insulation. Only one small probe hole is left accessible for measurement of cell voltage, as shown in *Figure 18: Inaccessible post with probe hole*

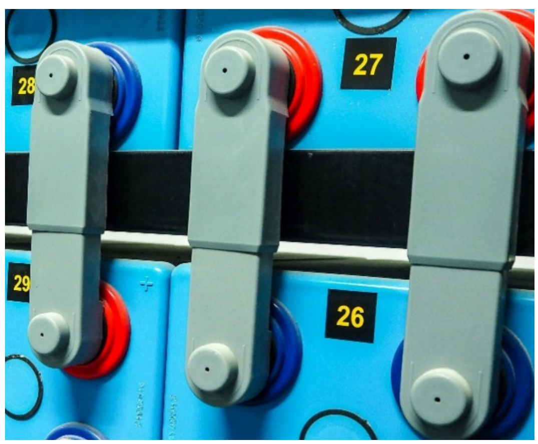


Figure 18: Inaccessible post with probe hole

This poses challenges for the measurement. First, if the post is male threaded the measurement hole provides very small access to the post, and in this case, a set of small concentric probes, like the ones shown in

Figure 19, which could fit through the hole could be used for the measurement. The external part of the concentric probe injects current, and the central conductor measures the voltage. In this case the test current may not be higher than 1A.

Figure 19: Concentric type probe

Second, if the post is female threaded, it does not provide direct access to the post, just the hardware that secures the strap as shown in Figure 20, which is not good for a measurement because the resistance being measured is the connection of the straps to the bolts, not to the posts.

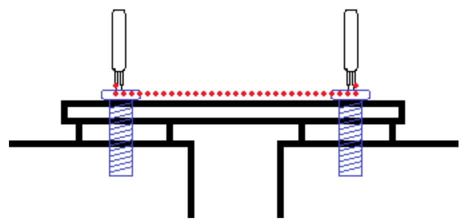


Figure 20: Incorrect measurement of connection resistance due to lack of access to the post

An alternative, since the main hurdle is to inject the current, is to measure with a high accuracy/resolution digital multimeter (DMM) capable of reading one-digit millivolts, the units for the voltage drop across the strap due to a circulating current.

Strap connections are typically designed for a 20mV to 30mV drop. If the battery is delivering current or being charged, the magnitude of the circulating current might be enough to cause a measurable potential drop. If there is only float current circulating through the battery, it may be better to inject an external current. As explained before, there are instruments that inject ac current through the entire string. Once the current is circulating, the DMM can be used to measure the potential drop across each strap. If the measured potential drop is less than 20mV it can be considered as acceptable, but higher values need to be investigated and it is better to consult the manufacturer.

6 Methods and Measurements comparison

There are many battery testing products on the market today, which use different methods of battery and strap connection resistance testing. When comparing ac and dc test sets, both tests have their pros and cons. Regardless of which test set you is being used, it is imperative to understand the effect that current magnitude has on strap resistance measurements. Following this, a study was done to examine the strap resistance values when measured with varying dc and ac current test sets and compare the data to be able to draw conclusions about a recommendable test current range.

6.1 Strap Resistance Connection Measurements – Multifunction Instruments - With Noise and Without

To examine the effects of current magnitude on strap resistance measurements, multiple test sets with different test currents were used to perform strap resistance measurements and the results were documented.

Three tests were done, labeled A, B, and C shown in Figure 21, Figure 22, Figure 23respectively, all on the same 24 straps using instruments 1 through 5 without any interfering noise to test for repeatability of the strap resistance measurements when a certain test current is used. In Figure 22, instrument 3 is not seen because the test current was set in 100mA injection mode, where it could not measure resistance values below 100µΩ. In Figure 21and Figure 23, instrument 3 was set to draw 5A of current instead.

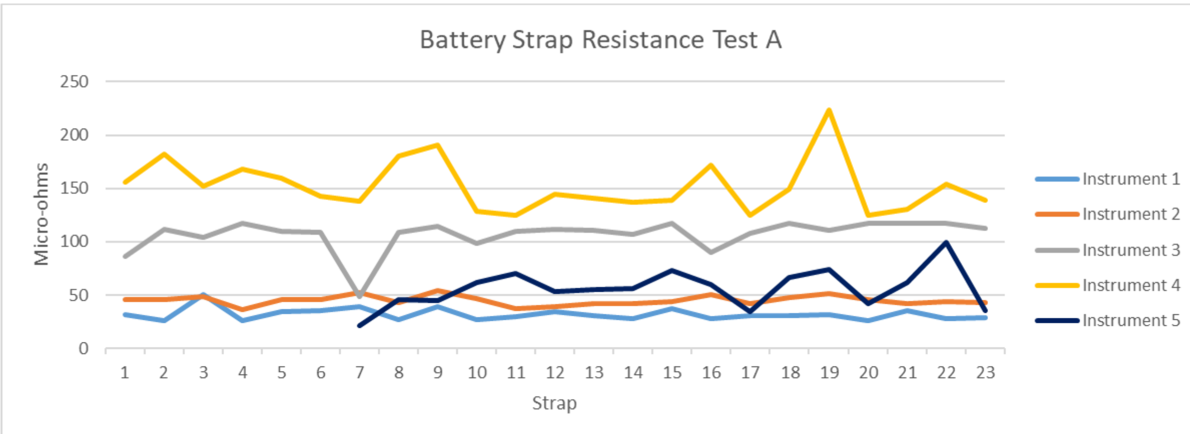


Figure 21: Battery Strap Resistance Test A

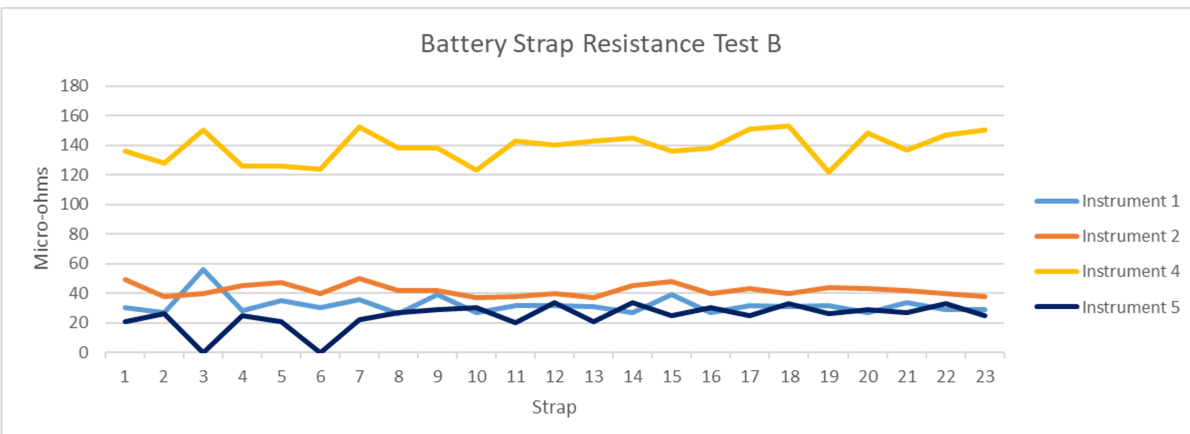


Figure 22: Battery Strap Resistance Test B

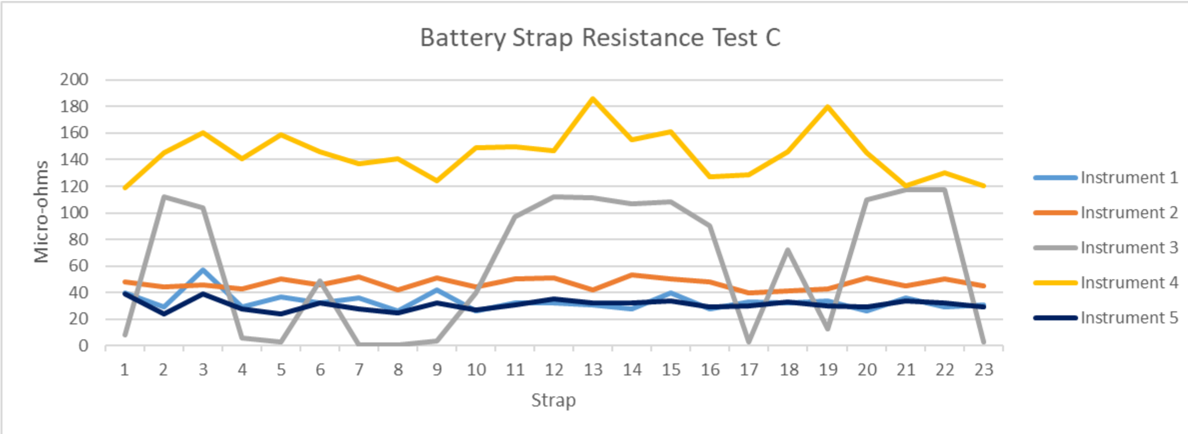


Figure 23: Battery Strap Resistance Test C

Next, out of those 24 straps, 2 straps were selected, and 5 tests were performed to again verify repeatability, this time injecting a low frequency (55 Hz) 10A ac current to the string. The chart shown below shows the average of 5 strap resistance tests done on the 2 straps with and without noise.

Instrument 1 was used to apply an ac impedance, injecting a low frequency (55 Hz) 10A ac current to the string.

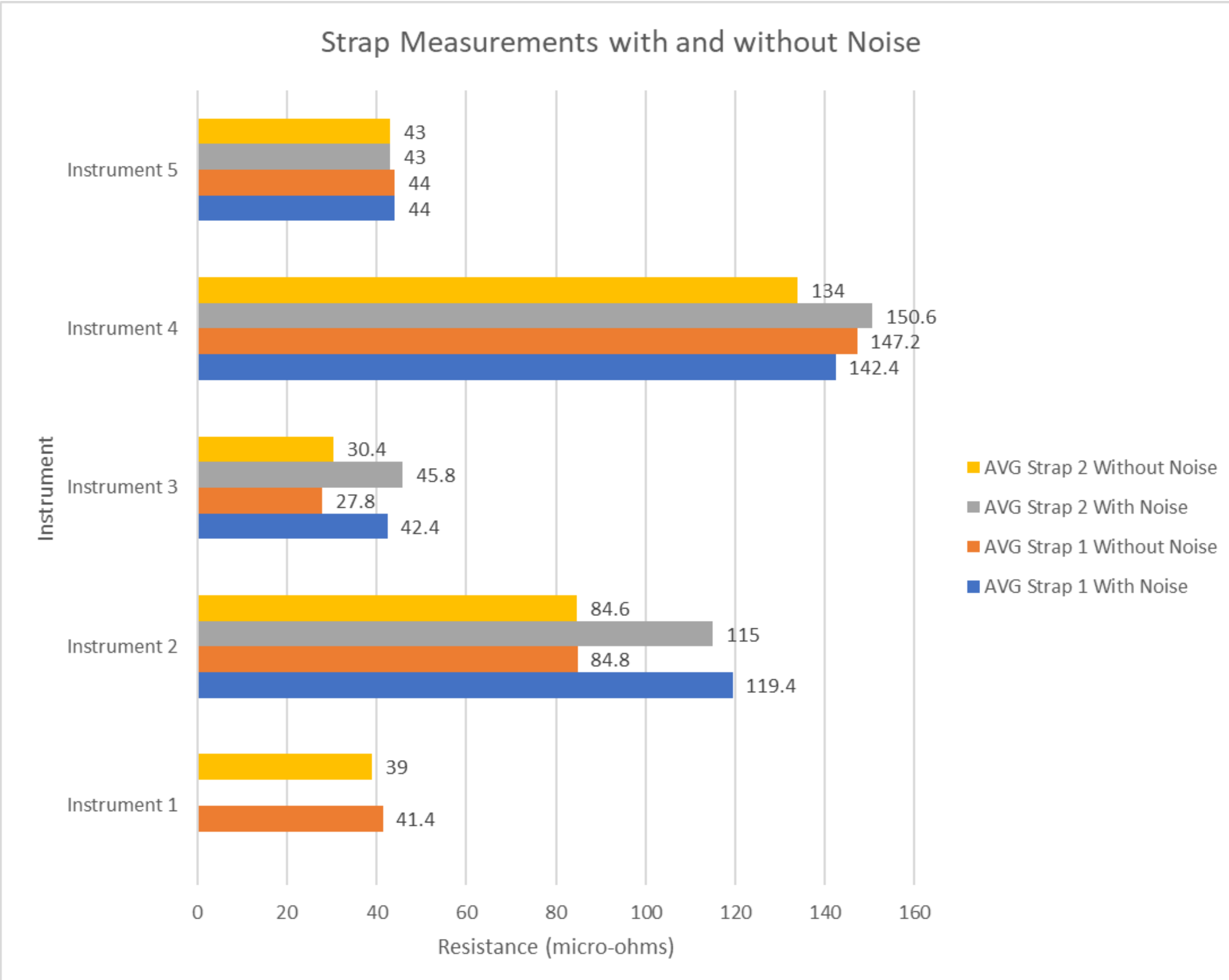


Figure 24: Strap Measurements with and without noise

In the chart, it is evident the effect that the noise has on instruments that are using a low test current magnitude. Additionally, it is seen that the instruments with lower test current also have differing results from the instruments with higher test magnitudes; as a result, it can be concluded that the probes used as well as the test current magnitude caused the resolution to be less than the instruments with the higher test current, making those measurements relative instead of absolute. This is also because the instruments applying larger test currents (instruments 1 and 5) are injecting current across the entire string, whereas the rest of the instruments are not.

6.1.1 Strap Resistance Connection Measurements – Results Analysis

The results and conclusions of both tests with and without noise are as follows:

- Instrument 1 injected 10A of ac test current and had an average strap deviation of 3.87%. The measurements were repeatable and accurate.

- Instrument 2 was injecting 500mA of ac test current had an average strap deviation from 8 to 10% when measuring strap values below 100µΩ. When low frequency noise is added the measured strap values increased by a factor of 50% to 100%; however, at these higher levels the average deviation improves to 5 to 7.5%.
- Instrument 3 performed two tests: one was injecting 100mA of ac test current to measure strap resistance, and the other was drawing 5A of dc current from the battery and measuring the strap resistance.
    - When injecting 100mA of ac test current to measure the strap values, the test set could not measure values below 100µΩ, regardless of noise. The measurements were extremely inconsistent, varying from 8% to over 200%.
    - In contrast, when Instrument 3 was set to draw 5A of dc test current from the battery to measure strap values, it could measure strap resistance readings down to 50µΩ. The measurements were still extremely inconsistent, varying from 80% to over 125%.
- Instrument 4 was using 100mA of ac test current, the same test current used by the first test done with Instrument 3. It could not measure strap values below 130µΩ and was recording an average strap deviation of over 27%.
- Instrument 5 draws approximately 50A of dc test current from the battery to measure the straps, providing accurate, highly repeatable strap measurements which are shown in tests A, B, and C. Additionally, the 10A of ac noise did not affect the strap resistance measurement like it did other instruments that used less test current.

When analyzing these results from the test sets, the most accurate and repeatable results were acquired when using instrument 1 and instrument 5, which had higher test current magnitude. This verifies the concept of higher test current providing more resolution and improving accuracy as discussed earlier. Also, the lower current ac units are heavily affected by low frequency noise and the average strap resistance measurements significantly increased when compared to measurements taken without noise.

6.1.2 Strap Resistance Connection Measurements – Low Resistance Ohmmeter

Different dc low resistance ohmmeters providing low magnitude to high magnitude currents were used to perform strap resistance measurements to further highlight the effects of current magnitude on strap resistance results. Figure 25 summarizes the results, showing test at 8 different test currents under two testing conditions: without noise and with noise. For each current and test condition it is shown the average result, the minimum, the maximum, the average deviation, as well as the difference between no noise and noisy condition.

Current	AVG No Noise	MIN	MAX	AVG DEV (multiple readings)	AVG With Noise	MIN	MAX	AVG DEV (multiple readings)	Diff. with noise
100mA	46	40	50	21.74%	46	40	50	10.87%	0
1A	46.6	46.0	47	2.15%	44.8	41	47	8.82%	1.8
10A	45.24	44.5	47	4.74%	45.2	44.5	46.4	4.29%	0.04
15A	37.26	37.1	37.4	0.56%	36.8	36.6	36.9	0.41%	0.46
20A	36.28	36.2	36.3	0.30%	36.4	36.4	36.5	0.30%	0.12
50A	36.14	36.1	36.2	0.16%	36.2	36.2	36.2	0.30%	0.06
100A	36.68	36.5	36.8	1.17%	36.3	36.1	36.5	0.72%	0.38
200A	55	51	66	14.69%	57	51	60	23.31%	2.0

Figure 25: DC Low Resistance Ohmmeter Measurements (all values shown in microohms)

The measurements in Figure 25 are the same as those analyzed in Figure 10 as discussed earlier; however, Figure 25 offers the comparison with and without noise and in using these measurements as well we are further analyzing the results to come to a conclusion on the ideal current range to test strap resistance. In these measurements, the average deviation of the readings was far less when the test current being used was between 1A to 100A. When the test current was 100mA the test set was not able to measure the strap resistance accurately since the value of the strap resistance was too small and the current did not provide enough ohmic resolution. When testing at 100A and 200A settings, the average deviation of the measurements saw a significant increase.

6.1.3 Test Current Analysis

In the previous section, the results of strap measurements were taken and documented for examination. The tests were done with a multitude of test sets using various currents as documented. Multiple straps were tested repeatedly using different test currents. This was done without any noise as well as with 10A of low frequency noise. The test currents that were used in the tests were 100mA, 1A, 5A, 10A, 15A, 20A, 50A, 100A and 200A. The study indicated that a 15A-20A +/- DC source would provide the best overall results. The measurements are not only accurate but repeatable to less than 1%.

The IEEE450 requirements state that straps that have a change of 20% need to be addressed; therefore, the poorer the repeatability of the measurement, the more false positives assessments are attained. The dc test current that was less affected by ac noise on the system and provided the most accurate and repeatable results without heating up the strap along with the ac test set testing was anywhere between 10A-15A.

As test currents approached 100A the average deviation increased. This is attributed to heating effects that occur at these higher currents. Up to 50A on inter-cell bar straps appear to be effective when taking strap resistance measurements (the resolution will be great enough for the expected microohm result). However, this level of current may cause heating effects on smaller straps commonly used on telecom applications where it would make sense to use a smaller test current of 10A-15A.

At 200A the average deviation was even higher, resulting in poor repeatability. Some of this may be attributed to heating effects as mentioned earlier.

7 Results analysis

7.1 Analysis criteria

The strap connection resistance result analysis is based on comparison to a baseline determined from the measurements taken at installation. Since intercell connections are the backbone of a battery string, the installation process requires detailed attention. Each post is cleaned and conditioned with a thin film of antioxidant grease and each interconnection is torqued to a specified value, followed by a resistance measurement.

The resistance of all similar size connections is averaged and any connection that deviates more than a manufacturer recommended percentage or value from the average needs to be reworked to measure within the limit. A typical limit is 10% from the average or five micro-ohms, whichever is greater. Once a balanced average is obtained it can be used as the baseline. A stricter criterion is to use the specific value of each connection instead of an average as baseline for comparison to each connection in the future.

In any case, it is important to consider that depending on the physical layout of the battery units, there may be straps of different lengths or sizes (inter-tier, inter-rack) which consequently will have a different resistance result. If an average is being used as a baseline, there needs to be as many averages as different sizes of straps are used in the string.

During maintenance, as per IEEE 450, if interconnection or terminal resistance measurements are above 20% of the installation baseline or a manufacturer reference value, the connections need to be retorqued and retested. If reference values are not available, the average from the maintenance test can be used as a baseline and any connection above 10% (or 5 micro-ohms, whichever is greater) of the average needs to be reworked to measure within the limit.

In addition to the 20% limit, there can be specific absolute limits established. For example, in the case of a specific nuclear facility, for flooded lead acid batteries, the maximum strap connection resistance value is 150 µΩ. The purpose of having this maximum value gives a Go/No-Go value based on the premise that exceeding this value will affect the regular charging of some cells, will cause overheating of some connections and in the end will affect the performance of the battery. This maximum value can be determined considering the voltage drop that it will cause, or temperature increase due to the circulation of the maximum design current.

7.2 Causes of elevated connection resistance

It could be natural to think that once a strap has been torqued and verified its condition would not change but as can be inferred at this point of the paper and from IEEE standards recommendations to test the strap connection resistance yearly, regular maintenance testing can find excessive deviations from the baseline. In these cases, troubleshooting needs to be done and there are several aspects to consider.

Assuming the proper instrument and test leads are used, test current is appropriate and best practices are applied, one of the first aspects is the signal-to-noise ratio. The current circulating from the charger and the load could affect the results. It is important to verify that the float current is low, ripple current is low, and that the battery is not delivering current when testing. Note that when testing an online UPS string, it is nearly impossible to get low “ripple” current that won’t affect the readings to some extent.

Vibration happens normally in the batteries and if torque is inappropriate, loose connections can develop over time. Elevated resistance results can also occur due to corrosion developed in the post-to-strap contact surface from environmental conditions. Excessive grease is a common cause of high resistance results. Aging will degrade the post material and over time it will not hold the torque from the hardware, becoming a loose connection.

7.3 Effects of high resistance connections

The circulation of current through a high resistance dissipates heat. Since there is a constant float current circulating in the battery, despite it being low, it will cause a low energy and constant hot spot. Furthermore, when the battery delivers current and reaches peak demand, the dissipated heat will be greater. The constant heat and heat peaks will gradually degrade the battery units associated to the strap with the high connection resistance.

8 Conclusion

The measurement of strap connection resistance is a straightforward process that involves some considerations that can aid in avoiding skewed or misleading readings. It is important to have a good grasp of these aspects to achieve proper results, perform good maintenance, and make educated operation decisions about the battery string being tested. Modern instruments simplify the measurement by providing different test currents, appropriate test leads, logging capabilities, and even alarm settings to identify and alert the user of a value that is out of limits. In the end, it is the knowledge of the operator that produces reliable results. This paper covers thoroughly all the aspects of strap resistance measurements to give the reader a better understanding of the testing procedure and faults that can occur during testing that need to be considered, providing the information needed to determine the best tools, testing practices, and troubleshooting steps during maintenance activity.