GAMBICA

Measurement accuracy

No instrument can be guaranteed to give readings that are absolutely accurate every time or exactly the same as another apparently identical instrument. Several factors influence the ability of an instrument to make and display a measurement.

Before we look at sources of error during a measurement, it is important to understand the limitations of an instrument and how they affect the performance. Part 1 explains instrument range, count, resolution and accuracy and how to interpret them. Part 2 looks at sources of error and where possible, how to avoid them.

For tests on electrical installations in the UK, BS 7671 references BS EN 61557. This European wide standard defines the performance of test instruments used in the verification of low voltage electrical installations under 1000 V AC. BS EN 61557 defines an internationally agreed minimum performance for which all instruments must conform on any particular application. This includes the test range, the types of test necessary and the minimum accuracy required.

Frequently, engineers find they are working at the upper or lower limits of an instruments capabilities. It is under these conditions that the declared resolution and accuracy has the greatest effect. Awareness of these limitations is essential to ensure correct application of a test and interpretation of results.

Part 1 – Range, resolution, accuracy and display count

Range, resolution and accuracy can affect the performance of a measurement instrument. Where they are not properly understood, poor or even dangerous assumptions can be made.

Range

The full measurement range of an instrument is simply the minimum to maximum values the instrument is capable of measuring in any particular measurement mode. Due to the limitations of design and cost, the vast majority of instruments will only show a percentage of this.

For example we will assume an instrument can measure from 0.000 V to 999.9 V. This is the instruments full range. To display the full range in a single display of 999.999 V requires expensive components and is not particularly easy to read, so the range is usually broken down into smaller groups, referred to as the display range.

For the example above an instrument may display very low voltages from 0.000 V to 9.999 V on its minimum range. To display 10 V the instrument has to move the displayed range up a decade to 10.00 V. Likewise to display 230 V the range would jump up another decade to 230.0 V.

So the displayed ranges would be:

0.000 to 9.000 V

10.00 to 99.99 V

100.0 to 999.9 V

The jump between decades can be manually controlled or automatic (auto-ranging).

Resolution

Often confused with accuracy, resolution is closely tied to range and is the smallest change between two values that can be displayed by the instrument on any particular range.

For a range of 0.000 V to 9.999 V the resolution would be 0.001 V

For a range of 100.0V to 999.9 V the resolution would be 0.1 V

With digital instruments designed to measure low resistance or impedance, BS EN 61557 and Guidance Note 3 of BS 7671 recommends a resolution of 0.01 Ω to be adequate. Therefore an instrument should be capable of measuring the difference between a resistance of say 0.95 Ω and a resistance of 0.96, two points are important to note:

(1) A resolution of 0.01 Ω does NOT imply an instrument's range extends down to 0.01 Ω. The measurement range may start at 0.10 Ω upwards but still have a resolution of 0.01 Ω. The instrument can measure 0.13 Ω, but not 0.03 Ω.

(2) A resolution of 0.01 Ω would apply to the minimum range, but not to higher ranges. Typically for each increase in the displayed range, the resolution also increases a decade.

Accuracy

No instrument can provide perfect measurements in all conditions. Therefore an instrument declares an accuracy within which the instrument should perform for any measured value. This performance is checked during manufacture against stable, reference sources under laboratory conditions, and should be checked periodically to ensure they remain within their stated accuracy.

Accuracy figures are usually given in two parts:

(1) a percentage

(2) a number of digits

Accuracy = ± 5% ± 2d

The percentage is simply the amount the displayed value can deviate from the reference value, as a percentage. It may also be quoted in the units being measured, such as volts, amps etc.

The ± 2d (or 2 digits) means how much the least significant number in the display can also vary. This depends on the resolution of the instrument and range selected.

Understanding the difference between the percentage accuracy and the variation of digits is essential in understanding an instruments performance over a wide range of values.

At very low values the digits can have a profound effect on accuracy.

At higher measured values the percentage accuracy can have the more significant effect and the variation in digits.

So putting this together, we will measure a voltage of 100 V on an instrument with a display that shows 100.0 V.

That is:

A single range of 0V to 100 V

A resolution of 0.1 V

An accuracy of ± 5% ± 2d

This produces the following "allowed" variations in the measurement at the high and low ends of the range:

For 100 V measurement:

5% of 100.0 V = 5 V and 2 digits = 0.2 V

Total range of variation is ± 5.2 V

Total % range of variation is ± 5.2 %

So in this case the percentage has a much bigger effect than the digits

However a small value, say 0.5 V, is affected by the digits far more than the percentage, as below.

For 0.5 V measurement:

5% of 0.5 V= 0.025 V and 2 digits = 0.2 V

Total variation ± 0.225V rounded to ± 0.23 V

Total range of variation is ± 46 %

It is clear that in the accuracy statement of ± 5% ± 2d it is the change in digits of ± 2d that matter for the low end of the measurement range, and the ± 5% figure that affects the high end of the measurement range.

Display count

To confuse matters further, some digital instrument manufacturers, especially on digital multimeters publish additional or alternative information about the measurement display. This is expressed as a “display count”.

An instrument that can display a range from 0000 to 1999 is said to have a two thousand count. There are 1999 steps plus Zero. For a range that can be displayed from 0000 to 9999 is said to have a ten thousand count. That is 9999 plus zero.

Count	Display	Digits
1000 count	000 to 999	3 digit display
2000 count	0000 to 1999	3 ½ digit display
4000 count	0000 to 3999	3 ¾ digit display
10000 count	0000 to 9999	4 digit display

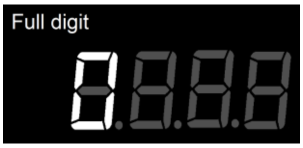
A display count is very useful in understanding the resolution of a measurement on each measurement range, and when the range changes up or down a decade.

For the <u>2000 count</u> display above, to establish when a range changes to the next decade simply move a decimal point along the 1999 display to give:

1.999 19.99 199.9 1999 (in other words 4 ranges)

More confusingly, a display that can show numbers from 0000 to 1999 can also be said to be a 3 ½ digit display. Here the term “digit” refers to the whole numbers in the display and not to be confused with the term “digits” used in the accuracy statement.

The ½ in a 3 ½ digit display refers to the most significant digit (left hand number) in the display being either 0 or 1. A display with a ¾ digit means the left hand number can display 0, 1 ,2 or 3 as below:



This method of describing a display is still in use but is being replaced by the display count method.

Part 2 - Sources of error

Errors that will affect the overall accuracy of an instrument vary considerably, depending on the type of measurement being made and the nature of the circuit being tested. They can come from the instrument and its accessories, or from the circuit under test.

The two most common types of measurement that can suffer significant variation are Continuity and Loop impedance. They each have their own sources or error but also share some common causes.

General sources of error

Resistance of the test leads – These should have their resistance nulled in the instrument so that measuring a short circuit displays zero Ωs. Typical test lead resistance will be around 0.035 Ω per lead (total of 0.07 Ω). Failure to null this resistance can add significant errors at low resistances, especially below 1 Ω.

Fused Leads – These can also add additional fuse resistance. A 500mA fuse (as recommended by GS38) can add an additional 0.85 Ω of resistance per lead.

Contact resistance – This will depend on the condition of the probe tip and that of the material to which they are applied. 0.04 Ω in not uncommon and significantly higher values can be present with poor contact. This can also apply to crocodile clips.

Crocodile clips – Due to the hinge mechanism within a crocodile clip, one side of a clip has a lower resistance than the other. The moving half having a higher resistance than the fixed half. Lead sets that are nulled prior to use may still induce errors if the croc clips were not nulled with their fixed halves joined together. Typical error can be around 0.03 Ω

Ambient temperature – Although this does influence the values reported, the changes in temperature are less significant than those detailed above. Compensation for temperature is well defined in electrical installation guidance documents and standards.

Calibration – When an instrument is calibrated the process allows for a small variation in the allowed value being displayed, compared to the reference value. Instruments that display a value within the stated accuracy will pass the calibration process. Instruments that fall outside the allowed range may be adjusted to bring them within the necessary accuracy tolerance.

This can leave a small spread of values across different instruments of the same model type.

Continuity (Dead testing)

Presence of supply voltage – On continuity measurement a small voltage across the measurement terminals can significantly affect the measurement. A continuity test typically uses 4 V DC to 5 V DC to make its measurement. A voltage on the circuit of only 2 V AC or DC can significantly affect the measurement, creating errors and variability

Loop impedance testing (Live testing)

Electrical noise – Changes in the mains voltage during a test or simply the shape of the AC waveform can create significant variation in the reported loop impedance. The more electrical noise on the circuit, the more variation in the results.

Load switching, harmonics, higher frequency noise all affect the measurement.

Micro-generation

Micro-generation, especially domestic solar power is a significant cause for variation in loop impedance, especially where load management is employed to divert power to internal loads rather than exporting to the grid.

RCD uplift

The RCD or RCBO can itself significantly affect the loop result during a non-trip test. The cause is the internal impedance in the coils in the Phase and Neutral of the RCD providing the leakage sense. Uplift can be as high as 1 Ω but is more typically around 0.3 Ω to 0.5 Ω.

This goes undetected during continuity as the DC only measures the resistance of the circuit, not the impedance.

Proximity of a transformer – Loop impedance testers tend to measure only the loop resistance of a circuit, rather than including the reactance (principally inductance) and calculating the true impedance of a circuit. Where the measurement is reasonably far away from a transformer, the most significant part of the measurement will be resistive, and reactance errors are very small: R = 0.3 Ω XL = 0.01 Ω Z = 0.301 Ω

Close to a transformer, the reactive component could be much higher compared to the resistance of the circuit, and the difference between the resistance and the impedance can be significant: R = 0.006 Ω XL = 0.025 Ω Z = 0.028 Ω

Most loop impedance testers struggle to measure reactance. Consequently the loop impedance and calculated fault current would use the resistance of 0.006 Ω and not on reactance of 0.028 Ω. This is one reason many loop impedance testers frequently measure <0.01 Ω when the circuit impedance is higher.

The impact on fault current calculation can be large. Using those figures above, at 230Vac the fault currant would be displayed on an instrument as:

Resistance of 0.006 Ωs	230 / 0.006 = 38.2 KVA
Reactance of 0.025 Ωs	230 / 0.025 = 9.2 KVA
Impedance 0.026	230 / 0.026 = 8.85 KVA

Fault current variations – Some instruments will use the measured circuit voltage to calculate the fault current. Others use a nominal value of 110 V, 230 V and 400 V. This can cause a significant difference between fault currents from different manufacturers instruments.

Applying instrument accuracy and resolution

As discussed previously, at measurement values at the very edge of an instrument's capability, instrument accuracy is also significant.

Using the original example of ± 5% ± 2 digits applied to the impedance measurement of 0.02 Ω we can see that there is considerable scope for variation in the displayed value:

Absolute circuit value = 0.02 Ω

5 % of 0.02 Ω = 0.001 Ω

+ 2 digits (assuming 0.00 resolution) = 0.02 Ω

Total error = 0.001 + 0.02 = 0.021 Ω

Assuming instrument rounds down, the total measured value is:

Total measured value = 0.02 + 0.02 = 0.04 Ω

So a circuit with an absolute value of 0.02 Ω could be measuring as low as 0.00 Ω or as high as 0.04 Ω and still be within the instruments declared accuracy.

Calibration

When an instrument is calibrated. Its performance is compared to a known value in a temperature controlled environment. Ideally the values reported by the instrument would be the exact value of the calibrated source.

In reality the reported value will often be a little higher or lower than the exact value. As long as the value reported in within the accuracy declared by the manufacturer, it is considered acceptable.

Frequently, a manufacturer will set tighter limits on its calibration than the accuracy stated in the instrument, to allow for changes in battery voltage, temperature etc.

This still produces a distribution of values across a sample of instruments, and explains why it is not uncommon for two identical instruments to report slightly different values.

Summary

It is important to understand both how the accuracies of instruments are defined and the sources of error in measurement. This is especially so were the values are at the extremes of the instruments measurement ranges.

Many loop impedance testers are used for measuring close to the source of the supply, where loop impedances can be very low. Certainly less than 0.03 Ω. Using an instrument with a resolution of 0.01 Ω cannot be guaranteed to give accurate results.

Always try to make the measurement with an instrument where the expected values are well within the limits of the instrument. Where this is not possible, understanding the affects of different types of error can help in assessing whether the measured results are dependable or where other methods of assessing the circuit's characteristics would be more appropriate, such as calculated values based on manufactures declared data.