ELECTRICAL MAINTENANCE

MEASUREMENTS AND MEASURING DEVICES

TRAINING MANUAL
Course EXP-MN-SE050
Revision 0

ELECTRICAL MAINTENANCE

MEASUREMENTS AND MEASURING DEVICES

CONTENTS

1. OBJECTIVES

Following this presentation, the electrician (or future electrician) will be able to

- Differentiate analogue and digital measuring devices
- Explain the different measuring principles, and the technologies used for analogue devices
- Explain the functioning of electronic/digital devices
- Differentiate the different electric values to be measured (U, I, R, Hz, etc.)
- Select the device to be used depending on the measurement to be carried out
- Differentiate RMS, average and continuous values, alternative components, continuous components, etc.
- Use the appropriate devices depending on the values to be measured (listed above)
- Use a multimeter ‘intelligently" (right span, right reading, etc.)
- Determine the methods for measuring the different D.C. and A.C. powers
- Read, identify and measure these powers and the power factor
- Explain the safety measures required to ensure that all measuring is "healthy"
- Make sure you use this document and apply the content carefully

2. INTRODUCTION

2.1. THE WORK OF ELECTRICIANS

Electricians (in the field) use measuring devices on a daily basis.

Figure 1: 'Our' measuring devices and accessories

Electricians use/monitor/check/adjust/calibrate/connect, etc. regulators, testers, display units, counters, multimeters, faultographs, oscillographs, current or voltage generators, etc.… Devices may be fixed, mobile, portable, front-facing, table-top, lab., simple, multifunctional, etc. Electricians also need leads, plugs, terminals, connectors, hook-on, and many other accessories, to sum up, they have much to do and being familiar with "their" measuring devices will make life easier!

They also need practice, experience, knowledge of the operating site, tools and a set of fixed and mobile measuring equipment enabling the correct execution of missions.

Electricians working on under-equipped sites should not be asked to perform miracles *(and many sites are under-equipped as decision-makers are often reluctant to invest in test material)*. To give an example, a quality adapted faultograph, *which is not needed when everything is running fine*, is an indispensable tool (for electricians and instrument experts) for the identification of the origin of a failure – *Fixed equipment (recorders) are not appropriate.*

In terms of personal equipment, it is preferable for all parties to have a "real" multimeter……..*Refer to the required qualities of a multimeter in this course…*

And above all, be aware that an analogue device is no less precise than a digital device (equivalent category), the latter is simply easier (and quicker) to read.

The other advantages and disadvantages of the two types are explained later in this course.

2.2. AIM OF MEASUREMENTS

Measurements are used to identify general electricity values with a degree of precision - according to the object measured and the purpose of the measurement:

- difference in potential
- electric and electronic flow
- resistance
- frequency
- power - (work done)
- phase lag angle
- capacity
- (etc.)

For electricians installing equipment or applying maintenance, measurements are used to check the safety of individuals (*human health always prevails over financial value*), installations and equipment according to applicable texts.

It is clear that more elaborate measurements, means of detection and comparisons of recordings exist and we will develop these in the appropriate courses. To give an example, high voltage distribution relays and protective devices, default current measurements, network surveillance (LV and HV), etc.

2.3. MEASURING IS NOT COMPUTING

The problem with our centralised control rooms is that nothing is easy to access. Indications and measurements are developed by third parties. Display devices and screens bring up a multitude of values, sizes, curves, graphs, reports, calculations (*impressive, in 3D, colours and figures to 18 decimal places, etc.)* which we (generally) accept as true without considering the source of the measurements and the quality of the measurement chain (or loop).

This is valid for electricity and instruments

I witnessed 'x' decimal places (8 or 12), on a "large" Total operating site on a display screen (commissioning and start-up). It was fascinating to note the 24.12345678 volts and an ambient temperature of 26.56488556°C, combined with a "major" memory problem and the mainly radio transmission time on this site. Sorting this out was neither simple nor quick, "high-level" authorisation was required, and took time to obtain…

These impressive results often hide major measurement errors. In addition, the personnel developing "your" measurements (the indications on the screens) are now part of the "systems" team, generally including computer specialists rather than electricians, electronic engineers or measurement specialists (instrument experts). They will accord priority to the interface to the detriment of the instruments or the processing of results (from a mathematical or statistical point of view).

Care is required!

The role of an on-site maintenance electrician or instrument expert is to check and calibrate the existing measurement instruments. The following are required:

- Enough calibration and measurement tools and instruments of the appropriate quality.
- Access to the entire measurement loop from the sensor to the screen.
- Cooperation (or at least understanding) between production, computing and systems' teams on sites.

This is valid for electricians and instrument experts.

This cooperation is far from ideal and is even increasingly ineffective!

To give another example: Total site, it took 2 years (2001-2003) to solve a synchronisation problem between 2 generators (coupling not possible). The vendor (Solar, without mentioning names….) was still in charge and only sent a control systems expert/computer expert who was only able to check "software" and refused to communicate with a 'simple' electrician. The problem was quite simply caused by a current measurement error which a "basic" electrician was able to detect by checking measurement loops.

3. MEASURING

3.1. TAKING MEASUREMENTS

When measuring, it is necessary to select the device which enables the target value to be measured or other values enabling the calculation of the target value.

We could start with our three basic measurements (routine measurements): I, U and R.

Examples:

- *impedance can be calculated with a voltmeter and an ammeter*
- *cos φ can be calculated with a voltmeter, an ammeter and a wattmeter.*

Reminder: An ***ammeter*** measures a flow of electrons and must be connected ***in series*** in the circuit; its ***internal resistance*** must be as ***low*** as possible.

A ***voltmeter*** measures a difference in potential between two points and is connected ***in parallel***. ***Internal resistance*** must (generally) be as ***high*** as possible

An ***ohmmeter*** is an ammeter with a source of voltage connected in series

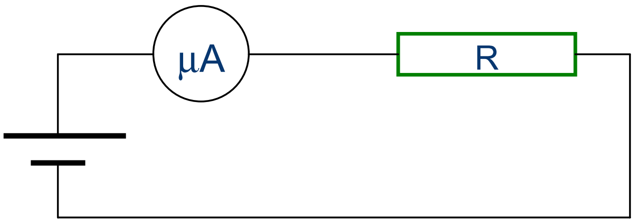


Figure 2: Principle of the ohmmeter

Measuring simply uses the voltage of the measuring device.

The needle will move proportionally to the current and the reading span is directly graduated in [Ω].

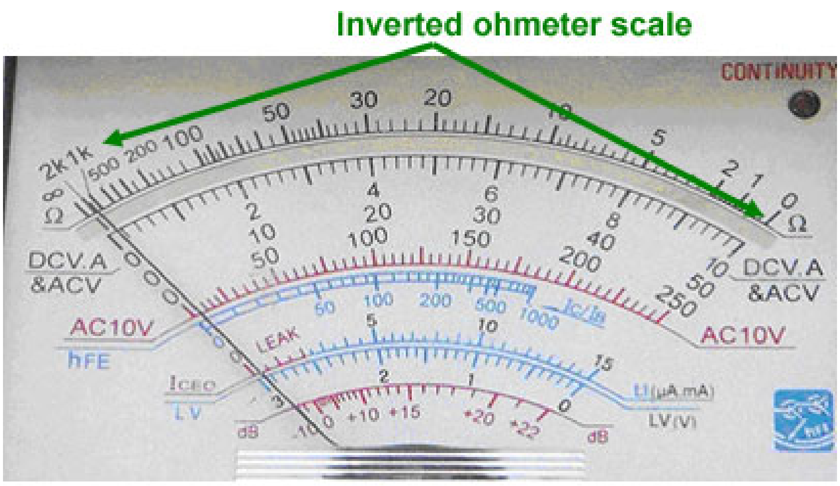


Figure 3: Ohmmeter reading

The graduation is the inverse of the current (the span distribution is hyperbolic).

Obviously only analogue devices are concerned by this principle.

3.2. MEASUREMENT AND DISPLAY METHODS

Observation is the basis of any physical science. The theoretical model is often quite simply an approximate description of a physical system. The comparison between the operating characteristics deducted from a proposed model and those observed experimentally enables the pertinence of the model to be judged.

Measuring means determining the value of a physical size using a set of experimental operations. This art requires careful attention, methodology, a sense of criticism, intuition and a solid understanding of the phenomena involved. The knowledge of the functioning of the measuring devices used is indispensable when selecting the right type of device, and to ensure the device is used correctly according to the purpose.

Measurement results must be carefully recorded, checked, criticised and compared with forecasts - even summary forecasts - in order to eliminate all avoidable errors. The level of criticism applied to results will determine the reliability of these results!

The following statements are applicable for both "on-site" measurements, sometimes in emergency circumstances, and for laboratory measurements carried out for research and development projects. The working methods need to be adapted to the working conditions.

The main measurement methods are:

- Direct measuring
- Indirect measuring
- Zero-based measuring

3.2.1. Direct measuring:

The value of the measurement is displayed directly by the device used for this purpose. Examples:

- A gage directly shows the dimensions of the object measured.
- A voltmeter directly displays the electric voltage measured.

In fact, only 2 sizes exist in electricity, intensity and voltage, and these sizes are transformed into "direct readings".

The other parameters measured in electricity are found using:

- Either one component of the two sizes (U and I), possibly with factors. This would include phase lag, powers, and other sizes or constants, e.g. counts.
- Or the measurement of another size (indirect measuring), hence, a frequency value is a count of the number of pulses emitted during a given period, or a time measured per pulse. Analogue output is unavoidably transformed into intensity or voltage and digital output into pulses which are themselves "signals" of voltage (with a determined quantity and order). Light intensity is another example using the ‘photovoltaic' principle, i.e. a production of voltage as per light.

3.2.2. Indirect measuring

The value of the target size is calculated on the basis of the direct measurement of one or several sizes. The calculation operation can be entrusted to a microprocessor or carried out more simply by electronic circuits.

Examples:

- The measurement of a temperature using a thermocouple requires the measurement of electric voltage, and conversion by comparison with the typical temperature - voltage curve for this thermocouple (see instrumentation course).
- The measurement of a resistance by applying Ohm's law requires the measurement of voltage and current. An ohmeter (integrated in the multimeter), generates a voltage and measures an intensity – or vice versa.
- Instrument measures, which transform the size to be measured into intensity or voltage (or pulses) using physical phenomena and laws.

3.2.3. Zero-based measuring

The difference between two sizes (the target value and a reference value) is reduced to zero. This method is generally slow, but far more accurate than the above methods.

Examples:

- The beam scale enables the measuring of the weight of an object in comparison with the reference weight placed on the other tray by bringing the beam to horizontal.

- The resistance measuring bridge (Wheatstone bridge) enables the accurate measurement of a resistance R_x as compared with a reference resistance.

  When the voltmeter V indicates zero voltage, we have:

  $R_X / R_{std} = R_1 / R_2$ enabling the determination of R_X

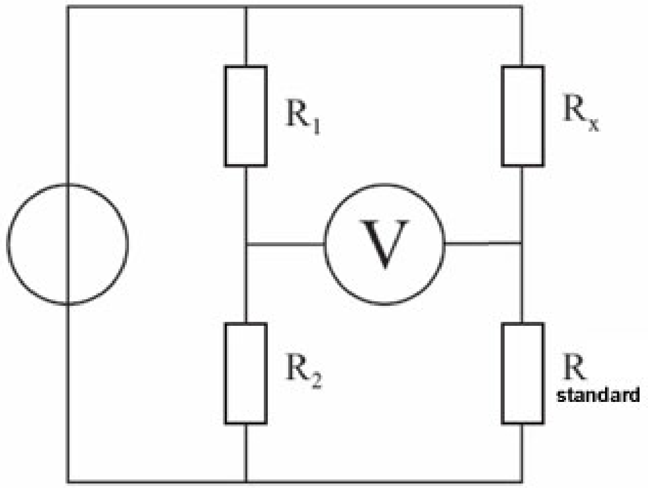


Figure 4: Wheatstone bridge

- The Sauty bridge works on the same principle as the Wheatstone bridge to measure the value of capacities.

3.3. DISPLAY OF MEASURING DEVICES

A **measuring device** establishes a correspondence between the physical size observed and an auxiliary size, perceptible to us via a **display** or exploited by automatic equipment.

We differentiate between **analogue instruments** (needle moving over a graduated span) and **digital instruments** (directly readable figures). Analogue measuring displays are based on the principle of the movement of a needle over a graduated span.

Electronic instrumentation is now widely used as it is simple and quick to read, error-free, and output may be directly accessed by a computer. The falling prices of this equipment have played a significant role in these developments, pushed by current trends, and above all the ***sometimes unjustified impression of precision*** caused by digital devices.

Analogue - numerical display.

3.4. MEASUREMENT ERRORS

A measurement is always an approximation of a true value. It is never exact, and errors are unavoidable.

3.4.1. The different errors

Terms defining measurement and/or reading errors.

The measurement of a size 'X' may be referred to as "*measurand"* in some texts.

The difference ΔX between the value measured X_m and the true value X_v of the size observed is known as the **absolute error**:

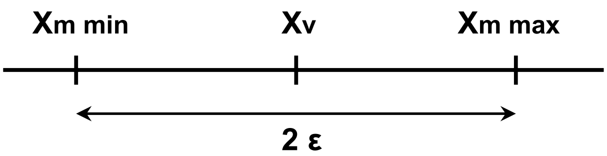
$$\Delta X = |X_m - X_v|$$

Relative error ε_x is given by the ratio "absolute error: true value" or

$$\varepsilon_x = \frac{\Delta x}{x_v} \approx \frac{\Delta x}{x_m} \text{ for } \quad \Delta x << x_m$$

ε_x is generally stated in percentage [%].

***The relative error** in some measurements is in fact **±ε** as the value measured X_m will be either positive or negative as compared with X_v*



The measured value will be between $X_{m\text{-}min}$ and $X_{m\text{-}max}$.
This is the interval for the "true" value.

E.g. a resistance of 1,000Ω at ± 1%: ε = 10Ω for a true value of between 990 and 1010Ω, i.e. an interval of 20Ω = 2ε

Many reasons can explain the presence of errors. These reasons are combined into two main categories:

- **Systematic errors** which re-appear in an identical manner every time the measurement is repeated. These may be due to:
  - device calibration imperfections (zero setting and span).
  - the device category and that of transducers (if used) in series (e.g. CT and PT).

- the influence of the measuring device on the system to be observed (a potentiometer in a resistance measurement circuit – influence of temperature, etc.).
- a supply default (discharged batteries).
- a "systematic" reading error by the operator (parallax on analogue device).
- etc.

- **Random errors** are due to causes governed by hazard laws such as:
  - the effect of thresholds due to analogue → digital conversion (resolution).
  - a noise or random interference superposing the signal measured.
  - an imperfection in the measuring device (friction, etc.).
  - use of the device in inappropriate conditions (too hot, too cold).
  - an accidental reading error.
  - incorrect contacts in measuring leads.

Intrinsic error is the upper limit of the sum of the typical random errors of the device alone.

The manufacturer of the measuring device will specify the **span**, i.e. the upper limit for the measuring interval. The manufacturer will also specify the **precision category**, i.e. the maximum error expressed as a% of the span.

Let us consider the example of a letter scale with a span of 2kg and a precision category of 0.5‰. Intrinsic error will be 0.5‰ x 2 kg = 1g. This is also the expected absolute error for the entire measurement interval. The corresponding relative error will depend on the weight of the object considered: For a letter weighing 100 g, relative error will always be 1g and reach 1%. *(This is not an electricity example, but remains a measurement error!)*

This is why it is preferable to work in the upper part of the measurement interval of a device as far as possible and to change the gage or device whenever required. *(See electricity examples later on in this chapter).*

3.4.2. Characteristics of measuring devices

Let us also define the terms used for the characteristics of the sources of errors for measuring devices.

3.4.2.1. Range

This is the area within which a value is measured, defined in terms of upper and lower limits, e.g.:

- 0 to 500V.
- -30 to +30V.
- 40 to 60Hz.
- --0.9 to + 0.7 (power factor).

Other terms may be used, such as: ***measurement scope***, *signal scope (instrumentation), indication of the measurement span, measurement range, etc… Or you might say, I calibrate this frequency meter for a range of 40-60Hz.*

3.4.2.2. Span

The span is the algebraic difference between the upper and lower values measured, e.g.:

- Range 0 - 500V Span 500V (range = measurement).
- Range -30 - +30V Span 48V.
- Range 40 - 60Hz Span 20Hz.

Other terms: *measurement span, signal span, span scope, size to be measured, etc…. Or you might say, my frequency meter has a measurement span of 20Hz after calibrating a range between 40 and 60Hz.*

The larger the span, with a large number of graduations (analogue and digital), the greater the precision of the measurement, *relative error* being assigned to the device category and the possibilities for measurement precision (see *examples later in the course*).

3.4.2.3. Exceeding the range

Rather than exceeding the span! (This expression is regularly heard……)
If range = span, then clearly this is the same thing.

This is "**acceptable overload"**. Acceptable overload is shown with a value relative to the measurement scope (maximum impact is used in fact), e.g. 150% or 1.5 x EM (Measurement scope or range).

Analogue devices do not particularly (at all) appreciate exceeding the range, and this may occur when handling multimeters or "monometers" (*ammeter, voltmeter, etc.)* with several ranges. If the needle is bent, the device is useless, and if the needle catches (to the right), do not waste your time shaking the device, it is useless too.

Digital devices (last generation – *(I have seen former generation devices go up in smoke…*) - have safety devices to avoid exceeding the range.

If the digits flash, you need to switch to a higher range. The device will not be affected.

3.4.2.4. Instrumentation measurements

The line between electricity and instrumentation territory is not clear. Measurement errors and error calculations are covered in more detail in the 'Instrumentation' course. In this course we will define the characteristics which may apply to a "purely" electric device, providing a quick overview. If you are interested and would like more detail, refer to the 'instrumentation' course.

- **<u>Sensitivity:</u>**

  The sensitivity of a measuring item represents the ratio of the variation in output signal to the corresponding variation in input signal, for a given measurement.

  Sensitivity is therefore shown by the response curve gradient for the item, i.e.:

$$S = \frac{\Delta input}{\Delta output}$$

- **<u>Linearity:</u>**

  Linearity is similar to sensitivity. It defines the stability of sensitivity for the entire measurement interval.

  The linearity difference is stated as a percentage of the measurement scope.

Rapidity:

"***Response time"*** represents the time required by the measuring item to ensure that the output value (or its indication) is within a certain variance in terms of a% of the final value, if the input value (or measurement source) is subject to a sudden level-type variation.

Hysteresis

A system is subject to hysteresis if the output value does not exclusively depend on the 'mesurand' (value to be measured), but also on the manner of achieving this value. Hysteresis is defined by the amplitude of the maximum variance, and therefore the error caused by the hysteresis.

Hysteresis may be mechanical or electrical.

Mechanical hysteresis involves dry friction and play in a mechanism.

Electrical hysteresis relates to mechanical or electrical polarisation phenomena.

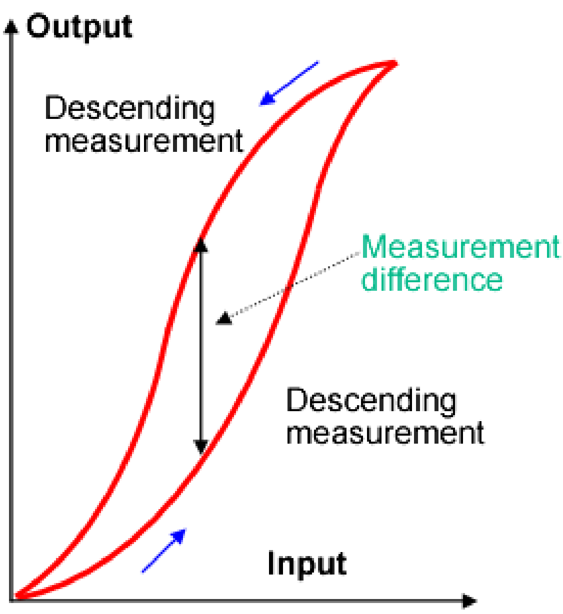


Figure 5: Hysteresis curve

The figure shows the hysteresis which may exist for an instrument between the input and output values, however this may apply for a 'simple' voltmeter, the input value representing the true measurement (X_v), and the output value representing the measured/indicated value (X_m) as per X_v with a first or last issue.

The graph shows a "large" hysteresis, the '*measurement difference'* being substantial depending on the scope (or span) of the measurement. You can see that the close the two curves (first and last issue) are, the better.

Repeatability

Repeatability is the short-term output fluctuation margin, when the same mesurand is applied on several occasions in the same direction. This margin may be due to several causes (the operator, among others) and be expressed as a percentage of the measurement scope.

Reproducibility

Reproducibility is the long-term output fluctuation margin, when the same mesurand is applied on several occasions in the same direction.

This margin may be due to several causes (e.g. aging) and be expressed as a percentage of the measurement scope.

Resolution

Resolution corresponds to the granularity of the measure, i.e., to the smallest variation discernable by the sensor. Resolution may not be constant over the entire measurement scope.

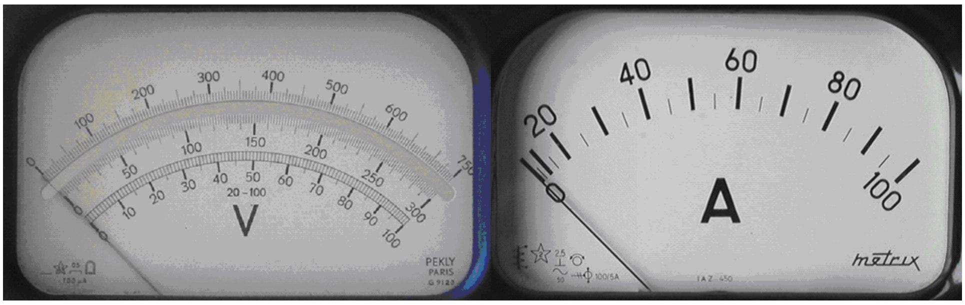


Figure 6: resolution over the measurement scope for 2 devices

With this example, the ammeter has a resolution of 5 Amp per graduation,

As the device is in category 2.5, it automatically has a relative error of 2.5 Amp, by adding reading errors, and the other ‘phenomena’ listed above, there is no point in fighting for a reading of 51.6 Amp.

Round up/down to 5 Amp and call it 50 Amp, this will more than likely be accurate.

This example concerns an analogue device, however the same applies to digital devices, a reading of 51.62 Amp with a category 1 multimeter, with the integration of intensity from a CT secondary (Current transformer) with a precision of 2.5% is a "luxury" reading (*that of 51.62*) *…*

Precision

Precision is one of the key parameters of a measurement system.

It enables the evaluation of the quality of the measurement by indicating the approximate amplitude of errors affecting the measurement.

Precision requires the use of the notions of integrity and accuracy

- The **"integrity"** of a device corresponds to standard deviation for a set of measurements taken for a given mesurand (constant X_v). It therefore represents the uncertainties of the device's measurements. Integrity depends on ***random errors.***

- The **"accuracy"** of a device corresponds to the difference between the average value for a set of measurements taken for a given mesurand and this measurand. It represents the ***systematic errors*** of the measuring system.

- ***Example:*** Calculate the relative precision (at 100 volts) and the precision category of a precision device with a measurement scope (range) of 0 - 1,000 volts, and an absolute error of ±2 volts.

  Solution: The absolute error 'a' is equal to ±2 volts and causes a ***relative error*** 'r' of ±2 volts /100 volts, and therefore ±2.0%. (For 100 volts measured).

  The ***precision category*** PC is equal to the ratio ±2 volts/1,000volts, and therefore ±0.2%. Relative error may therefore take dramatic proportions if the values to be measured are low. If, in the example, the measurement had been 10 volts, relative error would have been ±20%. This demonstrates the importance of selecting a device with an appropriate measurement scope for the application.

3.4.3. Examples of error calculations

I have "suffered" from error calculations during my training. These calculations were the subject of an exam twice consecutively (I managed to pull through…). However, I have never had the opportunity to apply these calculations professionally - perhaps I have been unlucky - consequently, and considering the "fascinating" nature of this topic, Taylor's series and other formulations will not be developed. (thankfully).

"In a word" if you need to "estimate" the quality of a measurement, add together all possible errors (*in%)* and take the relative error (*Manufacturer precision category with measurement/range ratio*) for the device (*copy the last example),* add any relative errors for devices in series (CT, PT, etc.) if required*,* multiply the total by 2 (*analogue and digital devices*) and you will have a ballpark figure. I did (despite everything) once need to check this estimate, and it was not excessive.

3.4.3.1. Stage 1: estimation of measuring errors

a) analogue devices with needles:

- reading of *x*: if the graduated scale has *N* divisions, and if the reading indicates *n* divisions, then: $x = \eta \times \frac{Range}{N}$
- error (relative) ε: depends on the device category: $\varepsilon = \frac{Category.x.range}{100}$

Example: range 10V; 200 divisions; category 0.5; measurement: *U* = 5.25 V

$$\varepsilon = \frac{0.5.x.10}{100} = 0.005V$$

"Globally" the total error can be estimated at ±0.1V for a true reading between 5.15 and 5.35V (important: this is not official, it is my personal estimate).

b) digital devices with numerical displays:

- reading of *x*: for a device with *k* digits (e.g. *k* = 5), the heavy weight digit is often only partially used (e.g. it may only take the values 0 or 1). It is said that the device displays *k* – 1 digits and a half (e.g. for *k* = 5: 4 digits 1/2).
- error ε: depending on the precision *p* of the device (expressed in%) and on the range used, and a fixed number of digits *n*: $\varepsilon = \frac{p.x}{100} + \eta$

Example: p = 0.5%; *n* = 4; measure: *U* = 5.2485V

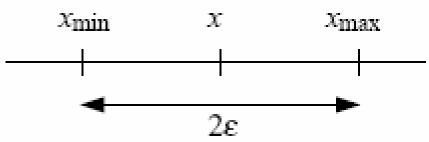
$$\varepsilon = 5.2485 \text{ x } 0.005 + 0.0004 \approx 0.027V$$

c) other - estimation of error using intervals:

For any other type of measurement (e.g.: measuring using a vernier caliper, measuring using a oscillograph, etc), the limits x_{min} and x_{max} are estimated for the value measured, and then the following is deducted:

$$x = \frac{x_{max} + x_{min}}{2}$$

$$\varepsilon = \frac{x_{max} - x_{min}}{2}$$



X = x ± ε

Examples:

- measurements of voltage, period, or the phase of a sinusoidal signal on the screen of an oscilloscope. In this case, errors relate to parameters (respectively: precision of the vertical amplification, the time base, synchronisation) or graphics (in particular: thickness of the lead, correct adjustment of the position on the screen as compared with the reticle).

  Clearly the latter prevail over the former, which requires the estimation of errors using intervals.

- measurement of the resonance frequency of a secondary electrical system using a voltmeter and a frequency meter. It is clear that the precision of this measurement will vary is depending on the gradient of the resonance curve: with shallow curves it may be complex to correctly define the extremities of the measurement interval. Solution: change measuring procedure!

- this type of reasoning is also applied to marked components. E.g., a resistance r = 1,000Ω with a precision category of 1% is such that 990Ω ≤ r ≤ 1010Ω, where ε = 10Ω.

3.4.3.2. Stage 2: calculation of standard uncertainty (or standard deviation)

We assume that the law of probability is **uniform** (or "rectangular"), i.e. that the probability of the interval [x_{min}, x_{max}] containing the "true" value for size X *is equal to* 1 (no value possible outside of this interval), and that, reciprocally, all values between x_{min} and x_{max} are considered equiprobable in principle.

In this case, standard uncertainty is proved as: $\sigma = \frac{\varepsilon}{\sqrt{3}}$

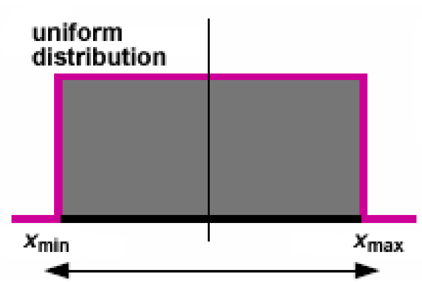


Figure 7: Rectangular (or uniform) standard uncertainty

The "true" value of x *has* a probability of 100% of being in this interval, with the same probability for the entire interval

3.4.3.3. Stage 3: compound sizes

This phase only concerns values which depend on several variables (e.g. a resistance *R* = *U* / *I* measured using the volt - amp method).

A simple and sufficiently reliable method involves the calculation of the interval bounds of the unknown value on the basis of interval bounds for the inherent values of the unknown value.

For the given example, if we know the intervals [u_{min}, u_{max}] and [i_{min}, i_{max}], then:

$$[r_{min}, r_{max}] = \left[\frac{u_{min}}{i_{max}}, \frac{u_{max}}{i_{min}}\right]$$

$$r = \frac{r_{max} + r_{min}}{2}$$

$$\varepsilon = \frac{r_{max} - r_{min}}{2}$$

$$R = r \pm \varepsilon$$

More accurate methods exist…..

3.4.3.4. Stage 4: calculation of the interval for a given confidence level

Excluding imprecision due to the device or the reading of indications, many factors may affect a measurement: electronic noise, interference, influence of temperature, etc. These factors are random. This time we assume that the law of probability for the distribution of errors induced is **Gaussian**.

We can simply state that the "true" value of *x* is statistically more likely to be in the middle of the interval [x_{min}, x_{max}] than on the edges. However, this value may also be outside of this interval with a probability not equal to zero! It is proved that uncertainty Δx equals:

$\Delta x = \sigma$ with a probability $p = 68\%$
$\Delta x = 2\sigma$ with a probability $p = 95\%$
$\Delta x = 2.57\sigma$ with a probability $p = 99\%$
where *p* is the confidence level.

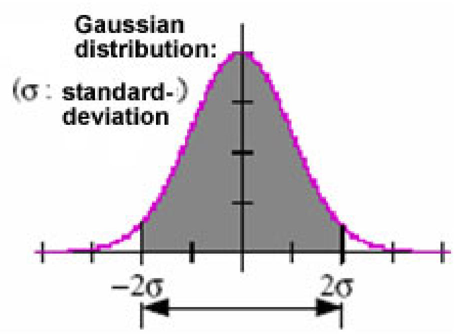


Figure 8: Gaussian type uncertainty

Therefore: $X = (x \pm \Delta x)p\%$

Therefore, where $p = 68\%$, for example: a probability of 2/3 (2/3 ≅ 0.68%) exists that value *X* will be between [$x - \sigma$, $x + \sigma$].

4. FUNCTIONING OF MEASURING DEVICES

4.1. ANA AND DIG

A simple table compares the 2 possibilities

Parameter/Criterion	Analogue	Digital
Price	Identical for equivalent precision – although ANA is slightly less expensive	
Reading	Parallax error	Direct reading
Precision	Harder to assess the measurement for high precision categories	Easier to read
Measurement variations	Fragile	Supports impact and sudden variations
Position for use	(Generally) requires a stable support	Can (in theory) be used in any position
Mechanical impact	Fragile	Better resistance
User friendly	Effort required to read the right span with multi – ranges (this is a source of errors)	Direct, single reading
Adaptability	Unique for its type. No adaptation possible	Can be networked – readings can be transmitted to other devices (printers, recorders, etc.)
Construction	Fragile in a moving coil – lower input impedance	Easier to produce
Conclusion / use	More convenient as a permanent indicator and for measurements where high precision is not required	More appropriate for "advanced" precision categories and as a mobile device Easier to use

Table 1: Comparison of analogue and digital devices – ANA vs DIG

4.2. ANALOGUE

4.2.1. Precision of an analogue measuring device

Let us reconsider precision and error as the quality of measurements depends on these elements.

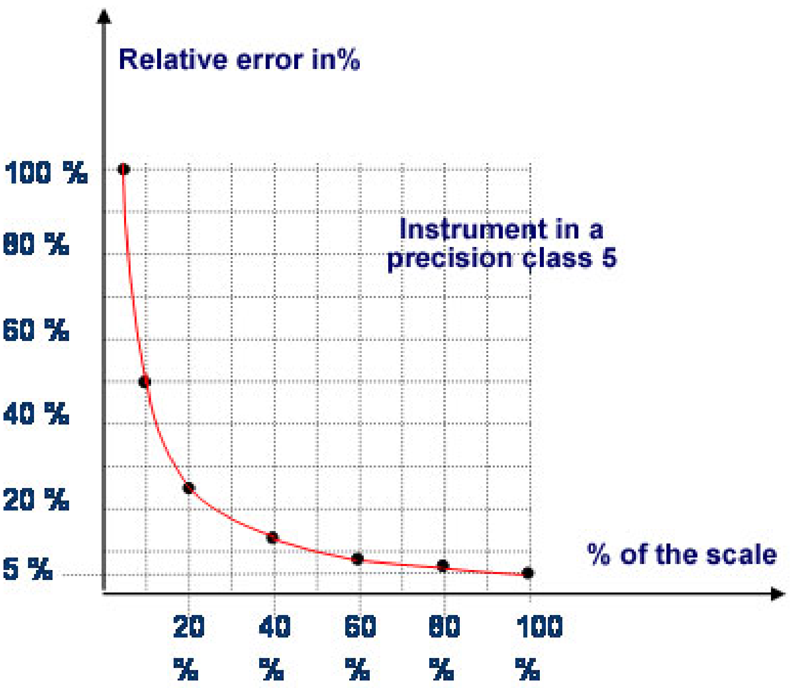
Precision category for an analogue measuring device: for analogue devices, the precision category is indicated with a figure (0.1; 0.2; 0.5; 1.0; 1.5; 2.5; 5.0) on the dial. This figure indicates possible error, expressed as a [%] of the measurement scope.

Example: An ANA (analogue device) has a measurement scope of 30 [V] and a precision category of 1.5. We can calculate absolute error:

Measurement scope x. precision category/100 = 30 x 1.5 /100 = 0.45 [V] = Δx

Absolute error may be constant for the entire measurement interval for this span. We can calculate relative error if the measurement is 10 [V]:

Absolute error x 100 / value read = 0.45 x 100 / 10 = 4.5 [%] = εx



The figure shows the variation in relative error as per the measurement in% of the selected span.

Figure 9: Relative error as per the measurement

To ensure a systematic acceptable error depending on the precision category of the selected ANA, the reading must always be in the upper two thirds of the selected span.

This is why ANA often have ranges which distribute the complete measurement interval in a regular manner - in multiples of 3 (1, 3, 10, 30,100, 300).

4.2.2. Importance of the input impedance of ANA

In addition to the precision of the regulator, the error induced in the circuit to be measured by the regulator must be accounted for. It is therefore indispensable to know the input resistance (internal resistance). The ANA includes a coil with a certain resistance, and a maximum current.

When changing range, the coil turret will connect other resistances in series for voltmeters and in parallel for ammeters, to guarantee the same behaviour of the measurement coil for higher measured values.

Internal resistance must be as low as possible in an ammeter to avoid limiting the current and/or producing a fall in voltage for the object to be measured, which would alter the measurement. The lower the resistance in series, the larger the measurement error (due to the insertion of the ANA), while errors will be small for high resistances connected in series.

I = supply voltage / (internal resistance + circuit resistance) [A]

The internal resistance of voltmeters must be as high as possible (except for default voltage measurements where a resistance of approximately 3,000 [Ω] is required). Connecting a voltmeter to the terminals of a resistor is the equivalent of connecting two resistances in parallel.

When resistors have greatly differing values, the equivalent resistance will be similar to the lower of the two values. However, if the two resistors have approximately the same value, the equivalent resistance will be equal to 50% of one of the two resistances, with a significant variation in current and voltage obviously.

Example:

We must measure a circuit with 2 resistances connected in series and a difference in potential of 12 [V]. The first resistor is equal to 150 [kΩ] and the second 220 [kΩ]. We wish to know the value of the voltage at the terminals of the second resistor.

We must use the following formula:

$$U_2 = U \times R_2 / (R_1 + R_2) = 12 \times 220{,}000 / (150{,}000 + 220{,}000) = 7.1\ [V]$$

A voltmeter with 20 [kΩ/V] must be used for the measurement.

We calibrate our regulator to 10 [V] which provides us with an internal resistance of 200 [kΩ] and the following schema:

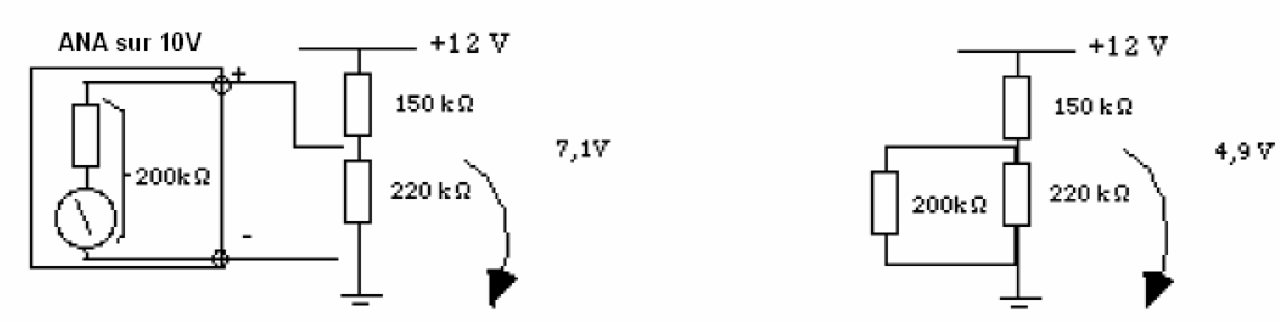


Figure 10: Example of the measurement of voltage

The two resistances connected in parallel have an equivalent resistance of 104 [kΩ] ***and the measuring device will indicate 4.9 [V] ± relative error****.*

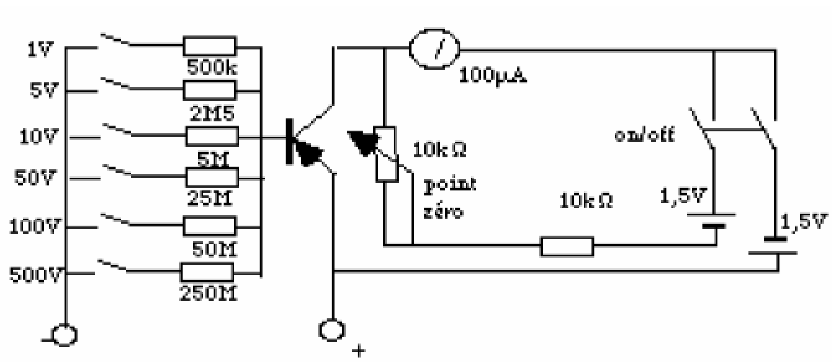
To compensate for this problem, we could be tempted to increase the span (to 30 [V]) to increase Ri (0.6 [MΩ]) which would only partially correct the measurement, however the relative error would increase (approximately 15% for a 2.5 category!!) and the precision of readings would also suffer. We will need to be fully familiar with the characteristics of the regulator if we intend to measure the voltage at the terminals of a high impedance or the current crossing a low impedance.

4.2.3. Increase in input resistance

To compensate the problem of the low input resistance of voltmeters, certain models are equipped with a (pre) amplifier which achieves an input resistance of 1 [MΩ].

This value is constant, and therefore independent of the selected span. This type of device is indispensable for the measurement of circuits with high impedance.

The figure shows a voltmeter with an amplifier. The input datum is 500 [kΩ/V]. This gives 250 [MΩ] for a measurement of 230[V]. The fuel cell and the potentiometer are used to compensate for the influence of the temperature.



The device must be reset after each measurement.

Figure 11: Device with amplifier

4.2.4. ANA symbols

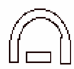
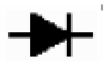
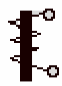
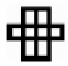
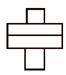
All AMA have a series of symbols which indicate their main characteristics.

The order in which they are (in theory) indicated is as follows (2 examples:

Figure 12: Symbols for analogue devices

- device type: moving coil/ferromagnetic device.
- current type: AC/DC.
- precision category: approx. 2.5% / 0.5%.
- 4. position for use: vertical / horizontal.
- test voltage: (delta) 2 [kV] / ? *2kV too.*
- Additional information as per the manufacturer.

The following table shows all symbols: (important: these symbols correspond to an operating or manufacturing mode, an operating mode may have several different names, e.g.: moving iron = electromagnetic = ferromagnetic = solenoid).

Category	Symbol	Description
Type of measuring device	 or 	Device with moving coil which may be used as DC or rippled
	 + 	Device with moving coil which may be used in DC or AC
	 or 	ferromagnetic device sensitive to the RMS value of the signal applied
	 or  or 	Electrodynamic Moving coil + ferromagnetic combination. For wattmeter
		Electrostatic – Voltage applied to plates, capacitor type
		Bimetal measuring device
		Vibrating blade measuring device
		Induction measuring device
		Crossed coil device
		Device with rotating magnets

Type of signal measured		Direct current
		Alternating current
		Direct and alternating current
		Instrument for the measurement of three-phase current, equipped to measure 1, 2 or 3 phases
Device category	***Figure***	From 0.1 to 5 corresponding to the uncertainty of the device according to the manufacturer
Position of the device		Device to be used horizontally
		Device to be used vertically
		Device to be used inclined (60° in this case)
Device characteristics		Device reset
Test voltage		Star with figure. Indicates the insulation voltage between the terminals and the box, (generally) expressed in kilovolts

Table 2: Symbols for analogue devices

4.2.5. The different types of ANA

4.2.5.1. General information on ANA

An ohmmeter measures current and its needle moves over a dial graduated in ohm. However, to complicate things, with the exception of an electrostatic measuring device, all other devices measure current even to "measure" voltage. The current used to measure is simply proportional to the voltage (Ohm's law).

The coil turret connects the resistances in series to create a fall in voltage before the measuring device. The needle will move proportionally to the current over a span graduated in volts. When measuring devices are used, users must pay careful attention to the form of the voltage (DC, sinusoidal, squared, partial sinusoid due to a triac, etc.) and the possibility of the presence of harmonics which can completely change a measurement.

In the presence of these various types of voltage and current, it is appropriate to use a TRMS (True Root Mean Square) device, which does not take one measurement, but rather a range of measurements and works out the average of the RMS value.

Example:

Take a traditional neon lamp (discharge lamp) of 20W (or 18W).
We need to determine the cos phi of this PL lamp whose active power is indicated (already measured as 17W) by finding ***U and I*** *with a multimeter.*
With a traditional device, we find the values for which the product indicates an active power which is higher than the apparent power!
With a TRMS device, we find some very different results:

The results of measurements are as follows

Multimeter	Traditional or 'normal'	TRMS
Current	0.068 (A)	0.1428 (A)
Voltage	227.5 (V)	224.64 (V)
P (measured elsewhere)	17 (W)	17 (W)
S = product of U x I	15.47 (VA)	32.08 (VA)
Cos phi = P / S	1.1 (?!)	0.53

Table 3: Measurement of U and I depending on the type of device

What happens?

A neon lamp has a very low cos phi (up to 0.3), therefore the 'TRMS' is right … (thankfully). The neon ballast (self / capacitor) creates harmonics which the traditional device cannot account for, causing an error.

The functioning of the different types of devices is often very similar. The first devices considered will cause the needle to deviate thanks to a magnetic force proportional to a current (in a coil) and a fixed flow (permanent magnet) or a flow between two coils. The repulsion of the identical magnetic poles creates the deviation. The antagonistic torque will be indicated by a spring or a pneumatic element.

4.2.5.2. Ammeter works

Ammeter works consist of a permanent magnet in U form with one north pole and one south pole at the extremities. A coil whose feed wires act as a spring to produce the antagonistic force is located between these two magnetic poles.

When a current circulates in the coil, a magnetic flow is created inside the coil and a pole at each end. If the poles are different, they attract each other (incorrect connection) and if they match, they will repulse each other proportionally to the flow, leading to a torque. The deviation will occur until the two torques (rotation - spring) balance each other.

Ammeter works are designed to measure DC. The device is equipped with a rectifier to measure AC (enabling measurements of up to approx. 10 [kHz]). The device measures the arithmetic mean of the current and the span is graduated to indicate the RMS value. Certain ammeter works are equipped with a heat converter.

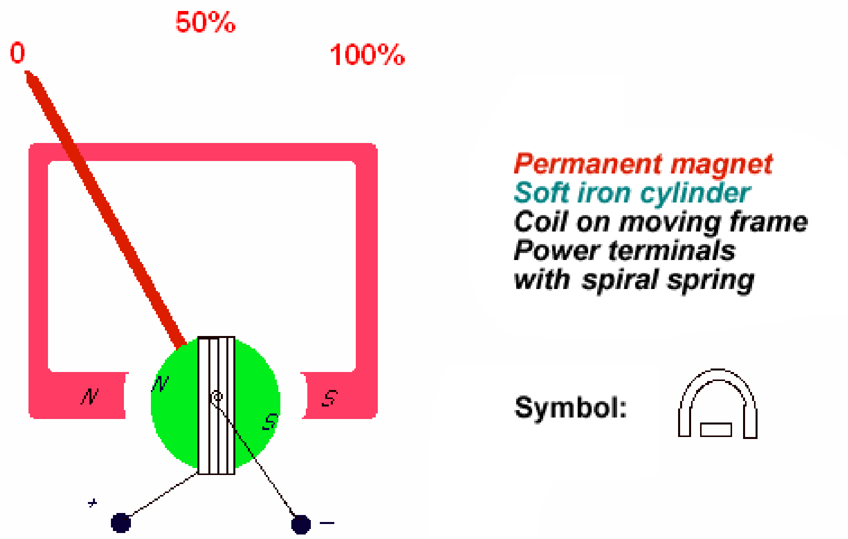


Figure 13: Principle of a device with moving coils

As the thermo-electric electromotive force is due to heating (Joule's effect) the device measures the RMS value of the current directly.

Frequencies of up to 10 [MHz] can be measured.

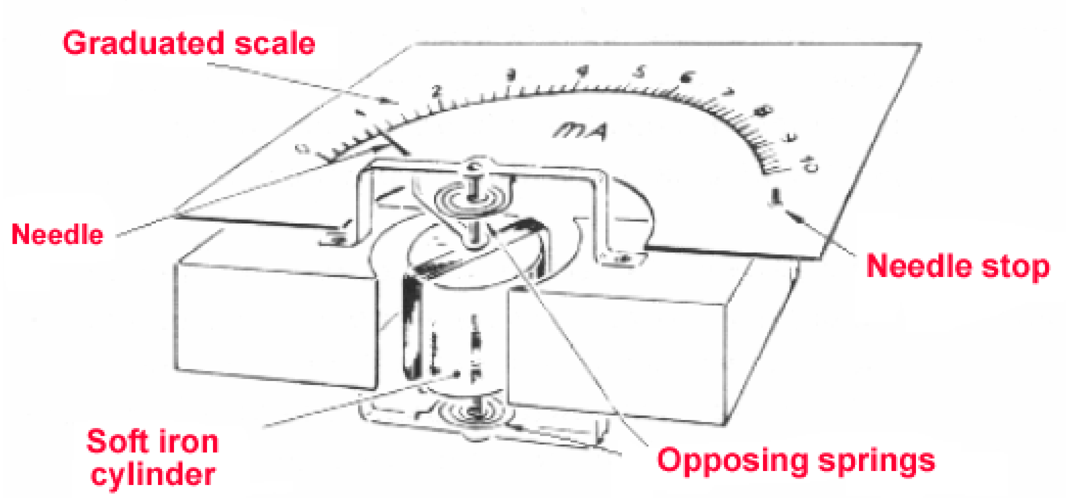


Figure 14: Ammeter works (mA)

Devices with moving coils can be very precise (category 0.5) and are very sensitive, they can be used to measure very low currents.

Example of characteristics for a multimeter with a moving coil:

DC voltage 0.1-1,000 [V], 20 [k Ω/V]

AC voltage 2.5-1,000 [V], 8 [k Ω/V]

Direct current 0.05-500 [mA]

Direct current 0.05-500 [mA]

*Resistance R *1, *10, *100, *1,000*

This device is absolutely not appropriate for non-sinusoidal currents or voltages.

4.2.5.3. Electromagnetic device

This is probably the type of device with the most possible design variants.

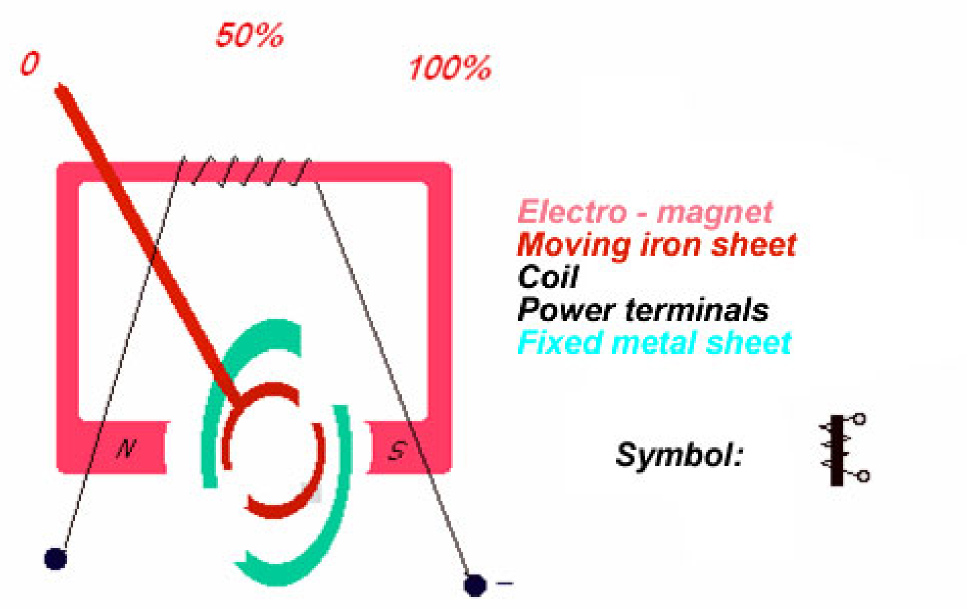


Figure 15: Principle of electromagnetic devices

In this example, the coil produces 100% of flow. The coil is fixed, which makes the device less fragile than devices with moving coils.

There is no permanent magnet. The needle is connected to a moving magnetizable iron sheet. A second fixed iron sheet is next to it.

When current crosses the coil, it produces a magnetic flow which also magnetises the two irons. Their magnetic poles are therefore side by side and repulse each other. The mobile iron causes the needle to rotate and the antagonistic torque is created by a spring.

In other models, the antagonistic torque is created by a plate moving in a closed chamber (compression of the air).
Variation of the direction of the current induces a change of pole in the two irons, but does not modify the direction of the deviation. We can therefore supply devices with moving irons with DC or AC. This measuring instrument is mechanically and electrically more solid than a device with a moving coil due to its construction.

It can accept significant overloads. However, it is less precise (category 1.5) and consumes ten times more current. The field coil of an ammeter uses large wire and few turns (low resistance) while voltmeters use narrow wire and many turns (high resistance). The value measured is the mean quadratic value. The type of current in the coil is of no importance (even when not sinusoidal). However, the use of shunt to extend the range is only possible with a sinusoidal signal.

4.2.5.4. Electrodynamic device

This type of device is in fact a combination of a device with a moving coil and one with a moving iron. It is constructed with a moving coil and a fixed trip coil rather than a permanent magnet.

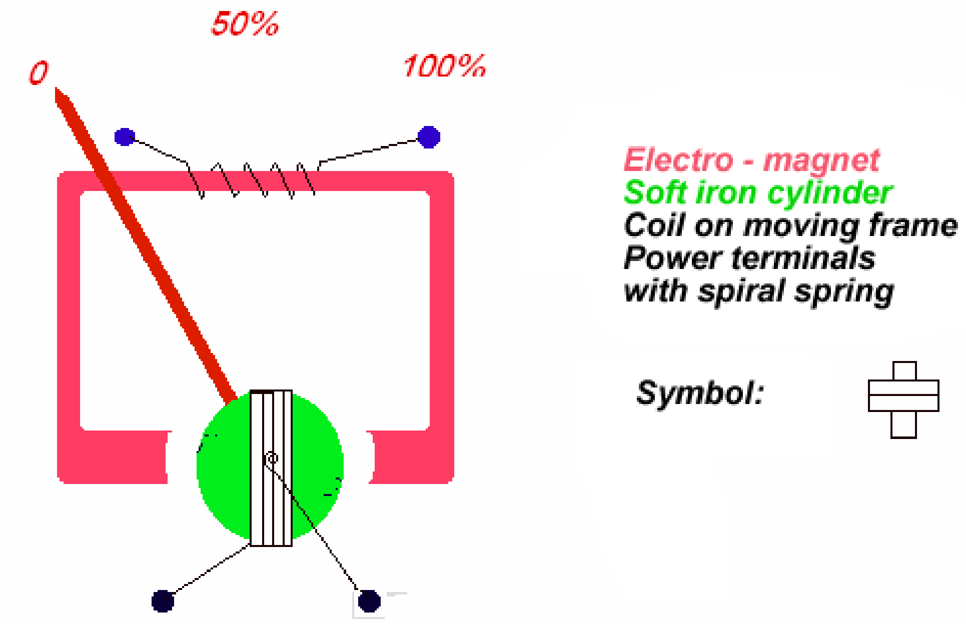


Figure 16: Principle of electrodynamic devices

These devices are above all used as wattmeters. A coil is used to measure current and the second to measure voltage. The needle deviation depends not only on the flow in the two coils, but also on the phase lag of U and I.

So this gives: **P = U . I . cos** ρ **[W]**

To use this type of device as a varmeter, simply create a phase lag of 90° for the voltage coil using an inductance or a capacity. The figures below (left to right) show this measuring instrument used as a wattmeter, varmeter, ammeter and voltmeter.

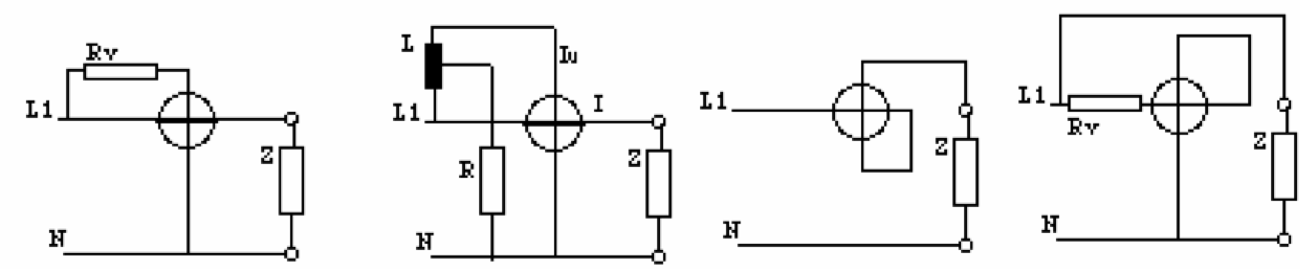


Figure 17: Electrodynamic device for measurements in W, VAR, A and U

When measuring power, the moving coil acts as the voltage coil and the field coil as the current coil. This device may be used for any type of curve and threshold frequency is 5 [kHz]. These devices are very precise, just like devices with moving coils (up to category 0.5).

4.2.5.5. Electrostatic device

This device works on the principle of the plate capacitor, with one moving plate. When a voltage is applied, the plates are charged differently and an electric field is created between the plates, establishing an attraction.

The force of this attraction will depend on the voltage measured. Frequencies of up to 100 [MHz] and voltage of up to 500 [kV] can be measured.

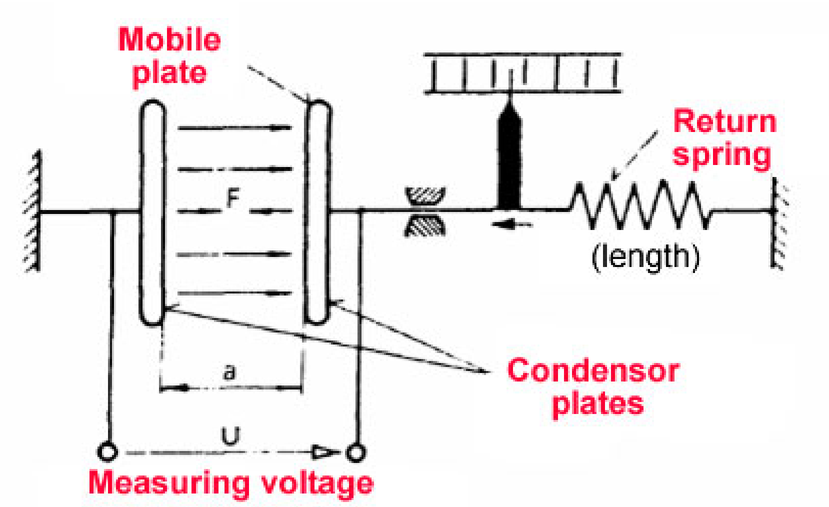


Figure 18: Electrostatic device

4.2.5.6. Bimetal devices

The principle behind bimetal devices is to adhere two materials with different expansion coefficients together. When the temperature (ambient or the bimetal unit directly) is modified, the length of the two materials varies. Bending will occur due to the different change in length of the two materials.

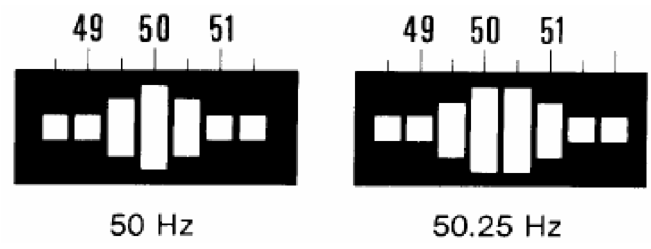
The needle will rotate due to the heating of a bimetal spiral in these types of devices. The spiral is heated by the application of an electric current to the bimetal.

This type of device measures a RMS current value irrespective of the curve and frequency.

This measuring device is not very precise (category 2.5) and has relatively high consumption. The device is based on the principle of heating, therefore it maintains a high level of inertia for current variations.

In certain cases, the device is directly connected to an electromagnetic device which indicates any variation, however small, in current, while the bimetal device indicates the general trend.

4.2.5.7. Device with vibrating blades



This type of device is used as a frequency meter. This device consists of steel blades, each with a different resonance frequency.

Figure 19: Frequency meter

The blades are subjected to a variable magnetic field. The blade reaching resonance will start to vibrate.

The device has a graduated window displaying which blade, or blades vibrate.

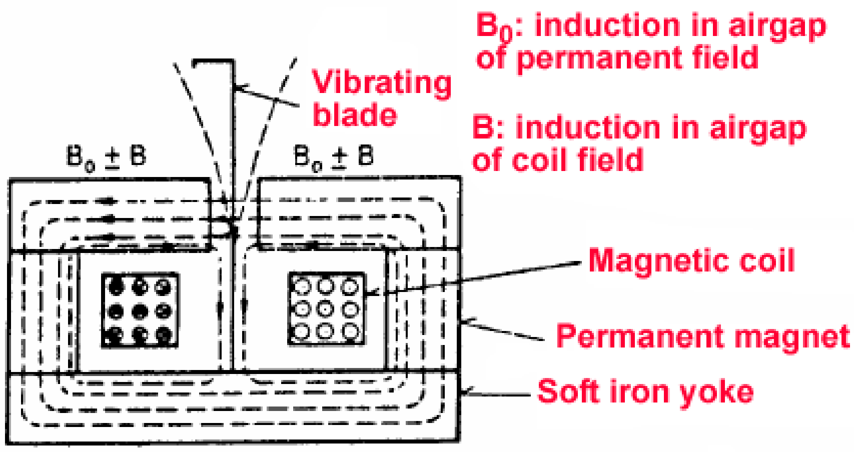
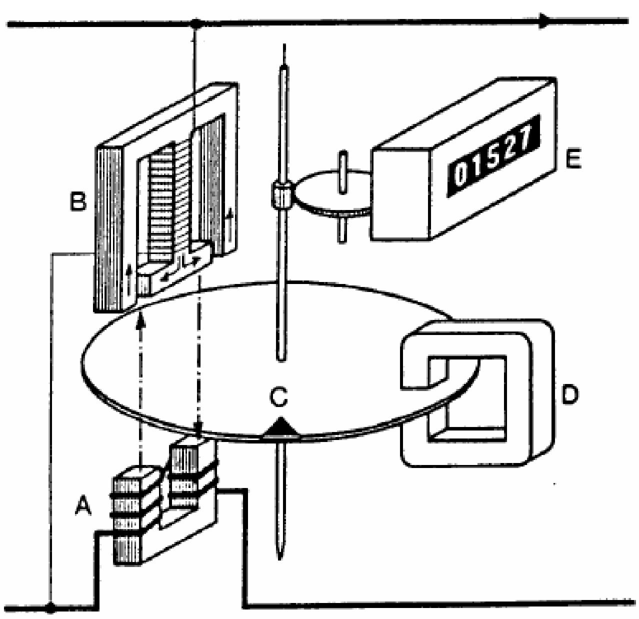


Figure 20: Principle of a device with vibrating blades: a frequency meter

4.2.5.8. Induction devices

Induction wattmeters exist, however this type of device is more generally known as an energy meter. The device works on the principle of a cage rotor asynchronous motor. It consists of two coils (one for current and a second for voltage), an aluminium disc and a mechanical integrator (worm gears driving the display).

Figure 21: Induction device



Coils A and B induce eddy currents in disk C. These then create an induced magnetic flow. A force is then created on the conductor (section of the disk conducting the eddy currents) and a torque on the disk, which will then start to rotate.

The braking torque will depend on the speed of rotation of the disk.

It is given by a permanent magnet D causing the same type of reaction as described above.

The energy meters all have a constant ‘c’ [kWh-1] which indicates the number of rotations which the disk must complete for an electrical consumption of 1 [kWh].

The power of a receiver can be calculated by deducting the time t [s] required for the disk to complete a certain number of rotations ‘a’.

Example:

A meter has a constant c which is equivalent to 75 [kWh-1] and the device which is connected to its terminals rotates the disk at 3 rpm.

What is the power of the receiver?

$$P = \frac{a \cdot 3600}{c \cdot t} = \frac{3 \cdot 3600}{75 \cdot 60} = 2.4\ [kW]$$

4.2.5.9. Crossed coil devices

In practice, we use crossed coil devices for ohmeters, to indicate the position of the valves or temperature measurements.

This instrument is an electrodynamic type measuring device. It is equipped with material with a moving coil consisting of 2 crossed coils connected to the moving element.

The span is graduated depending on the type of measurement, e.g. in [Ω] or OPEN/CLOSED or [°C].

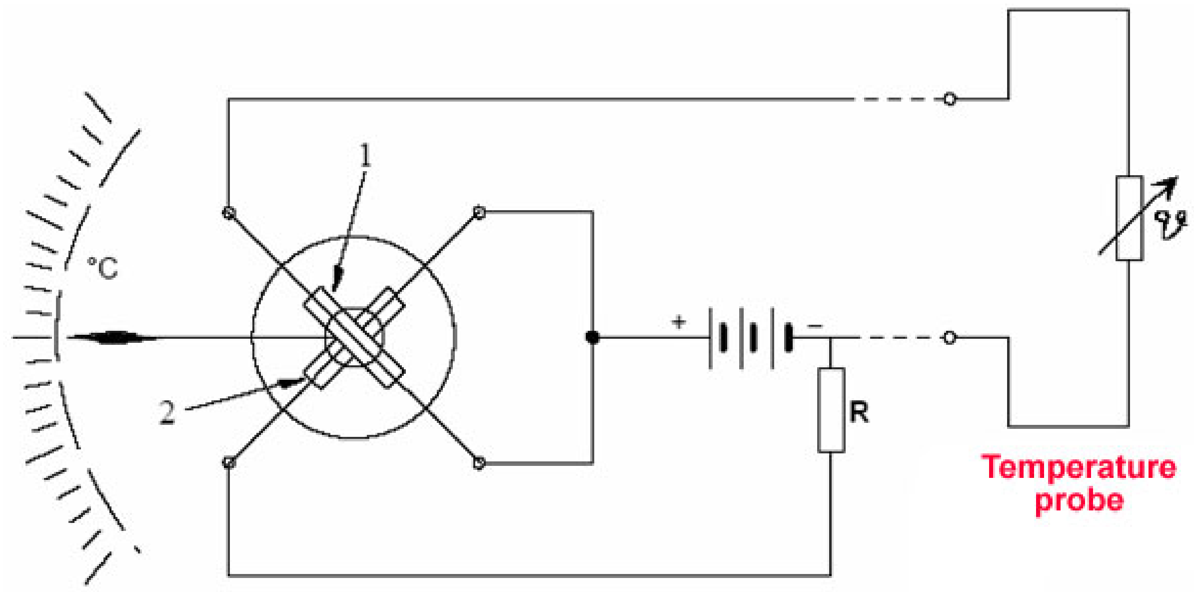


Figure 22: Principle of a device with crossed coils

Legend:
1. complete moving coil in which current I circulates, measured in the thermistor circuit.
2. complete moving coil in which current I circulates, measured in the adjustment resistances.

Operating principle

The current to be measured passes through the windings of a fixed or moving coil suspended between the poles of a core bearing the coil generating the induction field $\vec{B}$ of the thermistor. If the current is zero, the adjustment coil will influence the moving coil.

The needle will move to a certain position. This position is indicated by the adjustment of torque M caused by the current circulating in the resistor. If current I_1 circulating in the thermistor is equal to the adjustment current I_2, torque M generated by the two currents will be cancelled out.

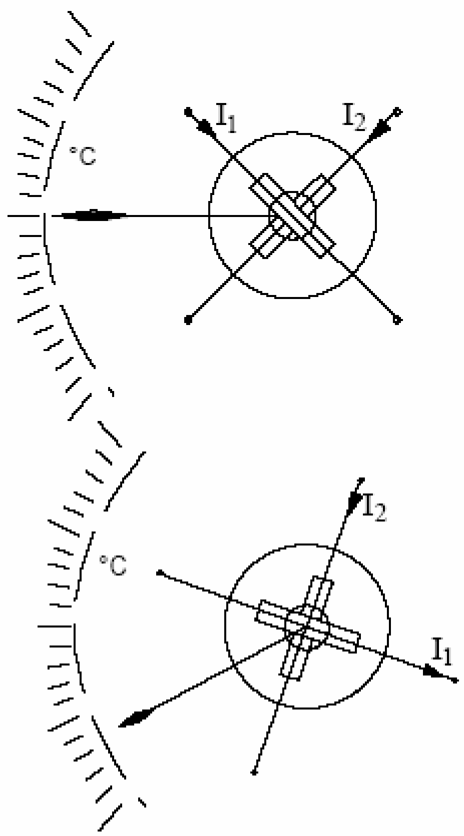


Figure 23: Principle of currents in a device with crossed coils

If current I_1 circulating in the thermistor is greater than the adjustment current I_2, torque M generated will move the needle to a certain position.

This instrument is sometimes known as a: **Quotient measuring instrument.**

4.3. DIGITAL

Before we 'attack' digital devices, it would be preferable to be familiar with how to read and interpret a digital measurement, although this may (initially) appear obvious.

4.3.1. Number of significant figures

4.3.1.1. Writing of a digital value

As the values corresponding to the sizes studied in physics are never exact, we need to pay attention to the number of figures used.

*Example: If you divide a wire with a length measured as **100cm,** with an accuracy of +/- **1cm,** into **3 equal sections,** is it correct to say that each section measures **33.33cm**?*

The length of the wire is between **99cm and 101cm**, which means that each section has a length of between **33cm and 33.7cm**.

You may note that the length of each section is **33.3cm**

The 4th figure has been removed as **it is not significant.**

There are only **3 significant figures.**

Any digital value obtained from a measurement or a calculation (based on measured values) **must be expressed with a number of significant figures depending on uncertainties.**

4.3.1.2. Significant or not significant

All figures other than zero are significant

1542.3 has 5 significant figures

15.423 has 5 significant figures (the point has no effect)

Zeros within a number or at the end of a number, after the point, are always significant

2005 has 4 significant figures

187.50 has 5 significant figures

187.5 has 4 significant figures

Therefore **187.50** and **187.5** are not identical, the former is more precise.

The zeros placed at the start of a number are never significant

0.52 has 2 significant figures

0.0052 has 2 significant figures

Zeros placed at the end of a number without a point may or may not be *(and this is easier than Shakespeare)* **significant**

200 mA, has 1, 2 or 3 significant figures

To remove any ambiguity, we could change the unit and add a point:

0.20 A, has 2 significant figures

0.200 A, has 3 significant figures

4.3.1.3. How to round up/down lengthy numbers

To obtain a result to a correct number of significant figures, certain results must be rounded up or down.

We retain the number of significant figures desired. If the first figure dropped is equal to 5, 6, 7, 8 or 9, the final significant figure is rounded up to the next number (possibly carrying).

527.397 5 rounds up/down to

527.398 with 6 significant figures

527.40 with 5 significant figures

527.4 with 4 significant figures

527 with 3 significant figures

530 with 2 significant figures

500 with 1 significant figure

4.3.2. Definition of a digital device

Digital measuring instruments consist of electronic components and the values measured are displayed using digits.

The main advantage of digital measuring instruments is that they remove reading errors due to imprecision.

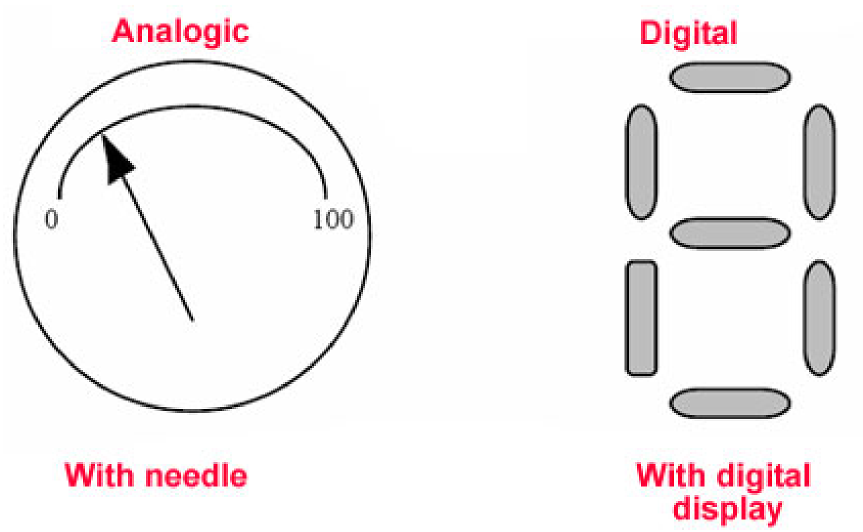


Figure 24: Analogue/digital differences

4.3.2.1. Definition of the term "numerical":

A device which is able to represent a value measured using a NUMBER is known as a NUMERICAL device.

Important! Do not mix up figure and number!

4 is a figure, and 1456 is a number made up of 4 figures.

Figures are to numbers what letters are to words!

4.3.2.2. Definition of the term "digital"

The term DIGITAL is a synonym for the term BINARY (2 states). Referring to measuring devices with digital displays is therefore incorrect.

In practice, catalogues for measuring devices maintain the use of this error by referring to displays with 4.5 digits, 4 digits, or 3.5 digits.

Definition of the term "*digit*":

The digit is defined as a 7-segment composition noted using the letters a to g and which gives the impression of showing a figure.

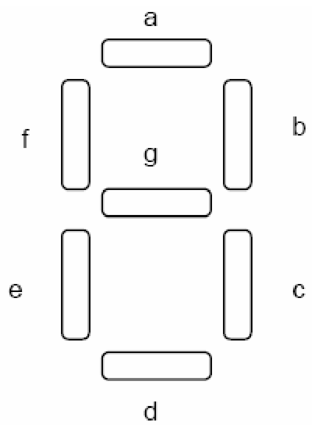


Figure 25: The creation of a digit

NB: The term digit is also used to define a 4-bit word used to control this type of display.

A "***semi-digit***" is defined as a 2-segment composition noted using the letters b and c and which gives the impression of showing a 1 or nothing.

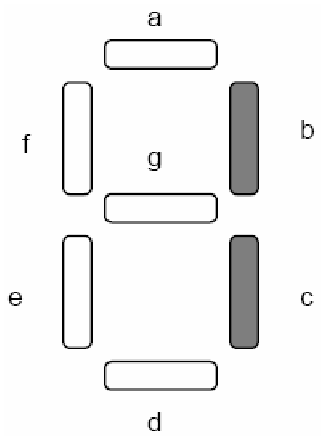


Figure 26: The creation of a semi-digit

4.3.3. Symbols and special indications used with digital devices

The main symbols of digital instruments are identical to those of analogue instruments. They generally allow for the automatic selection of the measuring range, and sometimes for the manual control of special measurements.

Unlike analogue instruments, the precision category and the symbols are not shown on the instrument. The triangle with an exclamation mark indicates that the characteristics are defined in the documentation enclosed with the instrument.

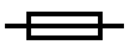
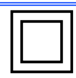
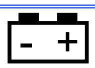
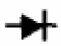
Symbol	Description	Symbol	Description
	Important - Safety The manual includes explanations – **See manual**		Possible hazardous voltage
	AC – alternating current		DC – direct current
	AC and/or DC		Ground
	Fuse		Double insulation – Class II protection
	Fuel cell		Continuity "bip"
	Diode		Capacitor
	Manual range	**H**	Automatic 'Hold' key

Table 4: Symbols on digital devices or their manuals

4.3.4. Flow chart of a digital measuring device

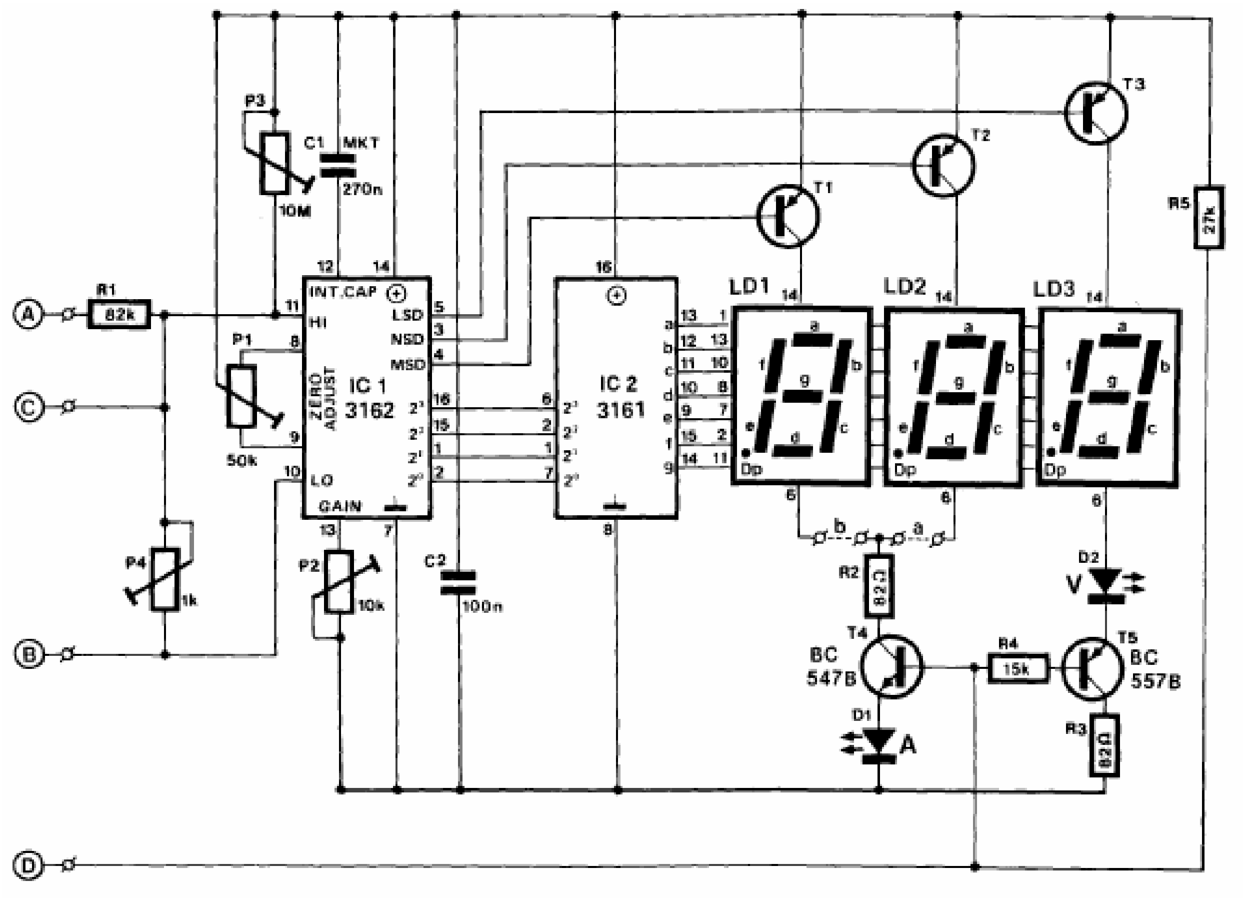


Figure 27: Flow chart of a digital measuring device

Description of the functioning:

This instrument consists of 3 displays controlled by an integrated circuit (IC2) and of 5 transistors (T1-T5). The first integrated circuit IC1 converts the analogue value measured as a numerical value and destined for display.

The IC1 receives the analogue value (voltage) on its terminals 10 and 11. This value is calculated using comparison. The integrated circuit provides a reference value (known) and compares it with the input voltage (unknown).

If the two values are not equal, the integrated circuit will increase the reference value and repeat the comparison. The integrated circuit will repeat this process until the two values compared are equal. This method enables the integrated circuit to determine the value of the input voltage precisely.

Once this value has been defined, IC1 will indicate a numerical value as the result of its comparison. This numerical value is transmitted to terminals 2, 1, 15, and 16 as a 4-bit word. IC2 receives this number and decodes it to control the 7-segment displays.

We note that the 3 displays are assembled in parallel. This should represent a problem, as all segments with identical names should light up simultaneously. This is not the case as a multiplexed display mode is used.

IC1 provides the numerical values of the voltage measured and controls the display. This control is applied using terminals 4, 3 and 5. Transistors T1, T2 and T3 control the display feed. If IC1 receives a value which must be applied by the first display, it will control feed via terminal 4 and transistor T1.

The displays light up consecutively with this type of multiplexed display. Two displays will never light up simultaneously. The displays light up rapidly enough to ensure that the naked eye does not observe the effect. The multiplexed display also enables energy to be saved as only one display is lit up. This characteristic is important for portable devices which operate using fuel cells.

4.3.5. Precision categories of digital devices:

The internal resistance of digital measuring devices is far higher than that of analogue devices, and will not vary, irrespective of the measuring range selected. The error induced in measurements will only be significant for circuits with very high impedance.

Two types of measuring error exist for digital devices:

1. Electronic error.

2. Error due to the number of measures applied for the analogue/digital conversion.

The error is generally given in% of the reading ± a constant expressed in units or digits. Certain manufacturers indicate the error in% of the span ± the constant. This procedure generally covers up the low quality of the device.

The error constant (indicated in "digits") indicates to what extent the least significant binary figure can be incorrect. The least significant figure represents the resolution of the device.

Example: for a span of 100 [mV] and 2,000 measuring points, resolution will be 0.1 [mV].

4.3.6. Examples of error calculations for digital instruments

We have already considered the calculation of errors, we will now give three examples which you can use as references if (one fine day) you decide to estimate the quality of a measurement.

4.3.6.1. Example 1

We measure a voltage of 50mV on a span of 100mV.

The device applies 2,000 measuring points.

Characteristics:

0.1% of the reading and ± 0.5 digits.

1 digit = 0.1 [mV]

Reading error: $(50 \times 10^{-3} \times 0.1) / 100 = 50 \times 10^{-6}$ (V) = 50 µv → **0.5 digit**

Constant error: $(100 \times 10^{-3}) / 2{,}000 = 50 \times 10^{-6}$ (V) = 50 µv → **0.5 digit**

In this case, precision is equal to ± 0.5 digits, i.e. a total of 1 digit, which gives an error of 100µV.

Total error = sum of all errors:

$(50 \times 10^{-6}) + (50 \times 10^{-6}) = 100 \times 10^{-6} = \boldsymbol{100\mu V}$

This error of 100 µV corresponds to 1 digit.

4.3.6.2. Example 2

We measure a voltage of 50mV on a span of 150mV.
The device applies 2,000 measuring points.

Characteristics:

0.2% of the reading.

± 0.1% of the range.

Reading error: $(50 \times 10^{-3} \times 0.2) / 100 = 100 \times 10 - 6$ (V) = 100µV → **1 digit**

Constant error: (0.1 x 200) / 100 = 200 x 10^{-6} (V) = 200µV → **2 digits**

Total error = sum of all errors:

(100 x 10^{-6}) + (200 x 10^{-6}) = (300 x 10^{-6}) (V) ***= 300µV***

This error of 300µV corresponds to 3 digits.

4.3.6.3. Example 3

We measure a voltage of 50mV on a span of 200mV.

The device applies 2,000 measuring points.

Characteristics:

0.1%.

± 1 digit.

Reading error: (0.1 x 200) / 100 = 200 x 10^{-6} (V) = 200µV → **2 digits**

Constant error: (200 x 10^{-3}) / 2,000 = 100 x 10^{-6} (V) = 100µV → **1 digit**

This error of 100µV corresponds to 1 digit. In this case, precision is equal to ± 3 digits, i.e. a total of 3 digit, which gives a constant error of 300µV.

Total error = sum of all errors:

(200 x 10 - 6) + (100 x 10 - 6) = (300 x 10 - 6) (V) ***= 300µV***

This error of 300µV corresponds to 3 digits.

See later sections for the use of digital measuring devices, particularly multimeters.

4.4. OTHER DEVICES…..

I.e. devices which are neither analogue or digital? I can't think of any!

With instrumentation, a measure generally starts with an analogue physical value which is transformed/converted (transmitter and converter) into an analogue or digital current or voltage signal. *See the course on instrumentation.*

Analogue and/or digital systems starts with initial pneumatic and/or hydraulic input (the sensor) and output (actuator, relay) and have converters/transmitters integrated in the system … See the *pneumatic and hydraulic courses in instrumentation and mechanical engineering.*

Speed can be measured by a shaft-end tachometer (manual device) and be transformed into an analogue mechanical value indicated on an analogue or numerical display.

Speed can be measured using a stroboscope, counting teeth on a pinion for a given period. This would be a numerical method as the pulses are counted (almost direct method).

When measuring a magnetic field, radiation can be measured and transform/convert a specific "intensity" into a signal which may be "read".

To resume, all methods involve analogue, digital and numerical input.

5. MEASUREMENT OF ELEC PARAMETERS

I.e. measurement of the main parameters, U, I and R

5.1. REMINDER OF NOTATION

5.1.1. Symbols, definitions, formulas

This chapter refers to voltage, but it also applies for current.

This chapter refers to the *official* symbols for the terms used in teaching documents and retailer manuals.

I measure a *signal* with my multimeter (*a sinusoidal signal I think)*, however, in fact, I can measure something which resembles the following curve, *for example.*

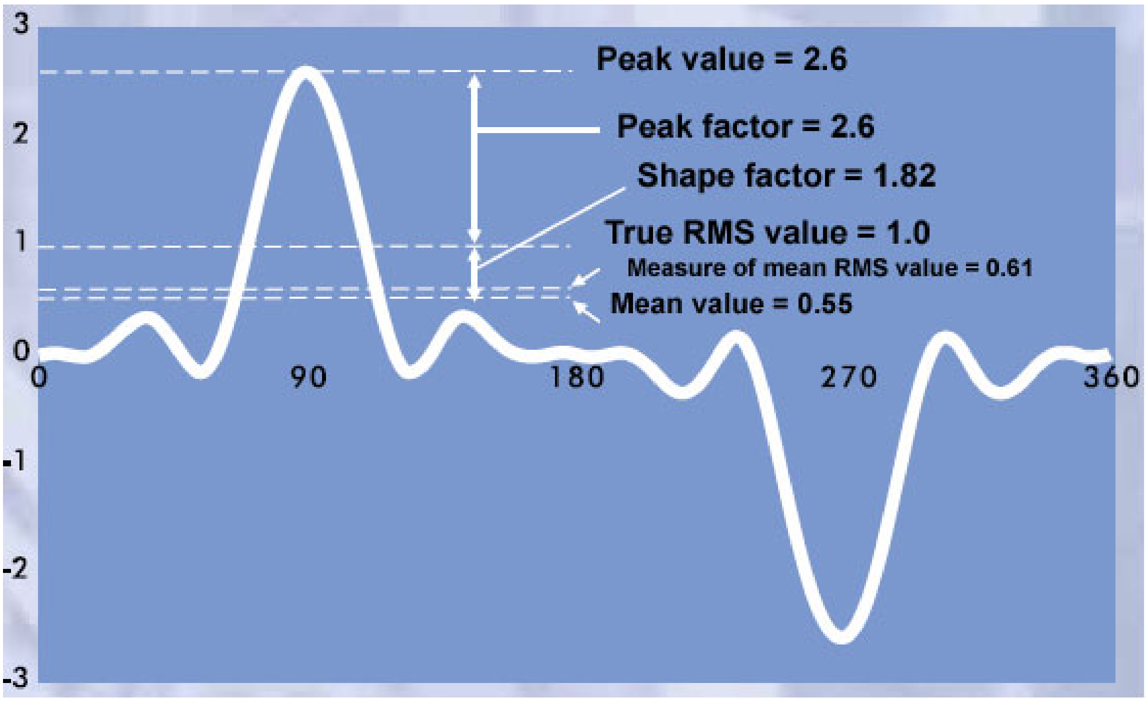


Figure 28: Example of the measurement of a signal

The following table should *(in theory)* help you to understand why different measuring devices *(which appear identical)* can indicate different values for the same measurement.

You must understand the difference between mean values, DC and AC components, RMS value and true RMS. There is no false RMS.

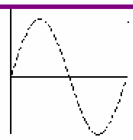
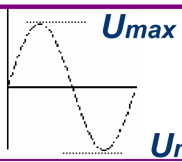
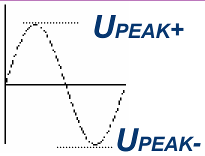
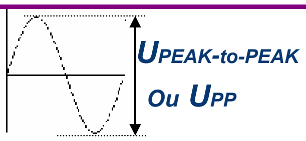
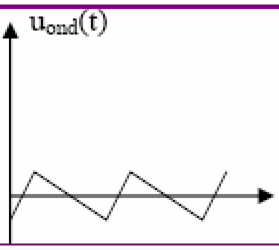
Symbol	Description	Representation	Comments
u(t)	Pure AC periodic signal		***U** = amplitude*
U_{min}, U_{max}	Minimum value, maximum value		Peak value '+' et peak value '-'
U_{PEAK}	Peak value		$U_{PEAK+} = U_{max}$ $U_{PEAK-} = U_{min}$
U_{pp} or $\hat{\hat{u}}$	Peak-to-Peak amplitude		$U_{PP} = U_{max} - U_{min}$
$<u>$ or u or U_{DC}	Mean value or DC component		*Sinusoidal alternative with DC component* $< u > = \frac{1}{T}\int_0^T u(t)\,dt$
U_{eff} or U_{RMS} or U_{AC+DC}	True RMS value	See last line of the table	$U_{eff} = \sqrt{< u^2 >}$
$U_{ac}(t)$	AC component *Can take any shape – The graph takes the shape of the example in the last line*		$u_{ac}(t) = u(t) - <u>$
U_{AC}	RMS value of the AC component	Idem above	$U_{AC} = \sqrt{< u_{ac}^2 >}$
Theorem	$U_{eff}^2 = U_{DC}^2 + U_{AC}^2$ ou $U_{RMS}^2 = <u> + U_{AC}^2$		

Table 5: Symbols and formulas for measured components

5.1.2. Results to remember

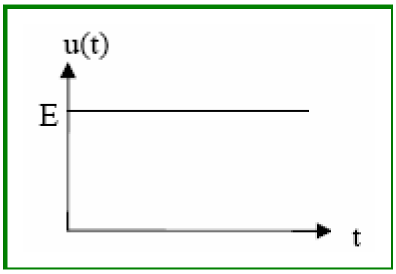
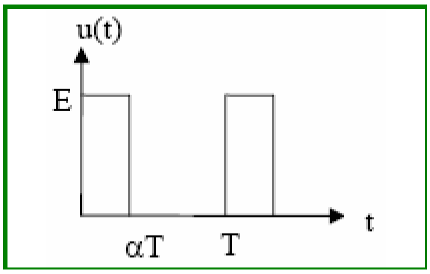
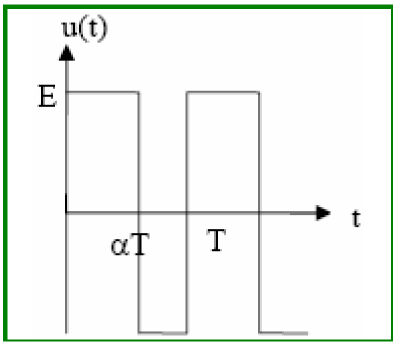
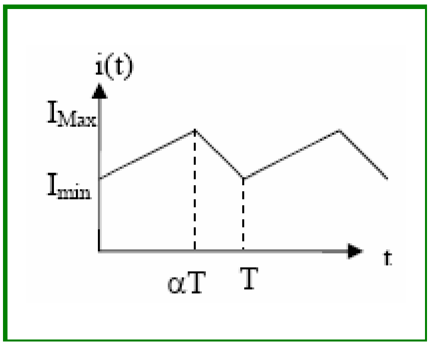
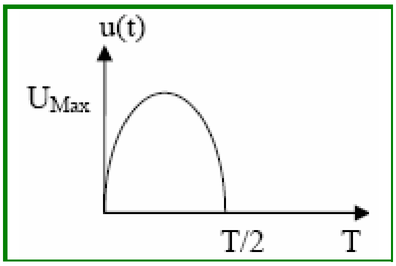
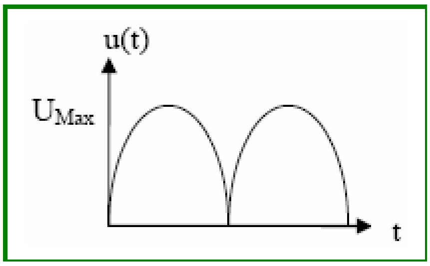
Symbol	Shape		Symbol	Shape
$\langle u \rangle = E$ $U = E$			$\langle u \rangle = \alpha E$ $U = \sqrt{\alpha} \times E$	
$\langle u \rangle = E(2\alpha - 1)$ $U = E$			$\langle i \rangle = \frac{I_{Max} + I_{min}}{2}$	
$\langle u \rangle = \frac{U_{Max}}{\pi}$ $U = \frac{U_{Max}}{2}$			$\langle u \rangle = 2 \times \frac{U_{Max}}{\pi}$ $U = \frac{U_{Max}}{\sqrt{2}}$	

Table 6: Symbols and formulas to be remembered

When you measure current, do not be surprised to find different indications on *different* devices.

Figure 29: 2 "identical" measurements

Which value is right?

The connection feeds a non-linear load.

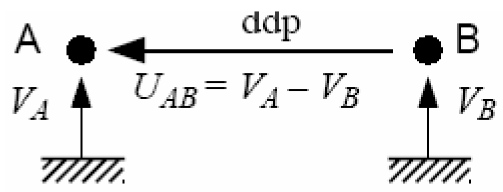
The true RMS hook-on (on the left) is the right reading, while the mean RMS hook-on (on the right) indicates 32% less.

5.2. MEASURING VOLTAGE – VOLTMETERS

5.2.1. DC measurements

5.2.1.1. Direction of connections

Potential at extremity:
(V_A)



Potential at origin
(V_B)

Figure 30: Connection of DC voltage

The direction of connection of the device marks the direction of the arrow representing the difference of potential (COM ↔ potential at origin, ⊕ ↔ potential at extremity). – *Direction of the arrow according to French standards*

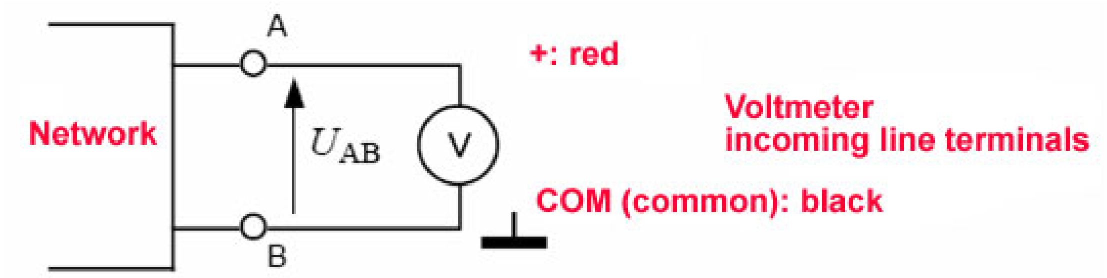


Figure 31: Connection of DC voltmeter

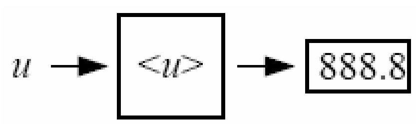
Indications of the voltmeter: +1 ⇒ U_{AB} = +1V ; U_{AB} > 0
–2 ⇒ U_{AB} = –2V ; U_{AB} < 0

5.2.1.2. Selection of the range

Always start measurements with the highest range.

Measurement of <u> = U_{DC}

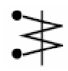
Any multimeter (ana or dig), whatsoever, measures the DC component of a signal in a **DC** position by calculating its mean value:



5.2.2. AC measurements

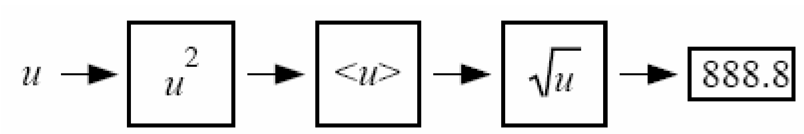
5.2.2.1. Measurement of U_{eff} with a "true RMS" multimeter

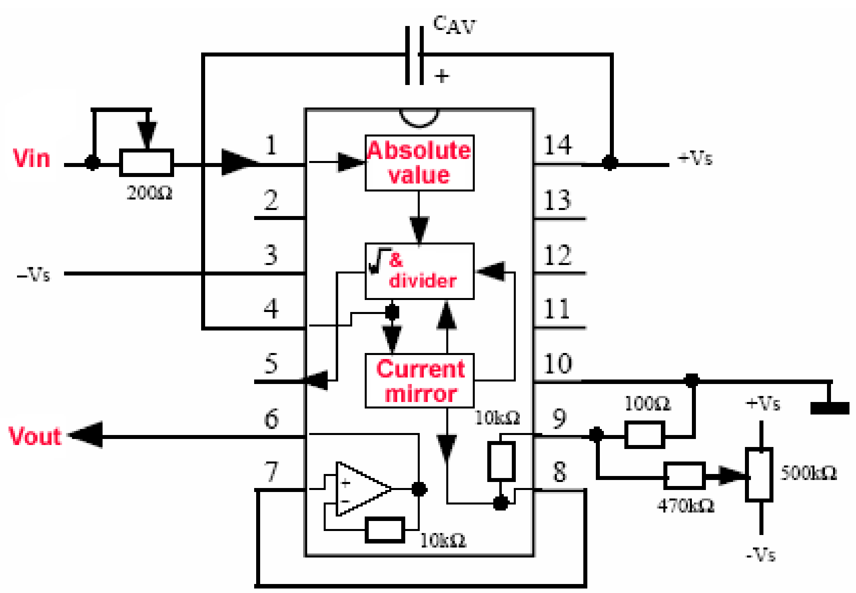
Instrument:



- ferromagnetic ***analogue*** multimeter (symbol:)

- true RMS ***digital*** multimeter, "AC+DC" coupling (**AC** input, commuter to **AC+DC** position): executes the algorithm for the calculation of RMS value:





Integrated measurement circuit for true RMS values (RMS/DC converter): same calculation.

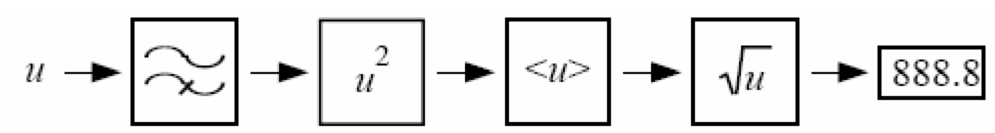
Example: AD636, '*Analogue Devices'*

Figure 32: Integrated circuit, AD636

5.2.2.2. Measurement of U_{eff} with an AC "RMS" multimeter only

Instrument:

- true RMS ***digital*** multimeter, "AC" coupling (**AC input**, commuter to **AC position**): this type of multimeter starts by ***eliminating*** the ***DC component*** of the signal using a ***high pass*** filter and only measures the RMS value of the AC component, using the above algorithm:



This operator must calculate U_{eff} after having measured <*u*> with **DC** coupling using the

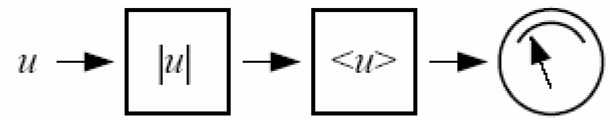
relation $$U_{\text{eff}} = \sqrt{U_{\text{DC}}^2 + U_{\text{AC}}^2}$$

5.2.2.3. Measurement of U_{eff} with a non-RMS" multimeter

Instrument:

- magnetoelectric analogue multimeter Symbol: 
- analogue multimeter
- non-RMS digital multimeter

This type of device can only measure (with **AC** coupling) the RMS value of a ***purely sinusoidal signal***. To do so, the device carries out the following operations:



However, with a purely sinusoidal signal, we know that:

$U_{\text{eff}} = \dfrac{U_{\max}}{\sqrt{2}}$ **and** $\langle |u| \rangle = \dfrac{2U_{\max}}{\pi}$ (mean value of the rectified signal) ⇒ $U_{eff} \approx 1.11$ <|*u*|>

⇒ The mean value of the rectified signal is multiplied by 1.11 to display the RMS value of the sinusoidal AC component.

⇒ For other periodic, non-sinusoidal, signals, the value read must be multiplied by a corrective factor accounting for the shape of the signal.

The following table shows the value of this corrective factor for various signals and various measurements. It is evident that this method only applies for simple signals, and is not generally applicable.

We continue to consider measurements with a non-RMS devices (e.g. an analogue device with a moving coil).

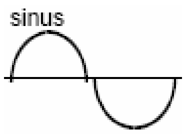
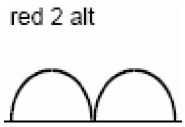
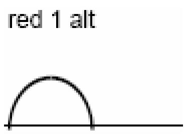
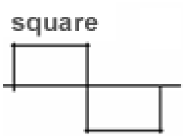
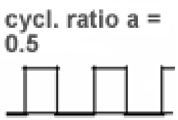
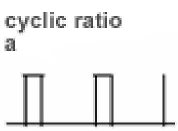
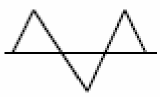
Input wave shape	RMS AC+DC	DC comp.	Peak to peak
	1,000	0,000	2,828
	2,375	2,138	3,359
	1,283	0,817	2.566
	0,900	0,000	1,800
	1,274	0,900	1,800
	$\frac{0,450}{\sqrt{a(1-a)}}$	$\frac{0,450}{(1-a)}$	$\frac{0,450}{a(1-a)}$
	1,040	0,000	3,600

Table 7: Multipliers for the conversion of measurements from a non-RMS measurement

5.2.3. Use of a voltmeter

The device is correctly connected (as a voltmeter), the operator now simply needs to interpret the measurements/indications and (if necessary) adapt the selected range.

This table is also valid for the use of a multimeter (see paragraph concerned) and this table will not be repeated in the chapter on multimeters.

Selection of range *depending on the type of device*		
		
I may select the following types and ranges for each of the 3 devices		
DCV: **Direct current voltage**	**V: Direct current voltage**	 **Direct current voltage**
range 1,000 => 1,000V range 200 => 200V range 20 => 20 V range 2,000m => 2,000mV range 200m => 200mV	range 200m => 200mV range 2 => 2V range 20 => 20V range 200 => 200V range 600 => 600V	range 1,000 => 1,000V range 200 => 200V range 20 => 20V range 2 => 2V range 200mV => 200mV
ACV: Alternating current voltage	**V∿ Alternating current voltage**	 **Alternating current voltage**
range 750 => 750V range 200 => 200V	range 600 --> 600V range 200 --> 200V range 20 --> 20V	range 750 --> 750V range 200 --> 200V range 20 --> 20V range 2 --> 2V range 200mV--> 200mV

Indications of the voltmeter			
	The value of the Voltage is zero **U=0** or The value of the voltage is too low for the selected range		The range that you have selected is too low....
	The negative value informs you that you have not accounted for the polarity of the multimeter. The negative sign will disappear if you reverse the terminals.		The fuel cell sign top left informs you that the fuel cell of the multimeter is low.
	If you are using range 200V, the value read is: **U = 151.2V** If you are using range 200mV, the value read is: **U = 151.2mV** The dot indicates the position of the decimal point under all circumstances.		
	If you are using range 600V VAC, the value read is: **U = 233 V** AC, i.e. the **RMS value**! (this is the mains value in this case). If you are using range 600V DC, the value read is: **U = 233 V DC.**		

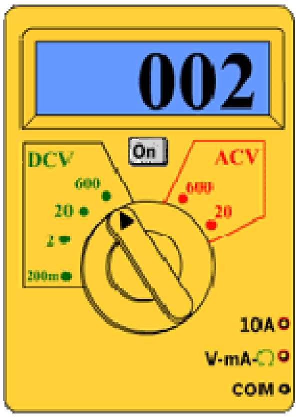
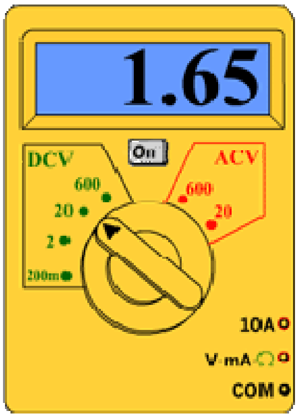
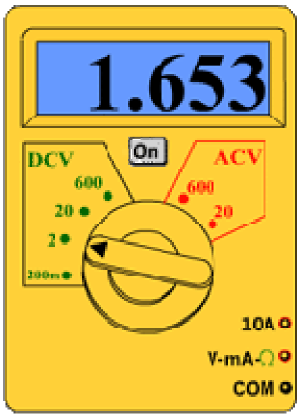
Sample readings and action to be taken		
State and result	**Reading**	**Action to be taken**
	positive terminal: V negative terminal: COM selected range: 600V DC (=) display: 002 i.e. **U = 2V** - DC voltage	**U = 2V** < 20V a lower range, 20V, may be used to obtain a more precise reading.
	positive terminal: V negative terminal: COM selected range: 20V DC (=) display: 1.65 i.e. **U = 1.65V** - DC voltage	**U = 1.65V** < 2V **you may** use the lower range, 2V
	positive terminal: V negative terminal: COM selected range: 2V DC (=) display: 1.653 i.e. **U = 1.653V** - DC voltage	**U = 1.653V** > 200mV, ⚠ you cannot use the lower range, 200mV
The measurement unit corresponds to that of the selected range under all circumstances. Terminals and range must be consistent.		

Table 8: Use of the voltmeter

5.2.4. Measuring high voltage

Only low voltages may be measured directly. You are not going to *(and you are not authorised to) wander* around a 20 kV conductor with your multimeter and connect the measuring points of your multimeter….

Electricians (and electricians only) are authorised to check the presence of voltage on the high voltage system using appropriate equipment. Electricians may use a voltage detector. Diodes will light up in the presence of voltage. The detector will be fitted on the end of an insulating pole.

Figure 33: Voltage detectors with electroluminescent diodes for interior use of U max.: 36 kV (CATU equipment)

Panel (or portable) indicators measure high voltage via a potential transformer. "Standard" secondary voltage corresponding to maximum primary high voltage is generally between 100 and 120 V

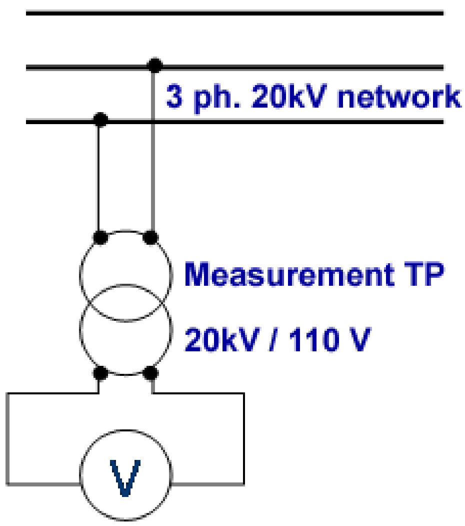


Figure 34: Measuring high voltage with mandatory TP

Details of calculations for transformation ratios + exercises are available in the course on "transformers" and "HV distribution and protection".

5.3. MEASURING CURRENT - AMMETERS

5.3.1. DC measurements (DC)

The direction of connection of the device marks the direction of the conductor (the conductor is directed from the ⊕ terminal to the COM terminal).

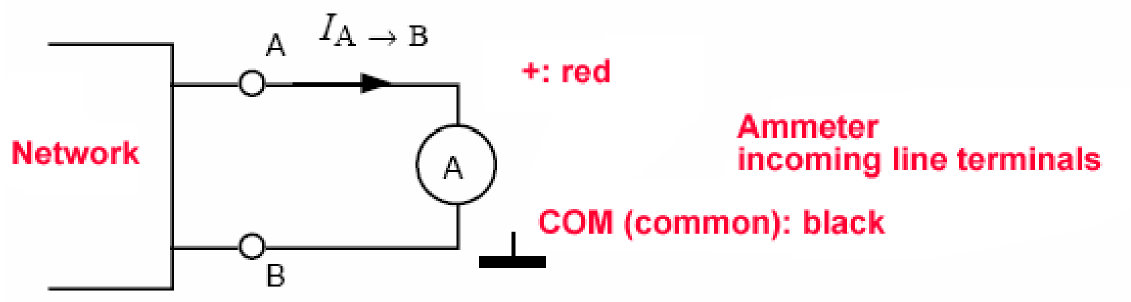


Figure 35: Connection and measuring with an ammeter

Indications of the ammeter:

+1 ⇒ $I_{A \to B}$ = +1A; $I_{A \to B} > 0$ ⇒ direction of circulation of I (from A to B) ≡ direction of the conductor

–2 ⇒ $I_{A \to B}$ = –2A; $I_{A \to B} < 0$ ⇒ direction of circulation of I (from B to A) ≠ direction of the conductor

⚠ Selection of the range: *always start measurements with the highest range.*

5.3.2. AC measurements

See voltmeter

5.3.3. Hook-on ammeter

Use: measurement of current *without cutting the circuit out.* Measurement of high intensities.

Operating principles as follows :

5.3.3.1. AC only

Intensity transformer with a ratio $m = \frac{N_2}{N_1} = \frac{I_1}{I_2} = \frac{U_2}{U_1}$; In this case, the central conductor in which the current to be measured circulates is the primary side, therefore $N_1 = 1 \Leftrightarrow > 1$. This transformer, where $I_2 < I_1$ and $U_2 > U_1$, is known as an "intensity transformer". An AC ammeter closes the secondary circuit (therefore $U_2 = 0$).

The ***secondary circuit of a current transformer must always be short circuited***.

Otherwise, if $I_2 \rightarrow 0$, the secondary voltage can be very high off-load, which may lead to the overheating of the circuit, discharge, or even electrocution, etc.

5.3.3.2. AC and DC

Hall effect cell:

This is a semi-conductive probe sensitive to magnetic field ***B*** created by the current *I* which runs through the central conductor. When this probe is run through by a current *i* perpendicular to ***B***, it has been proved that a difference of potential *V* proportional to ***B*** and therefore to *I* appears on the lateral surfaces of the cell.

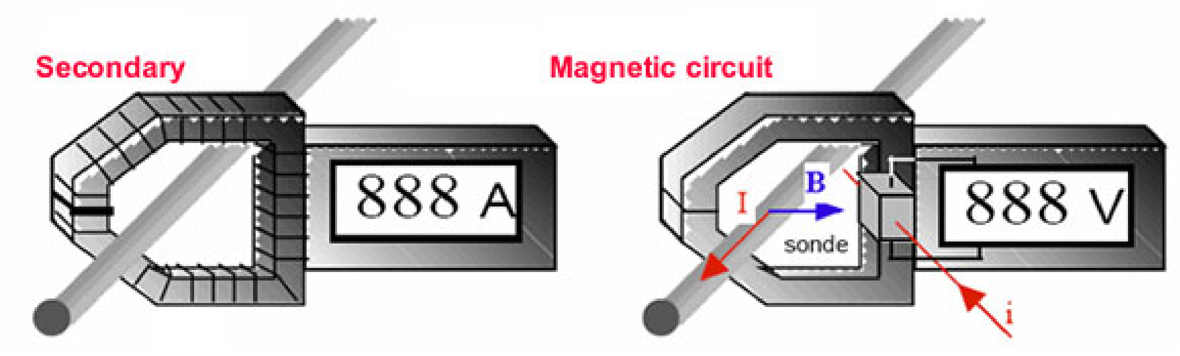
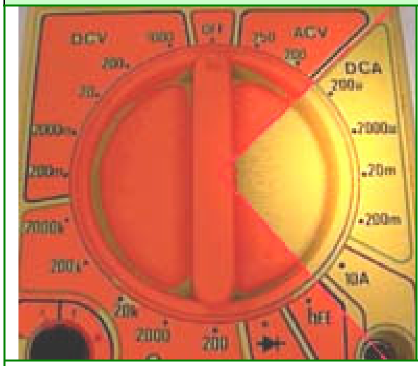
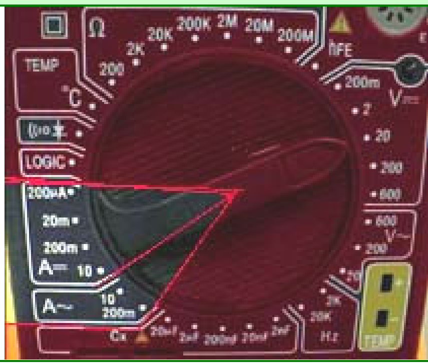


Figure 36: Hook-on ammeter, principle with the Hall effect cell

5.3.4. Use of an ammeter

The device is correctly connected (start with the highest range if you are not sure!), the operator now simply needs to interpret the measurements/indications and (if necessary) adapt the selected range.

This table is also valid for the use of a multimeter (see paragraph concerned) and this table will not be repeated in the chapter on multimeters.

Selection of range *depending on the type of device*		
		
I may select the following types and ranges for each of the 3 devices		
DC only: **direct current**	**A= direct current**	**DC=**: **direct current**
range 200µ => 200µA range 2,000µ => 2,000µA range 20m => 20mA range 200m => 200mA range 10 A => 10°	range 200Aµ range 20m => 20mA range 200m => 200mA range 10 => 10A	range 200AA range 2 => 2mA range 20 => 20mA range 200 => 200mA range 2 A => 2A range 10 A => 10A
	A∿: **alternating current**	**AC∿ alternating current**
	range 10 => 10A range 200m => 200mA	range 200AA range 2 => 2mA range 20 => 20mA range 200 => 200mA range 2A => 2A range 10A => 10A

<table>
<tr><th colspan="4">Indications of the ammeter</th></tr>
<tr><td></td><td colspan="3">The value of the intensity is zero I = 0 or

The value of the intensity is too low for the selected range or

You have melted the fuse protecting the selected range as the value of the intensity is higher than the range!</td></tr>
<tr><td></td><td>The range that you have selected is too low, you may melt the fuse!</td><td></td><td>the negative value informs you that you have not accounted for the polarity of the multimeter. The negative sign will disappear if you reverse the terminals.</td></tr>
<tr><td></td><td colspan="3">The fuel cell sign top left informs you that the fuel cell of the multimeter is low.</td></tr>
<tr><td></td><td colspan="3">If you are using range 200mA, the value read is: I = 96mA

If you are using range 200Aμ, the value read is: I = 96μA

The dot indicates the position of the decimal point under all circumstances.</td></tr>
<tr><td></td><td colspan="3">If you are using range 10A, the value read is: I = 0.10A
i.e. I = 100mA, you may change range and select the range 200mA

If you are using range 200mA, the value read is: I = 0.10mA
i.e. I = 100μA, you may change range and select the range 200μA</td></tr>
</table>

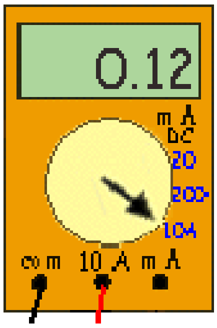
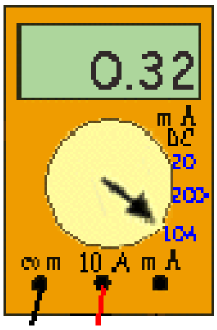
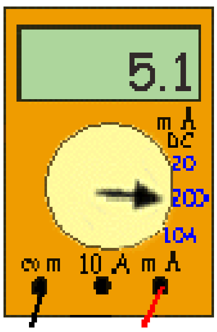
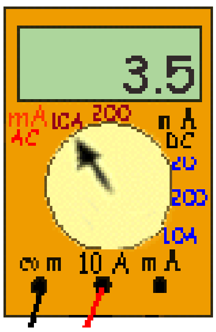
Sample readings and action to be taken		
State and result	**Reading**	**Action to be taken**
	positive terminal: 10A negative terminal: COM selected range: 10A DC (=) display: 0,12 i.e. I = 0.12A - direct current	I = 0.12A = 120mA, a lower range, 200mA, may be used to obtain a more precise reading.
	positive terminal: 10A negative terminal: COM selected range: 10A DC (=) display: 0,32 i.e. I = 0.32A - direct current	I = 0.32A = 320mA,  **you may not** use the lower range, 200mA, as the value would exceed the range. The fuse would melt.
	positive terminal: mA negative terminal: COM selected range: 200mA DC (=) display: 5,1 i.e. I = 5.1mA - direct current	I = 5.1mA, a lower range, 20mA, may be used to obtain a more precise reading.
	positive terminal: 10A negative terminal: COM selected range: 10A AC (∿) display: 3,5 i.e. I = 3.5A - alternating current	I = 3.5A,  **you may not** use the lower range, 200Ma, as the value would exceed the range. The fuse would melt.
The measurement unit corresponds to that of the selected range under all circumstances. Terminals and range must be consistent.		

Table 9: Use of an ammeter

5.3.5. Measurement of high currents

5.3.5.1. CTs

Current transformers (CTs) are fitted to many installations with permanent indications on HV and LV networks, including to measure (relatively) low intensities.

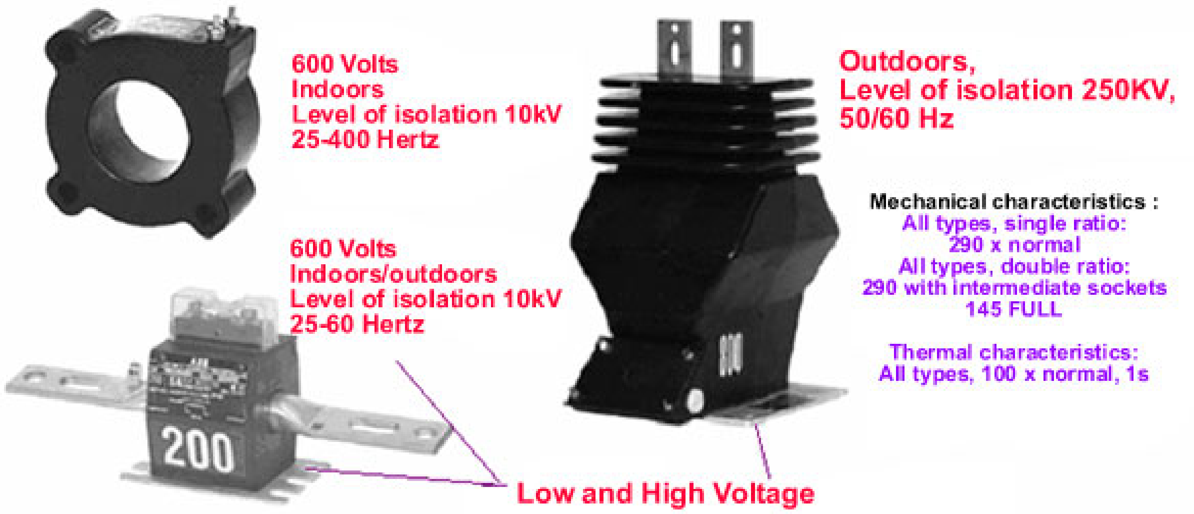


Figure 37: Example of a CT with LV and HV

The CT is a "*permanently connected hook-on ammeter*". Just like its hook-on equivalent, the secondary circuit (measuring circuit) must never remain open.

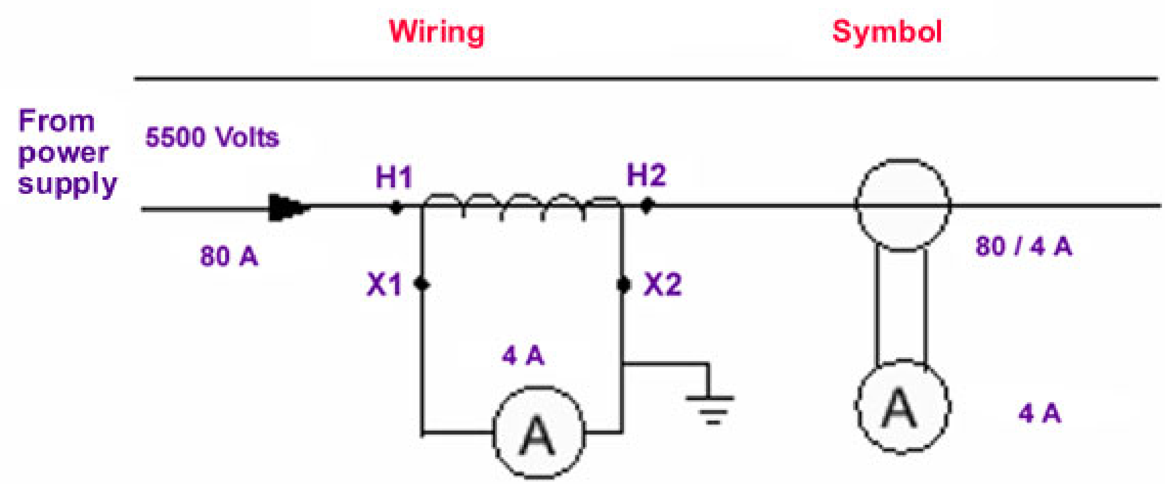


Figure 38: Cabling of a CT (2 versions of the symbol) with a HV network

The CT transformation ratio depends on the primary intensity, as the secondary current (generally) corresponds to one of two options: 1A or 5A.

Thus: a CT 1,000A/5A has a secondary current of 2.5A with 50A on the primary side
a CT 200A/1A has a secondary current of 0.75A with 150A on the primary side

See the courses on "Transformers", "LV distribution and protection", and "HV distribution and protection" for details, particularly on the three-phase connection flow charts (delta and wye), transformation ratio calculations and exercises.

5.3.5.2. Shunts

An ammeter has low internal resistance ((this is mainly the case for an analogue galvanometer) and is subject to a maximum current corresponding to the maximum indication on the span (range). To measure higher intensities (and even several ranges of intensities), (low) current must be deviated from the main current in the measuring device.

The most simple means of explaining a shunt is using an example

Example 1:

A ***device with a moving coil*** has a resistance of ***100Ω***. We intend to measure a current of 1 A. The needle reaches the end of the span if a current of ***10mA*** circulates in the device.

We know that the measuring device accepts a maximum current I_{max} *of 10mA*. Maximum current I_{mes} measured will be 1A.

This implies that we must run current 'I' somewhere other then in the measuring device. We will create a bridge connected in parallel to the instrument terminals.

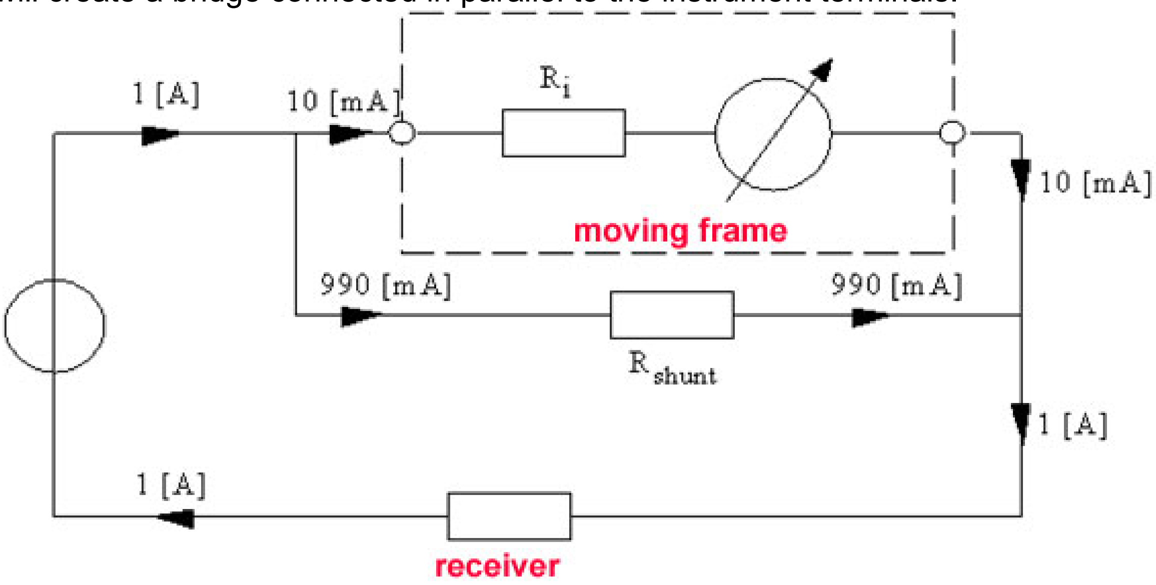


Figure 39: Current bridge = shunt

Sizing of the shunt*:*

At the terminals of the device: U = R x I = 100 x 0.01 = 1V

This voltage is identical at the shunt terminals,

R_{shunt} = U / I_{shunt} = 1 / 0.99 = 1.0101Ω

With the direct formula:

$$R_{shunt} = \frac{R_{instrument} \cdot I_{instrument}}{I_{total} - I_{instrument}}$$

And if we aim to obtain a value other than 1A, at the end of the span, we must replace this shunt by one with another value.

Example 2:

We have a measuring device with a moving coil and the following characteristics:

Maximum current: ***4.7mA*** Voltage at the terminals: ***700mV***.

This instrument must be used to measure currents of different intensities.

3 measurement extensions must be provided for this purpose (3 ranges) for the following values:

I_1 = 50mA, I_2 = 660mA, I_3 = 1250mA

Calculate the values of shunt resistances with the relation R_{shunt} determined in example 1.

The following flow chart shows the device with "its" shunts, the current in each shunt corresponding to the maximum current value to be measured.

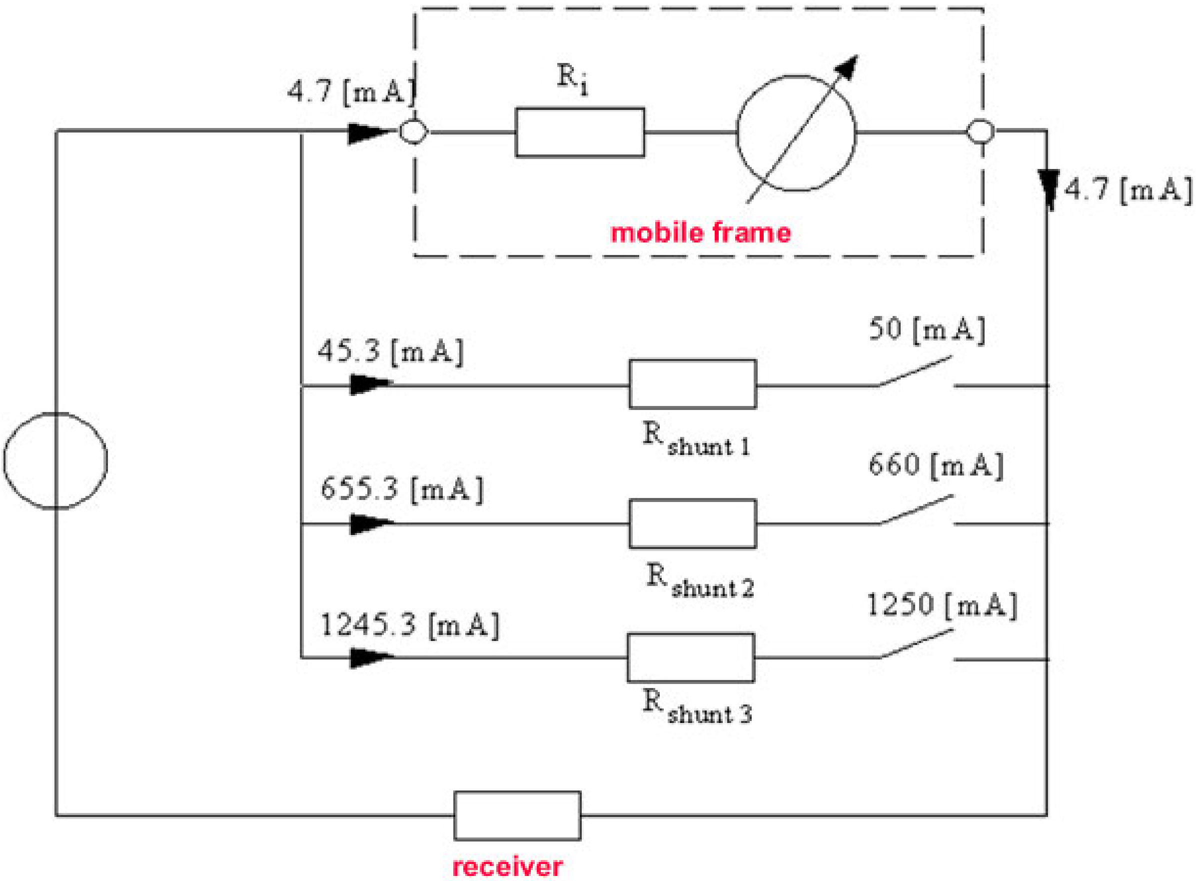


Figure 40: Calculation of shunt for 3 measurement ranges

We need the value of the internal resistance of the device. This can be calculated

$$R_{inst} = \frac{U_{instrument}}{I_{instrument}} = \frac{700 \cdot 10^{-3}}{4.7 \cdot 10^{-3}} = 148.94\ [\Omega]$$

Calculation of shunt resistances

$$R_{shunt1} = \frac{R_{instrument} \cdot I_{instrument}}{I_{total} - I_{instrument}} = \frac{148.94 \cdot 4.7 \cdot 10^{-3}}{50 \cdot 10^{-3} - 4.7 \cdot 10^{-3}} = 15.45\ [\Omega]$$

$$R_{shunt2} = \frac{R_{instrument} \cdot I_{instrument}}{I_{total} - I_{instrument}} = \frac{148.94 \cdot 4.7 \cdot 10^{-3}}{660 \cdot 10^{-3} - 4.7 \cdot 10^{-3}} = 1.07\ [\Omega]$$

$$R_{shunt3} = \frac{R_{instrument} \cdot I_{instrument}}{I_{total} - I_{instrument}} = \frac{148.94 \cdot 4.7 \cdot 10^{-3}}{1250 \cdot 10^{-3} - 4.7 \cdot 10^{-3}} = 562\ [m\Omega]$$

5.3.5.3. Additional resistance

We are currently considering ammeters, however we are going to revise the 'voltmeter' by using the same device (a galvanometer) as previously, in shunt example 1.

We know that the measuring device is designed to accept a current I of ***10mA*** and that its internal resistance Ri is ***100Ω***.

The maximum voltage U that we intend to measure is *300V.*

This implies that we must reduce voltage U by adding an additional resistor connected in series.

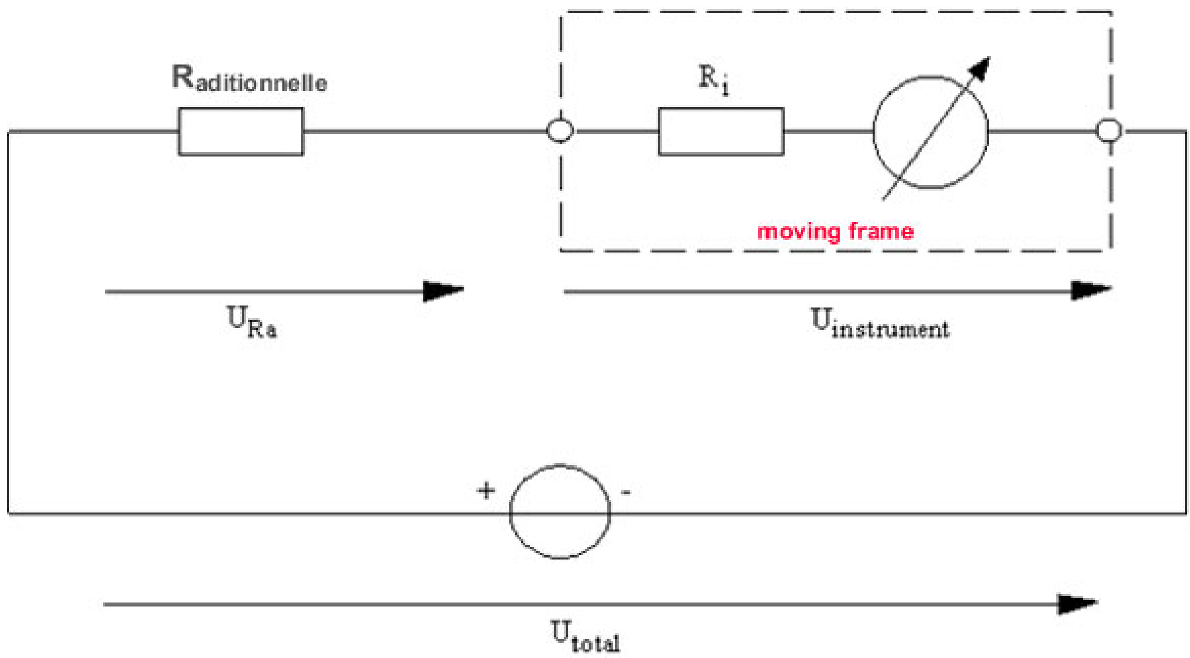


Figure 41: Additional resistor for measuring with a voltmeter

Sizing of the additional resistor:

As the resistor is connected in series, the current $I_{instrument}$ is equal to the current $I_{Radditional}$.

We abbreviate as follows: $I_{instr} = I_{Radd}$

We replace using Ohm's law and attempt to find the unknown element, R_{add}

$$U_{totale} = (R_{instr} \cdot I_{instr}) + (R_{add} \cdot I_{instr})$$

$$R_{add} = \frac{U_{totale} - (R_{instr} \cdot I_{instr})}{I_{instr}}$$

With our application:

$$R_{add} = \frac{300 - \left(100 \cdot 10 \cdot 10^{-3}\right)}{10 \cdot 10^{-3}} = 29.9 \ [k\Omega]$$

If we intend to obtain another value at the end of the span, we must replace this additional resistor with a resistor of another value and if the device includes several ranges, there will be several additional resistances.

5.3.6. Measurement of fault currents

Refer to the courses on "Grounding/ground networks", "LV distribution and protection" and "HV distribution and protection". Same courses for the measurement of loop currents.

5.4. RESISTANCE

The measurement of resistance using the comparison method, with a bridge, is covered in another paragraph below.

5.4.1. Circuit resistors

Use of an analogue ohmmeter:

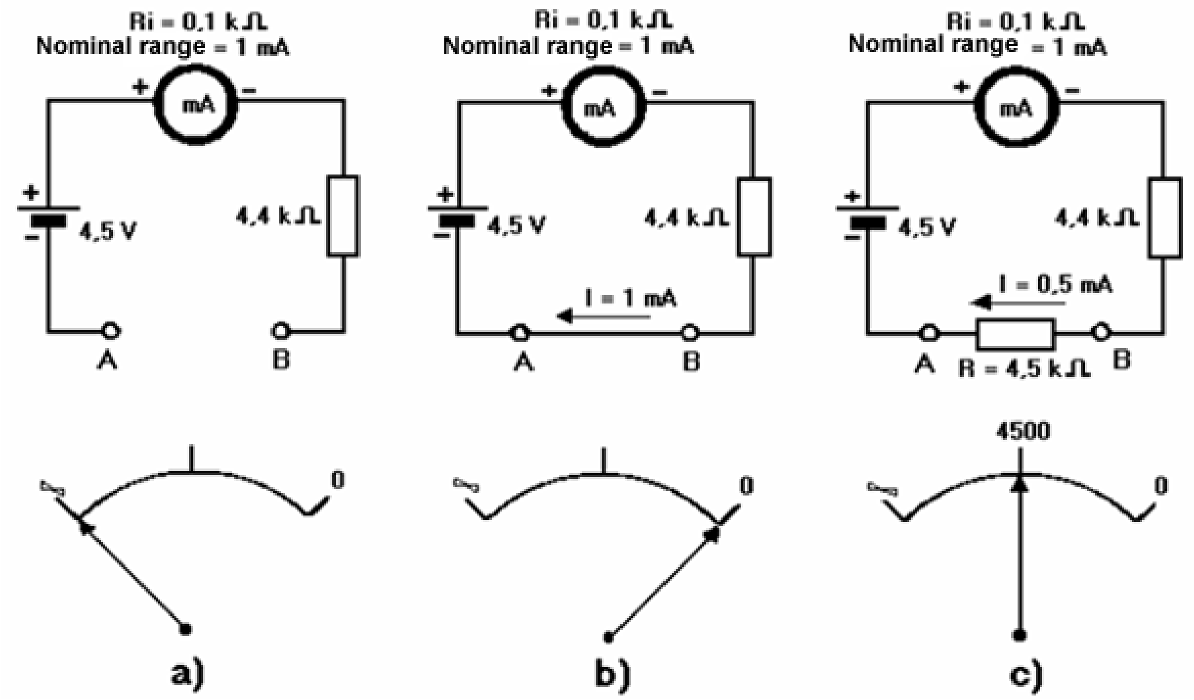


Figure 42: Setting of "zero" and reading of an analogue ohmmeter

Range = 1 mA

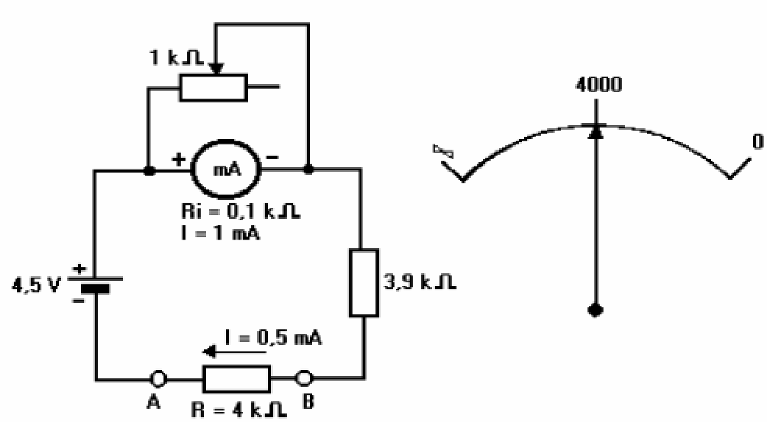
By using a fuel cell of **4.5V** and a galvanometer of range **1mA** to circulate the current and determine the movement of the needle at the end of the span, the circuit resistor, i.e. the fuel cell voltage divided by the current, must be **4.5kΩ** (**4.5 / 1 = 4.5**).

The device has an internal resistor of **0.1kΩ**. A resistor of **4.4kΩ** has been connected in series.

Figure 43: Potentiometer for setting zero

However, the fuel cell voltage will be "approximately" 4.5V, and the voltage will fall over time.

This is why analogue devices are equipped with a potentiometer to adjust the value of this resistance depending on the fuel cell voltage.



The current in the ‘galvanometer’ will not change. The potentiometer is installed as shown on the flow chart.

Figure 44: Connection of the potentiometer

Prior to measuring resistance, with this type of device, set zero by short-circuiting the connection wires and adjusting the needle to the "zero" position.

And if you do not manage to set the zero, change the fuel cell!

Digital devices are able to compensate “on their own”.

On Total sites, it is not generally necessary to obtain precision measurements, and the ohmmeter ranges of your numerical controller are adequate in principle. However, if you need to switch to a higher level to measure low resistances (e.g. the resistances of ammeter shunts), consider the 2 examples of devices which management *(and the purchasing service)* will be delighted to obtain for you below…. …
I recommend the ‘megger’, which is a worthy tool. Important: Megger is a brand and not an insulation measurement device. Megger also manufactures micro/milli/mega ohmmeters, ground current meters, etc.

MILLI OHMMETER RCN2 **"Sefelec" brand**

This device is used both in laboratories and on sites (mains and battery supplied). From 10 micro Ohm to 1999 Ohm Precision < 0.2%. Mains and battery supplied.

MICRO OHMMETER DLR0600 "Megger" brand

With the DLRO600, Megger has created a **digital**, **compact** and **ultra-light** tester. Light: less than 15kg Current ranging from 10A to 600A DC Resolution: 0.1µΩ Memory: 300 results and test notes RS232 port for the transfer of results from the memory or a real-time connection to a printer

Figure 45: Ohmmeter, milli – ohmmeter and precision micro – ohmmeter

5.4.2. Measurement of ground

To measure grounds, operators may use **ground current meters** directly, with the following **accessories: two 60cm ground rods (probes, diameter of 1cm) in good conductive materials and 3 lengths of insulated electric wire (section 1.5 or 2.5mm²) of at least 25m each**.

To measure the ground, position the two probes connected to S and HE and connected to output E on the ground (disconnected) in a triangle (at least 20cm in the ground) whose peaks are at least 20m apart.

You can also line up the probes with 40 [m] between the HE probe and the ground and place the S probe in the middle.

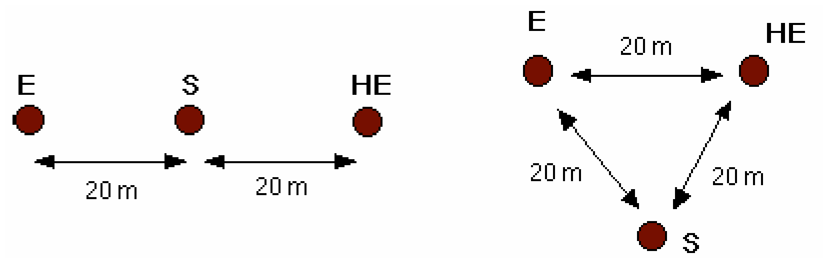


Figure 46: 3-point measurement of ground

If 20 [m] cannot be achieved between each probe, several measurements must be taken and the mean of the different values must be used. The results can be read directly on the ground current meter.

It is also possible to determine this resistance using a (simple) ohmmeter, by taking 3 measurements:

- from E to S (R_{E-S})
- from S to HE (R_{S-HE})
- from E to HE (R_{E-HE}) and then apply the following formula: $\mathbf{R_E = (R_{E-S} + R_{S-HS} - R_{E-HE}) / 2}$

The following measurement configuration always uses the same principle, only the letters change. Follow the connection instructions indicated in the device manual.

The ground to be measured is in ‘’T’ on the device, and the probes in A and B.

The ground to be measured is in ‘’Z’ on the drawing, and the probes in X and Y.

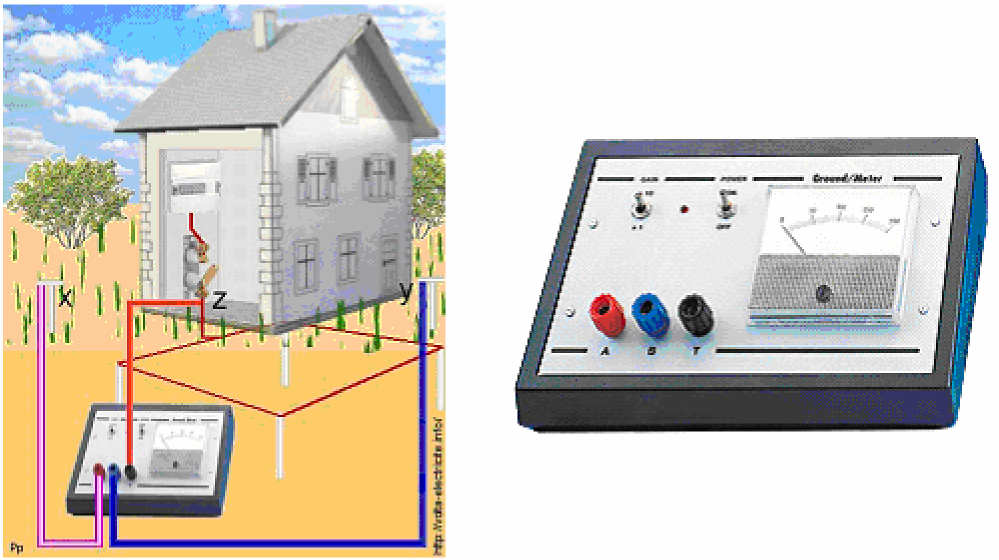


Figure 47: Measurement of an ordinary ground

Refer to the course on "grounding" for ground values and the materials and methods used.

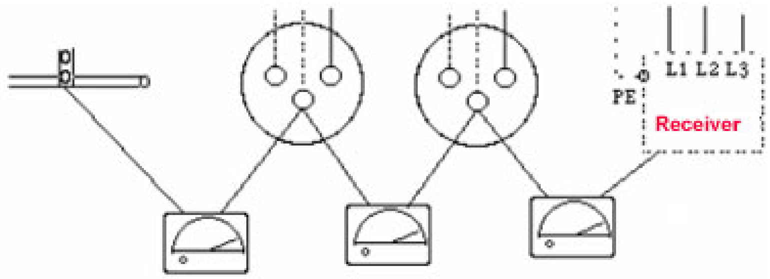
5.4.3. Measuring insulation

The aim of this measurement is to check that more than a certain resistance value exists between the protection conductor and the other conductors and receivers. You must carry out 2 separate measurements to achieve this measurement (the 2 are connected and inseparable) i.e.:

- Verification of the continuity of the protection conductor (very low value).
- Checking of the insulation resistance (very high value).

5.4.3.1. Continuity of the protection conductor

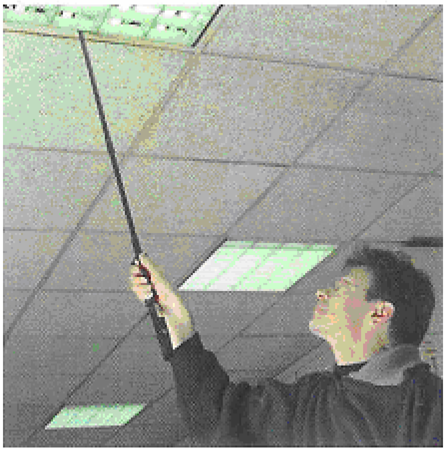
To practice this measurement, you must measure a very low resistance between the ground electrode, and the conductors and conductive objects/receivers connected to the PE (do not forget the protective sockets of network plugs).



Use an ohmmeter (analogue or digital) to check the value of this resistance

Figure 48: Measurement of the continuity of the protection conductor (PE)

If you simply need to check continuity (e.g. to identify if it is the right wire), you could use a buzzer, a pocket torch or quite simply the "bip-bip" function on your multimeter (ohmmeter measurement).



Continuity tests are used for all types of electric devices. The simple lighting device must be grounded and the ground connection continuity is part of the **annual** test and measurements**.** For industrial uses and buildings accessible to the public, an independent body must execute this verification on an annual basis. The photo shows a rod connected to an ohmmeter, which has a second conductor connected to a reference ground (somewhere).

Figure 49: Continuity checks with a contact rod

5.4.3.2. Insulation resistance

Measuring insulation resistance and dielectric testing: These two notions are often mixed up. They are used to characterise the quality of insulation and are worth explaining.

Dielectric resistance testing, more generally known as "discharge testing" reflects the ability of insulation to absorb a medium-term overvoltage without priming (spark). In practice, this overvoltage may be due to lightning or due to the induction caused by a default on a lead carrying energy, to give just two examples.

The main objective of the dielectric test is therefore to ensure that the construction rules relating to leakage paths and air gaps, as defined in standards, are complied with. Testing is often carried out by applying AC voltage, however DC may also be used. You will need a ***dielectrometer*** for these operations.

The result obtained is a voltage, generally expressed in kilovolts (kV).

Dielectric testing is more or less destructive in case of a default, depending on the power of the test device used.

Therefore, it should only be applied to new or renovated devices: only devices passing the test successfully will be re-used.

This test is carried out prior to commissioning on sites, and may be repeated in the future, however, attention must be paid to the voltage applied, which must be less than the initial value used as the installation has "aged".

Measuring insulation resistance, is non-destructive in normal test conditions.

This test is carried out by applying ***DC voltage*** with an amplitude which is less than that used for dielectric testing, and aims to obtain an result in ***kΩ, MΩ or GΩ.*** This resistance reflects the quality of the insulation between two conductive elements and provides reliable information on the risk of the circulation of leakage current. Its non-destructive nature is particularly beneficial and enables the monitoring of the aging of insulation during the period of use of material or of an electric installation. It can also be used as a basis for preventive maintenance.

Figure 50: Checking insulation in a cabinet

This measurement is carried out using an insulation controller, also known as a megohmmeter.

The megohmmeter generates a current which must be minimal to avoid destroying the insulation, but high enough to move the needle of an analogue device (or to achieve a display on a numerical device).

The megohmmeter generates DC voltage of varying levels, 500V or 1,000V, in "traditional" devices, to test low voltage installations.

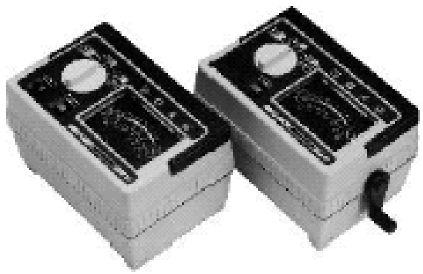


Figure 51: Megohmmeters with magnetos

E.g.: 500V device, R_{isol} measured 1 MΩ, current generated of 0.5mA

Important: voltage generated = 500 or 1,000V, watch out for prickles! How many electricians (at least those from the magneto generation) have played a "joke" on a colleague by sending magneto voltage in their direction…….

As for the 'dielectrometer', this device can generate several dozen kV, and that particular joke might not be so funny……

Key fact: Saying "megger" is like saying "hoover" or "selotape", it is a manufacturer or brand and not an item.

Insulation measurements for electric installations

- ***Prior to commissioning,*** disconnect the receivers (open circuits) between each active conductor (phase and neutral conductors) to check that none of them has sustained mechanical damage during the installation.

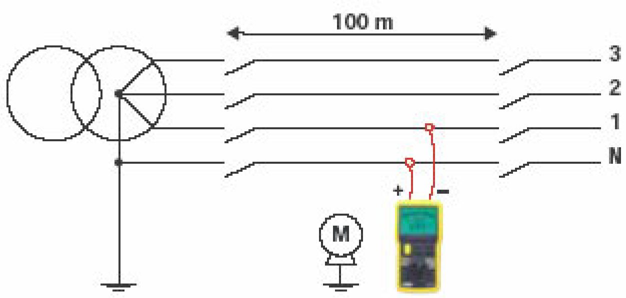


Figure 52: Insulation measurements for open circuits

- Before commissioning, connect all active conductors together, and connect the receivers, to check the insulation of all conductors from the ground.

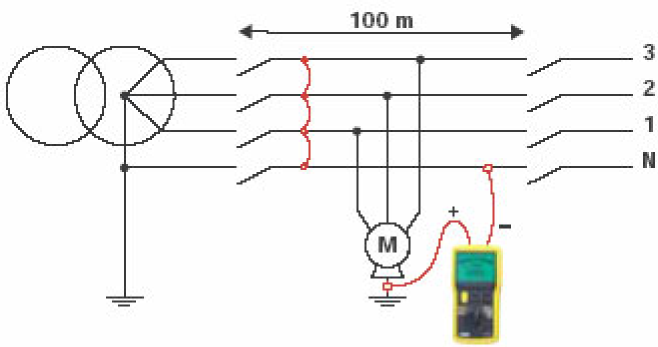


Figure 53: Connect the active conductors together

- If the installation includes sensitive electronic devices, it is preferable to disconnect these devices or check that the phase and neutral conductors are correctly connected during measurements.

These measurements are also carried out periodically for tertiary and industrial installations.

Measurement of the insulation of a rotating machine

Operators can check the quality of the insulation of windings from the ground or between the windings.

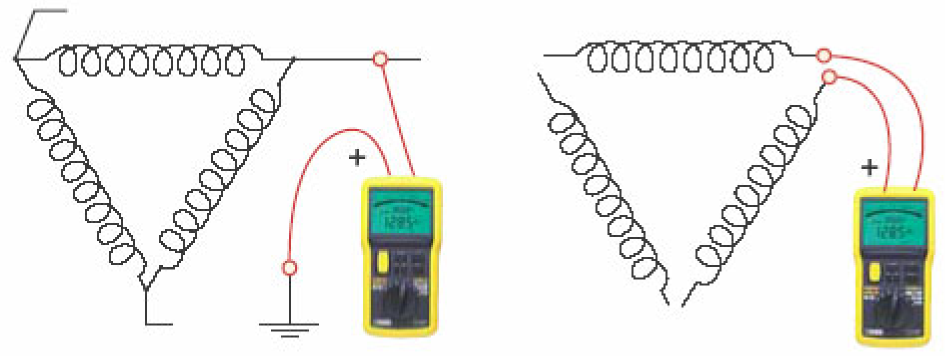


Figure 54: Measurement of insulation for rotating machines

Operators can also check the insulation between the engine connected to the installation and the ground.

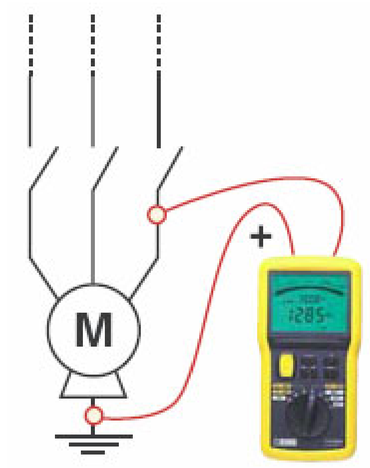


Figure 55: Measuring phase/ground insulation

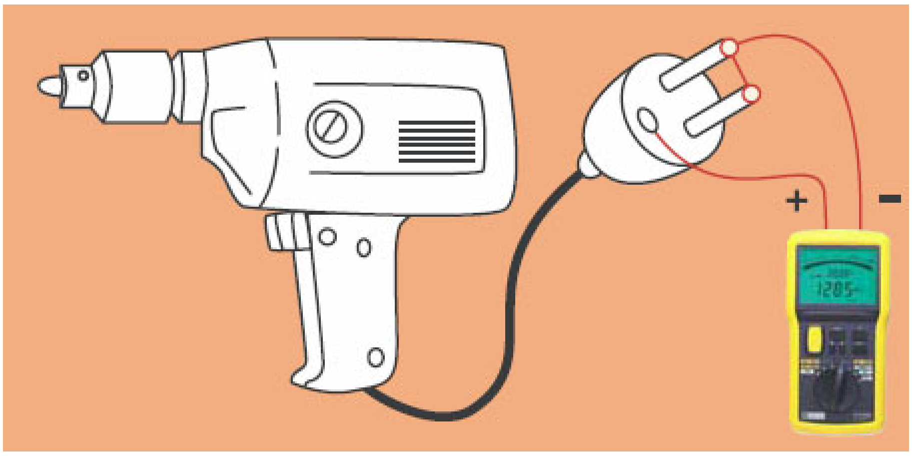
Test voltages of 500 V and 1,000V are obviously the most frequently used when testing rotating machines
Low voltage (<1,000V).

With rotating machines operating beyond 1,000V (medium voltage), insulation test voltages are frequently 2,500V or 5,000VDC.

Figure 56: Measurement of insulation for engines

Electric motors and devices

The number of standards relating to electric devices is proportional to their diversity. A test voltage of 500VDC is traditional and can be applied to machine tests (EN 60204), household electric devices (EN 60335), electric panels (EN 60439) and lights (EN 60598).



Minimum thresholds may vary between standards, however 1,000Ω/V often represents a minimum reference value.

Figure 57: Measuring insulation for an electric device

More details can be found for the measurement of insulation resistances, e.g.:

- Measuring cable resistance
- The influence of temperature
- The influence of measuring time (polarisation index)
- Measuring high insulation resistances
- Measuring insulation fault currents
- Measuring loop currents
- The influence of humidity and dust
- Typical insulation value (Total standards)
- The influence of the test voltage
- Etc,….

in the courses on "grounding" and "electric protection".

5.5. OTHER MEASUREMENTS - DIRECT

U and I are the 2 basic values which enable the calculation of other values and parameters such as resistance, impedance, power, phase lag, etc.

Let us consider these "other" typical measurements for electricity.

5.5.1. Chronometric measurements

5.5.1.1. Frequency meter

Used for high frequencies. The time base generates a fixed time ΔT (e.g. one second). The number of periods of the signal during ΔT are counted. The precision of the measurement depends on the precision of ΔT.

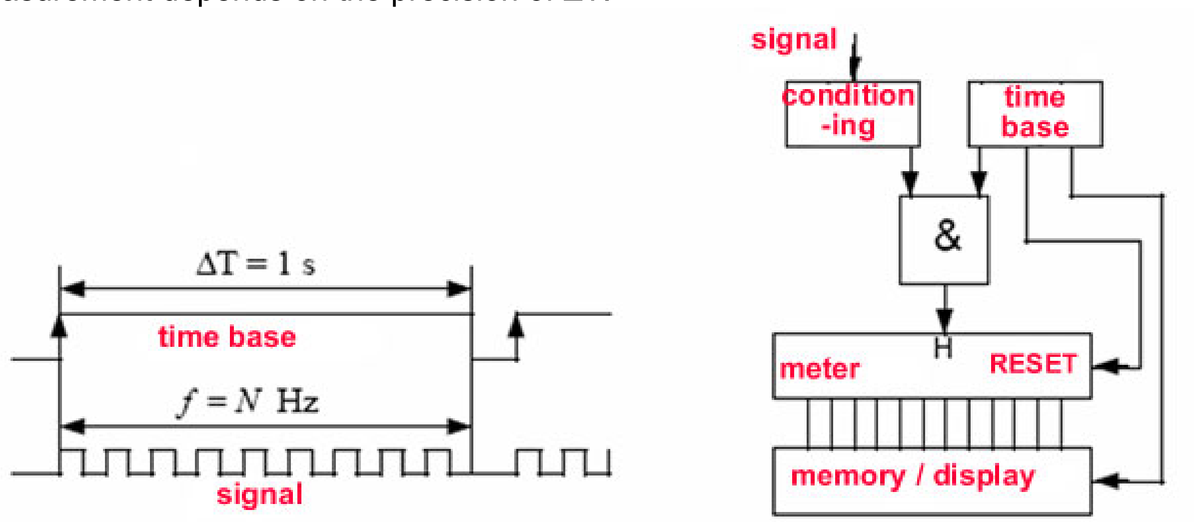


Figure 58: Flow chart for a frequency meter

5.5.1.2. Period meter

Used for low frequencies. The time base (a quartz oscillator) generates a fixed time ΔT (e.g. one millisecond).

The time during a signal period (e.g. between two first values) is measured by counting the number of intervals ΔT.

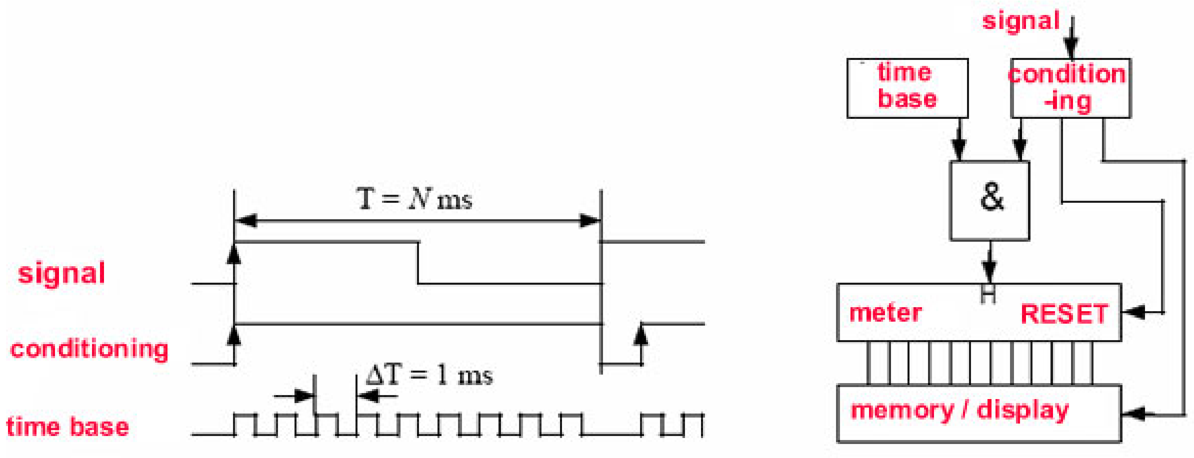


Figure 59: Flow chart for a period meter

5.5.1.3. Measurement of a cyclic ratio

This measurement is obtained by counting (period meter) or by using a low-pass filter (extraction of the mean signal value).

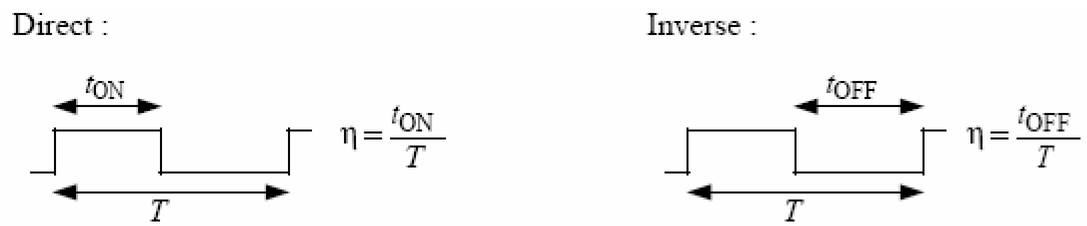


Figure 60: Measurement of a cyclic ratio

5.5.1.4. Phasemeter

This instrument is used to measure the phase lag between two AC currents or voltages with the same frequency. It enables the measurement of phase lag between two signals in a more precise manner than with an oscilloscope. *(cos phi – metre or phimeter).*

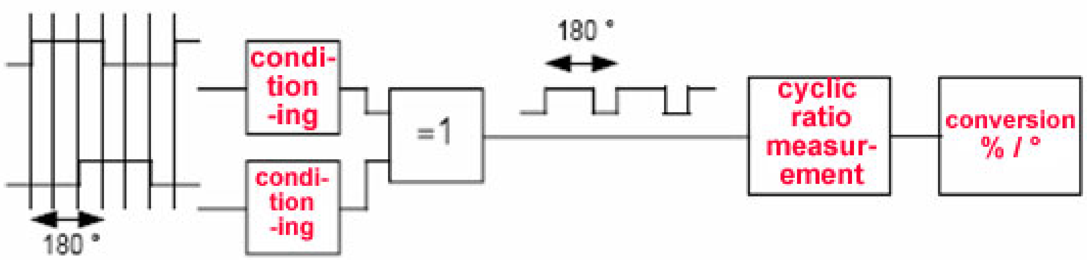


Figure 61: Measuring phase lag using cyclic ratio measurements

Let us consider the basic analogue method for measuring phase lag.

Measuring phase lag – 3 voltmeter method

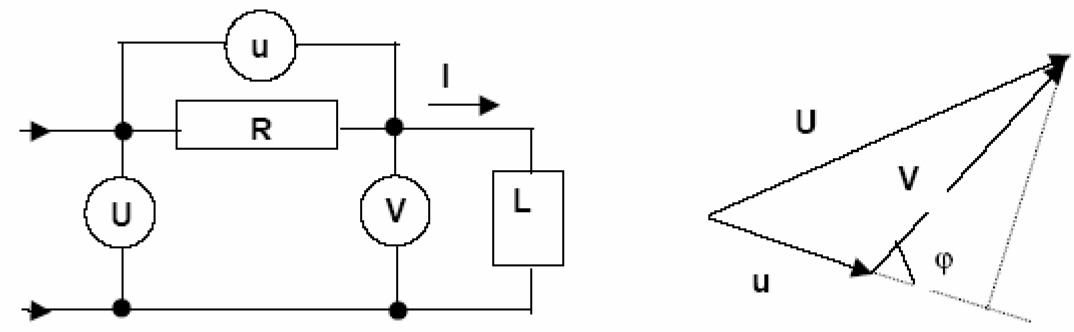


Figure 62: Measuring phase lag using the 3 voltmeter method

Where

u is the 'image' of the current and the voltmeter measures current I with a known resistance.

V is the voltage at the terminals of the load **(L).**

φ is the phase lag angle between *I* (represented by **u**) and voltag**e V.**

Using trigonometric ratios, this gives:

$$U^2 = V^2\sin^2\varphi + (u + V\cos\varphi)^2 = V^2\sin^2\varphi + u^2 + V^2\cos^2\varphi + 2uV\cos\varphi$$

$$U^2 = V^2(\sin\varphi^2 + \cos^2\varphi) + u^2 + 2uV\cos\varphi$$

$$\cos\varphi = \frac{U^2 - V^2 - u^2}{2uV}$$

Important: this use of this formula loses in precision when approaching a phase lag angle of 90°.

Measuring phase lag – use of a wattmeter + voltmeter + ammeter

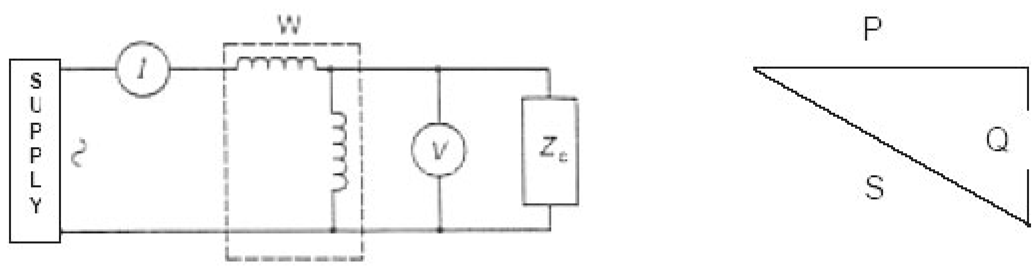


Figure 63: Measuring phase lag using W + (V x A)

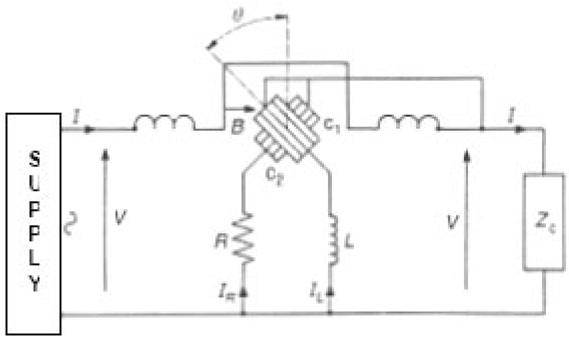
This is a 'simple' method which can be used in laboratories or workshops.

Active power 'P' is measured by the wattmeter and apparent power 'S' is measured by the voltmeter + and the ammeter.

Measuring phase lag – use of an electrodynamic phasemeter

Used as a single or three-phase panel indicator. This device can operate in 'aggressive' environments whereas electronic/digital devices do not support "difficult" ambient conditions.

Single phase electrodynamic phasemeter



This is a wattmeter to which a second moving coil has been added, perpendicular to the first and supplied via an inductance (L) creating a phase lag of 90° (or π/2) between I_L and the other current I_R in the first coil

Figure 64: Single phase electrodynamic phasemeter

It has been established, using trigonometric ratios, that a direct relation exists between the angle of rotation of the coil (θ) and the phase lag angle (φ) for the current and the voltage of load Z_C.

$$\text{Tan } \varphi = \frac{L\varpi}{R} \sin\theta$$

Three phase electrodynamic phasemeter

The angle φ to be measured is the angle between the current 'vector' of a phase and the voltage 'vectors' of the 3 phases of a "wye" representation of 3 voltages and currents (Fresnel diagram), all connected as shown below.

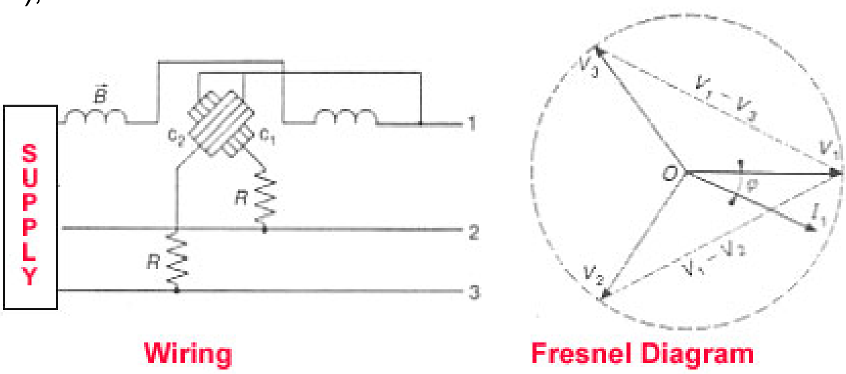


Figure 65: Three phase electrodynamic phasemeter

Trigonometric calculations give:

$$\tan \varphi = -\sqrt{3}\ \tan(\pi / 4 - \theta)$$

- The frequency does not alter the result (if not too high).
- φ could be measured with the single phase phasemeter by creating an artificial ground with 3 resistances. R and L are connected to the ground. This principle is used with standard panel phasemeters.

Synchronoscopes

These are used to synchronise 2 generators or to synchronise one generator with the network.

This is a single phase phasemeter in which the permanent coil (current) is supplied by the network and the 2 moving coils (voltage) by the generator (or vice versa depending on the elements to be synchronised).

Moving coils are free to rotate and are supplied by a system of collars/collectors and brushes.

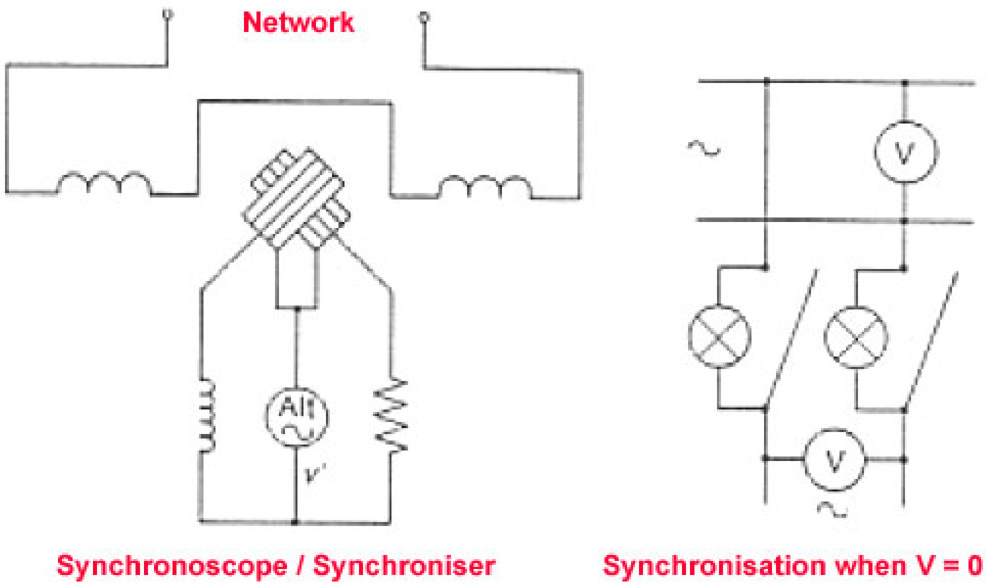


Figure 66: Principle of a synchronoscope

When frequencies differ, the moving coils rotate at a speed corresponding to the difference between these frequencies (e.g. 1 rotation in 4 s for 0.25Hz). The direction of rotation informs the operator of the direction of the adjustment required.

When the frequencies are equal, the coils do not move and the position indicates the phase lag angle between 2 sources. Important: the 2 voltages must be put "into phase" before closing the coupling circuit breaker/switch.

See the "Generator" course.

Other phasemeters:

- Electronic phasemeter systems with diodes or transistors.
- Analogue phasemeters with "flip-flop" (with logic circuits).
- Digital phasemeter: φ at a given frequency for a time, the one of I and V when they are “ordered” in the same alternation.
- Phasemetres using "x" methods with frequency, time, etc.

5.5.2. Measuring of rotating fields

Or rotation controller, or phase order indicator or phase order control relay, etc.

Figure 67: Examples of rotation controllers

A rotation controller is a small device which checks the direction of the rotating field of three phase equipment (on load)). Older devices have three plugs which must be connected to the network to be checked.

When the plugs identified as phase 1, phase 2 and phase 3 are all opposite the corresponding phases of the network, a LED will light up.

Recent devices have two plugs, and two phases must be tested. Hold one plug on the phase and move the other to the third phase. When the field rotates clockwise, the LED will light up, if the field rotates anti-clockwise, the LED will not light up.

This type of device is currently cheap and enables the absence of voltage to be checked (Voltage absence controller).

5.5.3. Measuring speed

In electricity, we need to know the speed of rotation of a rotating machine (motor or generator).

For this we use:

- Manual tachometers.
- "Automatic" tachometers.

5.5.3.1. Manual tachometers

Measures may be carried out:

At the end of a shaft, via a directing reading (analogue or digital), generally in rpm
On a pulley connected to the shaft. Speed (in rpm) must be calculated on the basis of the ratio pulley diameters: tachometer wheel.

Figure 68: Example of manual tachometers

5.5.3.2. "Automatic" tachometers

This is a transmitter which generally operates using a stroboscopic system and a meter.

E.g. it counts the teeth on a pinion passing in front of a sensor during a given period, i.e. a development of the number of teeth $\Rightarrow$ space during a given time $\Rightarrow$ speed.

Refer to the instrumentation course on sensors & transmitters.

5.5.4. Measuring lighting

If you install lighting, you will be required to check the quality and intensity of the light provided by the lighting equipment installed.

E.g., 300 lux min. in an office, 600 lux in an engineering office on the set, etc.

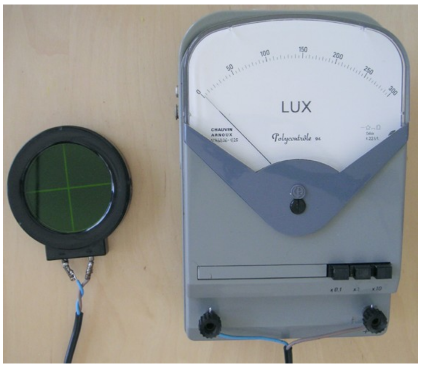


Figure 69: "Traditional" analogue luxmeter

You can also carry out more complete measurements using devices such as the one shown below as an example; (*Other brands and devices obviously exist)*

Figure 70: Digital luxmeter HD2302.0, brand: DELTA OHM

Large LCD screen (52 x 42mm)
2 lines x 4 digits 1/2 + symbols

Measuring units:
lux - fcd - µmol/m².s - cd/m² - W/m² - µW/cm²

Probe module input with an 8-pole male connector DIN45326.

Automatic module recognition (SICRAM module)

The luxmeter HD2302.0 is a portable instrument with a large LCD screen. It measures illuminance, luminance, ERP and irradiance (in the spectral regions VIS-NIR, UVA, UVB and UVC or in the RMS irradiance measurement depending on the UV action curve). The probes are equipped with SICRAM automatic recognition modules: in addition to automatic recognition, the measurement unit is also selected automatically. The manufacturer's calibration data are saved in these modules.

Refer to the course on "lighting, plugs and other" for more details on lighting.

5.5.5. Measurement of other non-electric values

All non-electric values such as humidity, pressure, liquid flow, filling levels or the surveillance of combustion phenomena (analysis of gas), electrochemical phenomena, radioactive radiation, etc., will required appropriate probes, also known as sensors.

The contract proposes sensors which can also measure values according to the bridge assembly principle (paragraph below), and by using measurement amplifiers. This is the field of instrumentation, please "switch" to this discipline if you require further information.

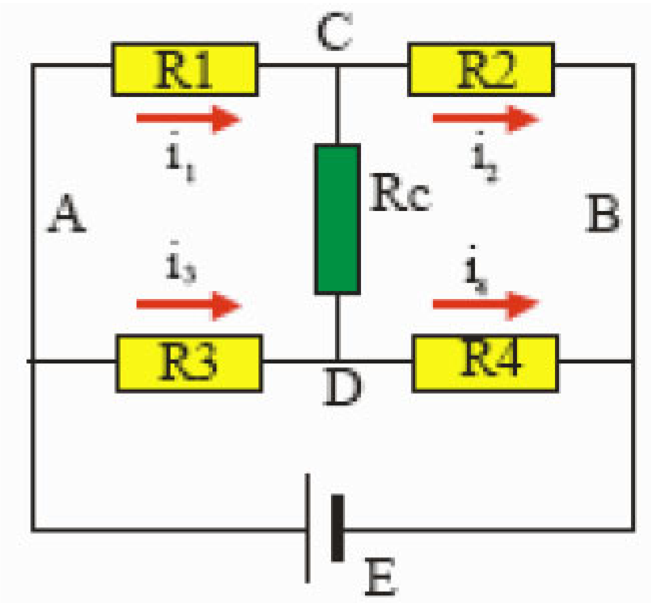
5.6. MEASUREMENTS USING BRIDGES

Otherwise known as measurement by comparison

Bridges were widely used to measure resistances, inductances and capacities (mainly Wheatstone and Sauty bridges), and even frequencies until 1975. Progress in electronics and digital equipment have rendered bridges somewhat obsolete for metrology purposes. However, bridge structures continue to be used in many assemblies (e.g. temperature measurement thermistor, Pt 100).

5.6.1. Wheatstone bridge

5.6.1.1. Balanced bridge



Four resistances (R_1 - R_4), are connected as shown. R_C is the resistance of a detector placed between C and D (bridge diagonal).

The bridge is supplied by an EMF generator E between A and B.

Figure 71: Balanced Wheatstone bridge

It is said that the bridge is balanced when the difference in potential between nodes C and D is zero; If this condition is satisfied, no current will circulate in section CD.

Currents i_1 and i_2 and currents i_3 and i_4 are equal.

$$\mathbf{E = (R_1 + R_2)\, i_1 = (R_3 + R_4)\, i_3}$$

Balanced: $\mathbf{V_{AC} = V_{AD} = R_1 \,.\, i_1 = R_3 \,.\, i_3}$

$$\frac{R_1 E}{R_1 + R_2} = \frac{R_3 E}{R_3 + R_4} \Rightarrow R_1 R_4 = R_2 R_3$$

A bridge is balanced when the crossed products of the resistances are equal

In practice, an unknown resistance is established as R_1. R_2 is a known adjustable resistance and R_3 and R_4 are fixed resistances with a known ratio ($K = R_3 / R_4$). The detector is a galvanometer or an electronic/digital comparator. When balanced, $R_1 = K \,.\, R_2$.

5.6.1.2. Unbalanced bridge

The simplest means of studying an unbalanced bridge is to identify the 'Thevenin' equivalent of the circuit between terminals C and D.

Remove R_C: V_{CB} = E. R_2 / (R_1 + R2) ; V_{DB} = E. R_4 / (R_3 + R_4).

The EMF of the Thevenin generator is therefore equal to:

$$E_T = V_{CD} = E\left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4}\right)$$

If the internal resistance of generator E is negligible, the resistance of the equivalent generator is equal to (R_1 // R_2) in series with (R_3 // R_4):

$$R_T = \frac{R_1 R_2}{R_1 + R_2} + \frac{R_3 R_4}{R_3 + R_4}$$

This bridge structure is used in many systems using resistive sensors. The sensor is placed on a section, and the three other sections are created with fixed resistances. The error signal is the unbalanced bridge voltage.

5.6.2. AC bridges

The DC generator is replaced by a low frequency generator and the resistances are replaced with impedances. The calculations applied for the Wheatstone bridge remain valid, except the resistances are replaced with complex impedances.

A bridge is balanced when the crossed products of the impedances are equal

Generally speaking, two dipoles are used as pure precision resistances. The third will be the unknown impedance and the fourth will consist of precision capacitors combined with precision resistances. Avoid working with inductances as their value varies with frequency.

Many combination possibilities exist and we will examine the most frequently used possibilities.

5.6.2.1. P/Q bridges

With "P/Q " bridges; Z_3 and Z_4 are pure resistances. $Z_1 = R_X + jX_X$ is the unknown impedance, $Z_2 = R + jX$ is a variable and unknown impedance.

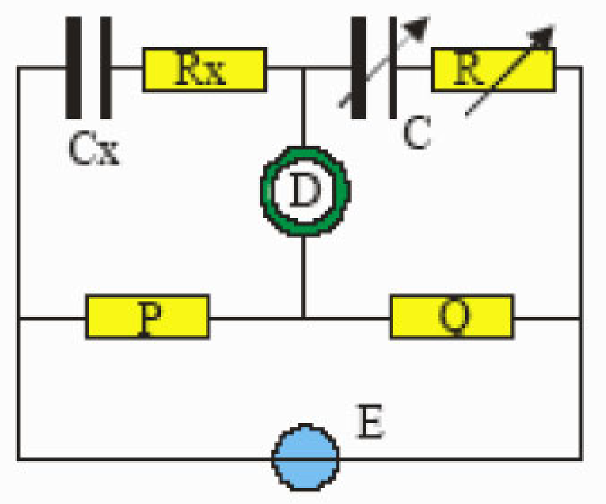


Figure 72: P/Q bridge

The equality of the real sections implies:

$P \,.\, R = Q \,.\, R_X$

That of the virtual sections implies:

$P \,.\, X = Q \,.\, X_X$

I.e.: $R_X = R \,.\, P / Q$ and $X_X = X \,.\, P / Q$

X_X and X have the same sign: they are impedances of the same type.

Sauty bridge

With good quality capacitors (serial resistance of capacitor R_X negligible), it is often useless to use a resistor R with the reference capacitor.

A balance is obtained by modifying the ratio P:A and therefore $C_X = C.\ Q / P$

Nernst bridge

With capacitors with significant leakage, a parallel P / Q bridge is used. Z_2 is a reference capacitor connected in parallel with a resistor R. The parallel model is used for the capacitor to be determined.

Same relations as for the Sauty bridge: $R_X = R \,.\, P / Q$ et $C_X = C \,.\, Q / P$

5.6.2.2. "P.Q" bridges

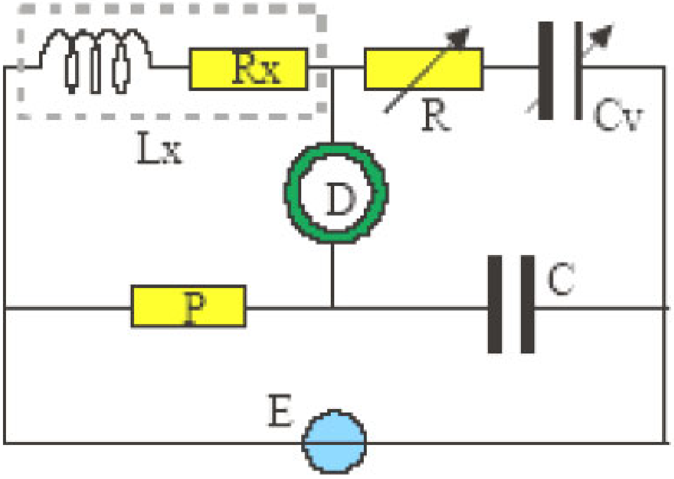
With "P . Q" bridges, $Z_3 = P$ and $Z_4 = Q$ are pure resistances.

$Z_1 = R_X + jX_X$ is the unknown impedance, $Z_2 = R + jX$ is a variable and unknown impedance.

So this gives: $P \,.\, Q = (R_X + jX_X)\,(R + jX) = R \,.\, R_X - X \,.\, X_X + j(R \,.\, X_X + R_X \,.\, X)$.

Therefore P . Q = R . R_X – X . X_X and R_X / R = - X_X / X: Z_1 and Z_3 are dipoles of different types.

Maxwell bridge



Z_1 is an unknown inductance with a mediocre quality factor Q = Lω.R: the series model is therefore used.

Z_3 is an adjustable capacitor in *parallel with an adjustable* resistor.

Figure 73: Maxell's bridge

When balanced, this gives: R_X = P.Q / R.

And L_X = P . Q / C

It is often difficult to balance these bridges and operators often use two stages.

Start by supplying the DC bridge. The capacitor has an infinite impedance and the inductance an impedance of zero.

When balanced, R_X = R as is the case for a traditional Wheatstone bridge.

Without modifying R, we supply the bridge with AC and modify C to balance the bridge.

Hay bridge

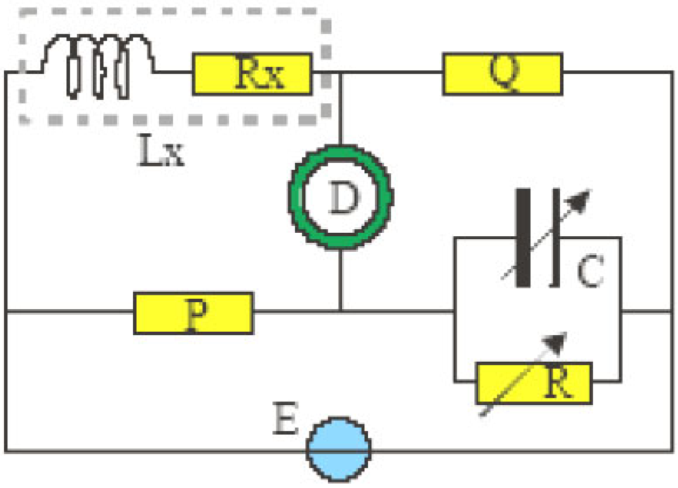
With this bridge, operators use a *parallel* model for inductance (inductances having a good quality factor). 3 is an adjustable capacitor in *series* with an adjustable resistor.

It is demonstrated that balance conditions are the same as for the Maxwell bridge.

According to the model used for inductance, the values of L are practically identical, however the values of the resistance are very different (low for the series model and very high for the parallel model).

5.6.2.3. "P.C" bridges (Owen bridges)

With "P.C" bridges, Z_3 = P is a pure resistance; Z_4 is an ideal capacitor.



Z_1 = R X + jωL_X (series model) or $Z_1 = (R_X$ // j$\omega L_X)$ (parallel model) is an unknown inductance, Z_2 is a variable impedance.

If we use the series model for inductance, Z_2 is a variable capacitor C_V in series with an adjustable resistor R.

Figure 74: "P.C" Owen bridges

If we use the parallel model for inductance, Z_2 is a variable capacitor C_V in parallel with an adjustable resistor R.

It is proved that, in both cases: **R_X + P . C / C_V et L_X = P . C . R**

In this case, the values of RX vary widely depending on the selected model.

5.6.2.4. "P/C" bridge (Schering bridges)

With "P/C" bridges, Z_3 = P is a pure resistor; Z_2 is an ideal capacitor.

$Z_1 = R_X + 1 / \omega C_X)$ (series model) or $Z_1 = (R_X$ // 1 / j$\omega C_X)$ (parallel model) is an unknown capacitor, Z_4 is a variable impedance.

If we use the series model for the capacitor, Z_4 is a variable capacitor C_V in parallel with an adjustable resistor R.

If we use the parallel model for the capacitor, Z_4 is a variable capacitor C_V in series with an adjustable resistor R.

It is proved that, in both cases:

$R_X = C_V$. P / C et C_X = R . P / C

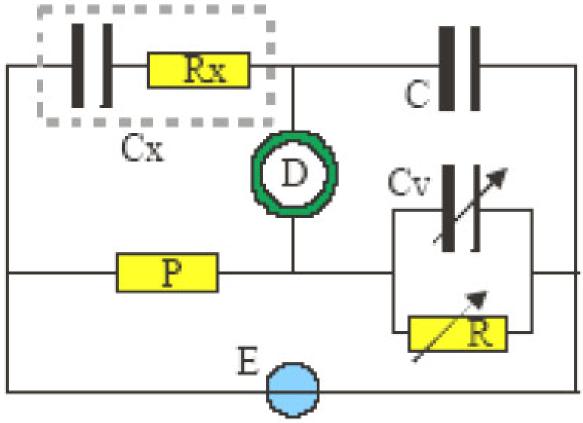
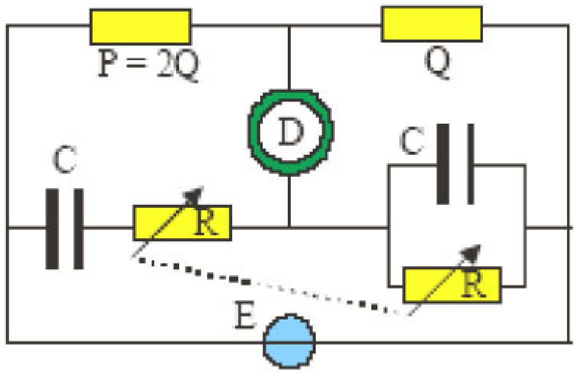


Figure 75: "P/C" Schering bridge

5.6.2.5. Robinson's bridge



Let us consider a Nernst bridge in which P = 2Q and C_X = C. The two resistances R are coupled and have a single joint control.

Figure 76: Robinson's bridge

When balanced, this gives: $\boldsymbol{\omega = 1 / R \cdot C}$

The device may be graduated directly in frequencies.

6. ELECTRICITY MEASURING DEVICES

6.1. USE OF MEASURING DEVICES

6.1.1. Electric measurements for machines and installations

The role of measuring devices is to provide information for operators, e.g.:

- the traction effort of certain engines.
- available electric voltage and the current or power consumed.
- temperature and pressure for certain items of equipment.

Electric measuring devices designed for this type of use operate according to the same principles as laboratory devices. They generally cost less, are less accurate, and are designed for integration in control panels.

Figure 77: Panel indicators, analogue devices and numerical displays

6.1.2. Maintenance and commissioning measurements

When commissioning or installing a machine, and during maintenance operations, we must obtain information which is of no use in normal operations. These measurements are obtained using ***portable devices.*** These devices must be connected to the systems concerned by the technician and removed at the end of the operation.

The devices used in this context are generally the same as those used in laboratories. They are designed to be moved and transported. Generally speaking, a few devices are adequate for all measurements used by technicians:

- An **electronic multimeter** is an essential component in a technician's kit. It enables the verification of the availability of electric supply and the integrity of cabling, and the direct measurement of the output of the different sensors equipping the machine or installation.

- The **oscilloscope** enables the representation of one or more voltages over time. It is used to analyse the behaviour of certain systems, either to adjust them or repair them.

6.1.3. Laboratory measurements

The electric measuring devices used in laboratories are often designed to be moved and transported. More specialist and more sophisticated devices, intended for the measurement of various physical values, are general fixed.

They are available for all types of measurements and a wide range of precision categories. An exhaustive list is not required for this course.

6.2. MULTIMETER

We now consider that the multimeter is a digital device, however analogue devices still exist, and in certain cases, they are better!

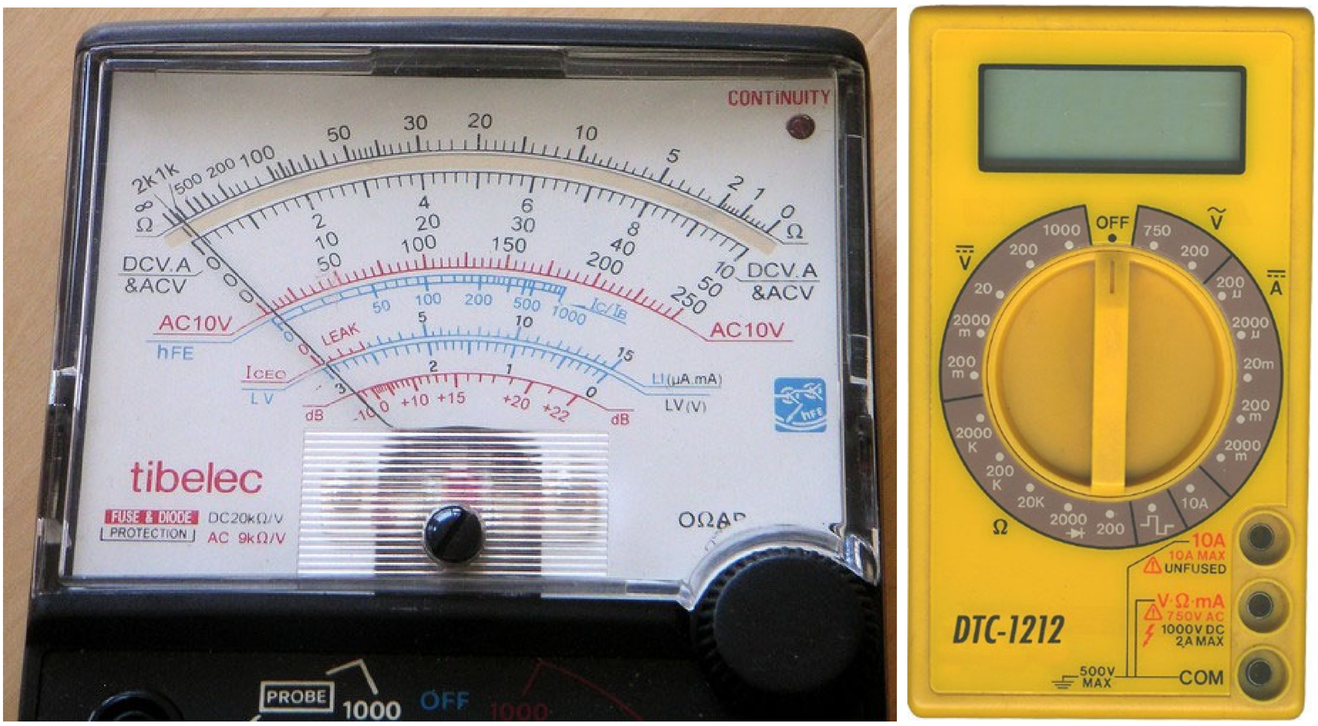


Figure 78: Analogue and digital multimeters (electronic and basic)

The analogue multimeter shown is a galvanometer. It requires a supply, but enables a range of measurements thanks to its management electronics.

6.2.1. General information on multimeter

6.2.1.1. Analogue and digital devices

Besides the range of multimeters, portable voltage testers exist, enabling the rapid identification of pre-calibrated levels with a LED display of the voltages present in the circuit, and the phase or polarity (see chapter on *'safe measurements' below*). Portable voltage testers are often used by electricians.

Multimeters with needles are still highly appreciated as they enable a better evaluation of fluctuating voltages. The use of devices with the highest possible internal resistance is recommended (e.g.: 20,000 ohms/volt), to avoid inducing additional current in the circuit measured (when measuring an electronic circuit).

A good needle multimeter has a small mirror which avoids parallax error and improves the precision of reading. Certain manufacturers still currently have analogue multimeters in their catalogue.

6.2.1.2. Measuring with a digital multimeter

Most electric measurements are currently carried out with an **electronic/digital multimeter**.

Even bottom of the range devices enable the measurement of electric voltage, currents and resistances. Their range may be automatically adjusted depending on the value measured.

Most electronic multimeters are able to measure both AC and DC voltages. Just select the appropriate measuring mode:

- When set to **DC mode**, the device permanently calculates and indicates the mean value of the voltage applied. With DC voltage, the voltage will be displayed.

  Possible sources of error:

  - If voltage varies slowly over time and, follows a sinusoidal curve with a frequency of less than 1Hz, for example, the value displayed will follow the instantaneous voltage approximately.

  - If the voltage is AC and follows a sinusoidal curve with a frequency of 50Hz, and as the mean value of a sinus is zero, the device will indicate zero voltage. This error could be extremely dangerous!

- When set to **AC mode**, the device permanently calculates and indicates the RMS value of the voltage applied using an approximate method which is only valid if the voltage applied is actually sinusoidal.

  Possible sources of error:

  - If the voltage is, e.g. the superposition of two sinusoid curves with different frequencies, or the superposition of a DC voltage and an AC voltage, the value displayed will be incorrect.

  - Some devices are able to calculate the true RMS value (*true mrs*).They use a more sophisticated algorithm which remains correct in the presence of any voltage.

This type of device is basically a **voltmeter**. It measures the electric voltage applied between the two terminals using an **input amplifier**. To avoid influencing the system measured, it must ideally behave as an open circuit, i.e. an infinite value resistor.

In reality, it behaves as a very high resistor known as an **input resistor**.

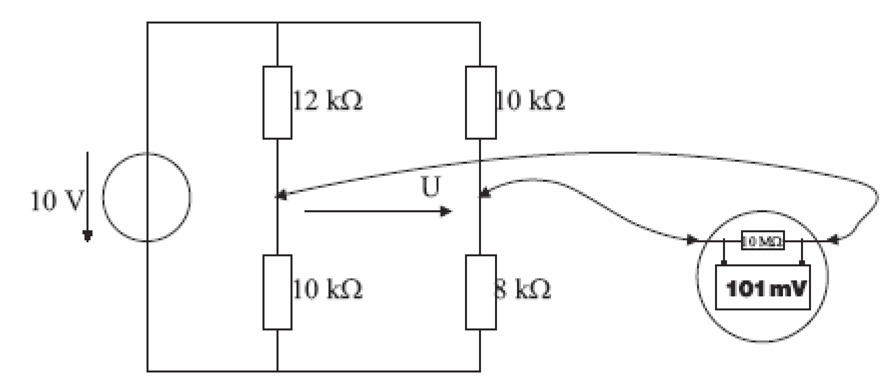


Figure 79: Connection to measure voltage

Operators must be aware that **all measurements influence the system observed to some extent**.

EXAMPLE:

Let us consider a device with an input resistor of 10MΩ. For a voltage measured at approximately 1V, the current deviated in the device will be 0.1µA. If currents of approximately 0.1mA circulate in the circuit measured, the measurement error caused will be 1% as a maximum and is therefore acceptable. However, if the circuit observed operates at lower voltages or lower currents circulate, you will need another measuring device with a higher input resistor.

The input amplifier for electronic multimeters is not generally strictly linear. In particular, if input points are not connected, or if they are short circuited, and if the voltage measured is therefore zero, the multimeter can indicate a value not equal to zero (a few millivolts).

This error is known as **offset voltage**. This imprecision thankfully only varies slightly over time, and can be offset in the same way as a tare weight on scales.

6.2.2. Instructions for the use of a multimeter

6.2.2.1. "Approximate" instructions

Set the device (analogue or digital) to its ***highest range***: we know (more or less) what we aim to measure, be it in amps or volts.

Think, check more than once, if measuring voltage, do not select a range in 'amps' or 'ohms'; do not just connect up rapidly (quick repair needed…) and then – oops! -, too late…

Digital devices are now all equipped with safety systems, however, do not count on the latter, any electrician needing to (often) replace the fuse in a device, is a '*bad electrician'*. And electricians making their devices smoke, are *very* bad…

Refer to the paragraph on "safe measurements" later in this course.

6.2.2.2. "Detailed" instructions

The following are a few safety instructions to be read before using your multimeter (analogue and/or digital):

1. Check that your measuring leads (cables connecting the contact points to your multimeter) are in good condition (no exposed wire or damage). It is preferable to read the documentation supplied for your multimeter before using it.

2. Pay attention to not cause a short circuit with contact points when measuring.

3. Do not touch the metal section of contact points with your hands when taking measurements.

4. Check the connection of your measurement leads on your multimeter, if you have accidentally connected the banana plug in the location intended for the use of your multimeter as an ammeter and you intend to measure using the mains, you will create a short-circuit even if you have taken the precaution to adjust the multimeter to the AC measurement range 1,000 Volts. We recommend that you immobilise the terminal for the use of the multimeter as an ammeter using adhesive tape or a banana plug to avoid this type of incident. Depending on the multimeter model, the location of the terminals to select the type of measurement will vary.

5. Select the range above the value to be measured for voltages and currents. Should this value be unknown, start with the highest range and then switch to lower ranges to obtain maximum measurement precision.

6. For AC voltages, such as the mains or the output of a non-rectified transformer, use ranges with the ~ (AC) symbol.

7. To measure AC, if you reverse the measurement leads on the multimetre or the contact points (black and red), the value displayed will be strictly identical as this is a RMS value, and always positive by definition.

8. For DC voltages such as fuel cells, batteries or rectified mains adapters, use ranges with the = symbol.

9. The polarity of contact points is only important for DC voltages (fuel cells, batteries or rectified mains adapters), standards require that black is used for the negative terminal (the negative terminal is always designated by the letters COM) and that

red is used for the positive terminal. Should the colours be inverted, an electronic multimeter will indicate a negative voltage.

10. When measuring heating resistances, whose resistance is very low, the lowest range must be used, as higher ranges would indicate a value close to a short-circuit.

11. Most multimeters are protected by an internal fuse if the maximum intensity able to be measured is exceeded. If this fuse is replaced, it is essential to insert the fuse value and type recommended by the manufacturer.

6.2.3. Digital multimeters

This refers to the devices used by pretty much everyone on sites: electricians, instrument experts, heating specialists and hvac experts.

Explanation of the different functions (device shown on next page)

- **AC volts**: The low-pass filter is used to remove "electronic noise" (various inductions, for low-level measurements).

- **DC volts:** These are useful for electricians and instrument experts when checking logic signals; system input/output.

  Input: Open contact = presence of voltage = fault (in general).

  Output: Output to EV: 48VDC, output to relaying (e.g. electric service: (24VDC in general).

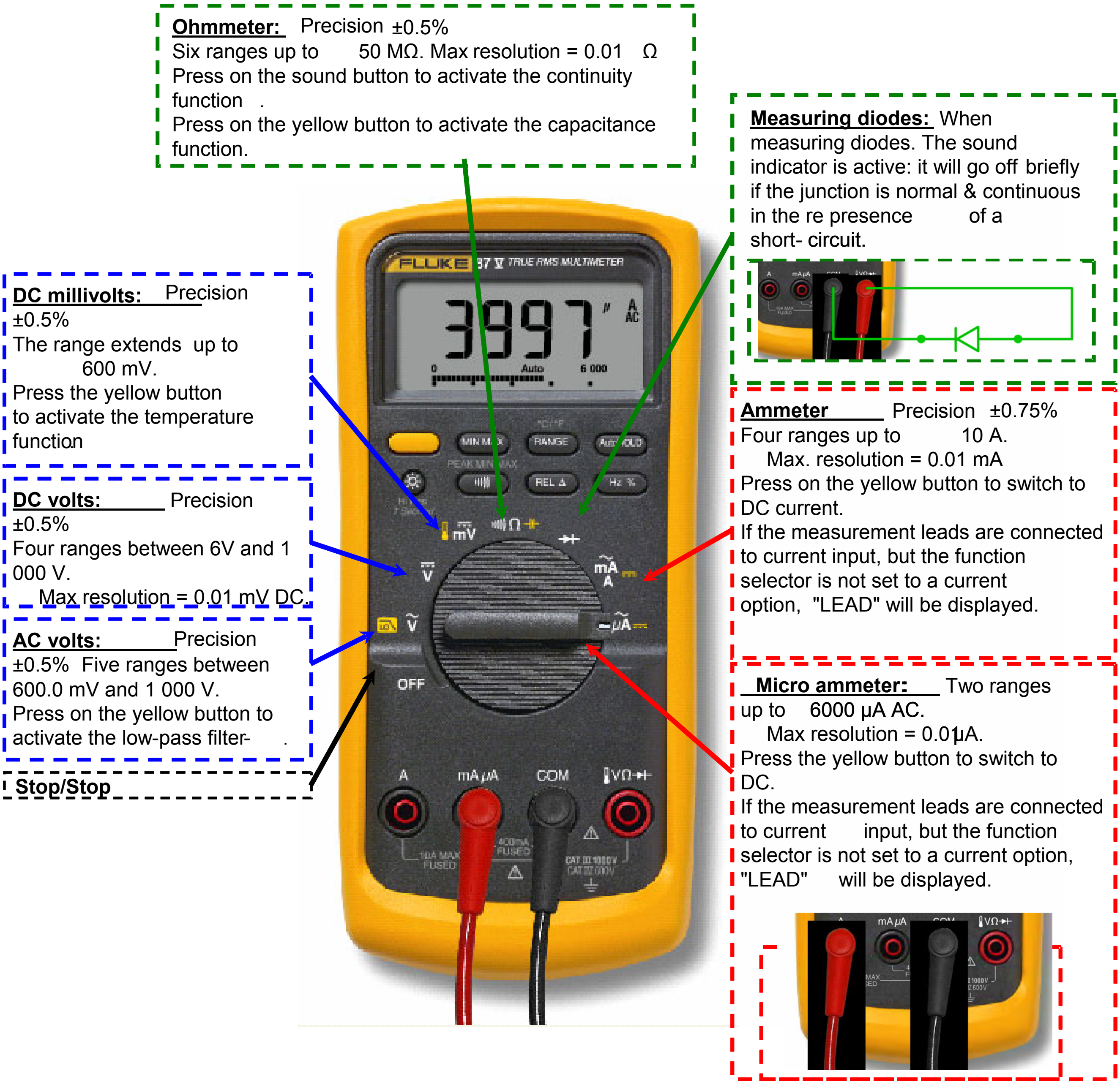


Figure 80: Details of a digital multimeter

- **<u>DC millivolts:</u>** Useful for thermocouples.

  <u>Reminder:</u> A thermocouple is a difference in potential which appears at the junction between two different metals; therefore, when contact is made with the contact point, a new CT is created.

- **<u>Ohmmeter:</u>** Be aware of parasite resistance. Do not connect in parallel…

- **<u>Measuring diodes</u>** <u>(or semi-conductors):</u> Operating principle of a diode; diode curve, e.g. a check valve.

For electricians, diodes are used for coils, to avoid overvoltages (Lenz effect).

Refer to the specific case of the zener diode;

You could also refer to the operating principle of a transistor; "TRANSFER RESISTOR"; the three terminals: emitter, base, collector, NPN and PNP.

- **Ammeter:** A quick word on the impedances of measuring devices. A voltmeter must have an infinite impedance, an ammeter must have an impedance of zero: let us review why this is.

  A deadly mistake: measure a voltage when in ammeter mode…

- **Min - Max button:** To give an example, when we intend to note the extreme values of a measurement (this is particularly true for flows) and regulator output and we do not have a SNCC, although we can access trends (this applies for instrument experts).

- **Range button:** This button is of no real use. It is simpler to stick to automatic.

- **AutoHold and REL buttons:** Refer to Min - Max, used to monitor changes in measurements.

- **Hz button:** Measuring frequencies; a quick word on sinusoidal signals; for electricians and instrument experts: with the signals of certain meters, for the control of certain valves (ROTORK, either the electrician or the instrument expert will handle these tasks depending on the site).

6.2.4. Immobilising digital multimeters

When measuring voltage with a multimeter, it is recommended to prevent connection to the current measuring terminal by immobilising it, to avoid any risk of short-circuiting or damaging the measuring device.

Figure 81: Immobilisation of a multimeter

The green arrow on the photo indicates the banana plug (female) to be immobilised on your multimeter, and which corresponds to the input point for measuring amperage. (Ammeter function only)

The photos below show immobilisation:

- Using a male banana plug (right).

- Using a screw cover or female RCA plug. (left).
- You may also use adhesive tape.

Figure 82: Methods of immobilising multimeters

6.2.5. Analogue multimeters

A digital multimeter is the easy solution, *the value of the measurement is displayed directly, ….,* however seeing an electrician 'stuck' with an analogue device, wondering how it works, should not happen.

Those "old machines"

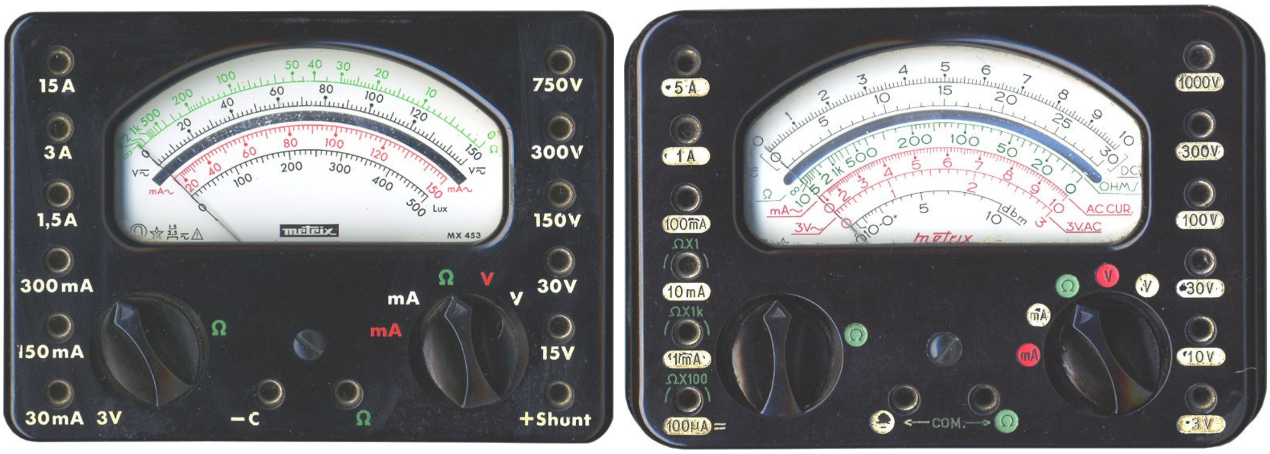


Figure 83: Metrix MX 453 and MX 462

"Old" French electricians, used to "have fun" with this type of device, Metrix 462s and 453s (or the Chauvin - Arnoux "Monoc"), and many of these electricians came across a needle caught to the right or completely bent, not to mention smoke coming out of the device, at least once…

I don't get it boss, my Metrix doesn't work too well …., can I change it…

Of course it doesn't work, you used the wrong range, or you switched to ammeter mode to measure voltage. Here's a new machine, but next time, it'll be docked from your wages!

And suddenly, a miracle occurs! Now that the analogue multimeter had become personal, and the operator held liable, the machine acquired a practically unlimited life cycle, and electricians ceased making errors when taking measurements! However, if, by bad luck, an electrician regularly "burns up" his device, it would be preferable to consider a "reclassification" as warehouse or gardening staff, for example…..

Early digital devices suffered the same sort, however, nowadays the (new) digital devices have integrated safety systems and electricians have an unfailing trust in these systems, making if difficult to detect an undisciplined electrician.

6.3. OHMMETERS - MEGOHMMETERS

We have seen how to measure a high resistance or an insulation measurement, let us consider the devices themselves.
On a site, while U and I can be measured using the multimeter, resistances must be measured using a "true" ohmmeter, and insulation measurements with a "true" megohmmeter.

While this course includes a paragraph dedicated to this type of device, on our sites, adequate insulation measurement devices are rarely available. Controllers (too frequently) detect problems in annual inspections of installations (by an independent body), thanks to the devices of the independent body…. However, if you have "done the necessary", great stuff, just remember to acquire or request advanced equipment for the others.

The following are a few examples of devices

Megger = manufacturer's name

Figure 84: Megohmmeter (5 KV and 15 KV) - megger

For testing cabling and MV distribution

Variable DC test voltage - Solid design - Protection using circuit breakers

5 and 10kV megohmmeters are high voltage instruments operating on the mains supply. They generate a variable DC test voltage for very high insulation measurements on all types of electric equipment and energy cables. These instruments are designed to operate in difficult environments and are fitted in solid cases, with a removable cover and adjustable carrying handles. A storage compartment is available for test leads and the user manual, to ensure complete portability.

Other devices may generate higher voltages. The maximum voltage on site is 30kV

PRO 2,000 M.ohms 250 / 500 / 1,000V. (Voltages generated)

Figure 85: DT 5500 Numerical megohmmeter

For LV installations, cables, cabinets, receivers (motors)

Insulation test: - 200 M.ohms for 250V 3% - 200 M.ohms for 500V 3% - 2,000 M.ohms for 1,000V 3% - Voltmeter 750V AC - Voltmeter 1,000V DC - Ohmmeter up to 200 K.ohms - Audio continuity test – Integrated back lighting. Fitted protective duct. Test button with possible locking. Supply: one 9V 6F22 DT5500 fuel cell.

Digital megohmmeter PRO 1,000V with back lighting, Volt. function, ohmmeter.

Figure 86: RL 2200 megohmmeter - ohmmeter

*For LV and **VLV***

Measuring insulation resistance:
From 0.01 to 1,000MΩ for 50V.
From 0.1 to 10,000MΩ for 500V.*
Measurement to lead resistance (0-10kΩ). *
Measurement of DC voltage (- 100V to 500V) and AC voltage (RMS 0 to 400V).
Double analogue + numerical display.

Figure 87: ACA 9500 ground current meter - Helita - (ABB)

For ground and ground loop measurements

The ACA 9500 ground current meter is an autonomous and portable device which enables the automatic measurement of parameters R (resistance), Z (impedance) and X (reactance) for a ground for a frequency interval of 10Hz-1MHz. This device allows for measurements exceeding current ground measurements, while respecting the notion of ground frequency response with regards a discharge pulse current. The energy spectrum of a lightning wave can reach into the MHz range, therefore it is essential to be aware of the capacity.

4 devices have been presented, these are ***4 different, but complementary devices.*** Remember to equip your site with at least 4 devices of this type of any brand, but select quality equipment! Do not be influenced by hierarchy (*are you sure you need this equipment*…?) or by the purchasing service (*we have found a far cheaper model*…).

Ground default detection devices also exist (see the course on "ground and neutral"……

6.4. SELECTION OF A MEASURING DEVICE

6.4.1. Testing systems for measuring instruments

In principle, all measuring devices have been tested.

It is essential to satisfy the service directives for the instrument prior to use.

Each device has a **test voltage** indication.

This voltage is noted using a ***5-point star*** indicating the voltage U in kV.

	An **empty star** indicates a test voltage of 500V.
	A **star with a figure in the middle** indicates a test voltage of the figure shown. This device (the example) has been tested with a voltage of 1kV between the terminals, without the terminal "exploding" or breaking mechanically. Remarks: This does not mean that your device can measure the value of the test voltage.
	Certain devices also have a triangle with an exclamation point. This indication may imply that the device requires specific precautions or specific use (special terminals or maximum voltage/current). This indication may also imply that the measuring device has electric components inside which do not accept electrostatic loads. These loads may be present when disassembling the measuring device.

6.4.2. Selection criteria

The following are a few questions we could ask to determine a measuring device.

Sort through these questions depending on your requirements:

- The device does not trigger the DDR when measuring (can avoid a few mishaps).
- Range and precision (currents can reach thousands of amps, not all devices can obtain such high measurements even with a hook-on ammeter).

- One single device able to carry out all measurements (often heavier and, if repairs are required, no measurements are possible. often more complex to use).
- One device per measurement (heavy going if you need to carry them all at once).
- Possibility to record results (eliminates the need for a pen, paper and writing while taking measurements).
- Possibility to print results (while measuring records do not replace the unified completion notices, they can be useful). The device can run various calculations/compilations automatically (no manual work).
- Resistance to mechanical forces.
- Dimensions, position for use and ease of measurement
- Prices – only compare the comparable.

6.4.3. Calibration

You will systematically maintain site equipment, either in production, mechanical engineering, instrumentation, electricity or other.

For electric equipment, you have a systematic maintenance plan for all systems and equipment (for electrical components).

You will also regularly check tests, calibrations (or verification of calibrations) for trigger relays and fixed measuring devices (verification of thresholds).

All of your measuring devices require regular verification and recalibration.

Even devices at the backs of cupboards, which are rarely used, must be checked and calibrated. You will not appreciate finding the device offset the day you actually need it.

Remember to regularly send your measuring devices for recalibration *(by the manufacturer or a specialist workshop).*

With regards the measuring relays for LV and HV cabinets, refer to the courses on "Protection" and "Distribution tables"; You can re-calibrate these relays yourself. Technical data is available on-site (you can find it…). Sub-contracting the calibration of fixed measuring devices and protection to an independent body is common practice on our sites and I would describe this as the easy-way-out.

Test equipment is clearly necessary (*re-calibrated…).*

The following is an additional recommendations for measuring and calibration equipment on your site, and three phase voltage and current injection cases. These are indispensable for the calibration/testing of all relays equipping high and low voltage panels.

The equipment shown is "Euro-Test" brand, and the comments are extracted from the technical instructions.

	Current injection case	Voltage injection case
Photo		
Description	**Electric protection test (injection cases): 50A-3PH - three phase 50A intensity**	**Electric protection test (injection cases): DVS3 - three phase voltage**
Characteris-tics	Simple and straightforward interface - Three phase current outlet - 0-50A per phase - Numerical display of the RMS value - Ammeter with memory - Multi-functional chronometer - External signal measurement input - Large back-lit display - Heat and overload protection - Compact and portable - Three-phase 220V or 400V supply - Optional three-phase 115V-440V supply	- Three phase 0-130V ac injection, 40–1,000Hz - High precision and three phase output + stability - Single phase 240V supply - Individual or grouped control of voltage, phases and frequencies. - Adjustment using a turn knob or via direct keypad input - Graphic display of voltage parameters and the frequency with a vector diagram showing phase relations - Protection against short-circuits at output - Compact, light and tropicalised
Details	The 50A-3PH three phase injection case can inject currents ranging between a few mA to in excess of 50A and voltages of up to 18V. Operators may select 3 ranges enabling the selection of the full span value for true RMS values and trigger thresholds.	The DVS3 injection case produces a three phase voltage from a single phase source. It was designed using the latest digital technologies to obtain a variable output voltage controlled with an easy-to-use keypad and display
Applications	The 50A-3ph can be used to test single phase and three phase protection relays, including: - Overcurrent relays - IDMT relays - Re-triggers - Time delay relays - Homopolar relays - Miniature circuit breakers - Power relays - Trigger relays - Heat relays	Single or three phase voltage injection. The DVS3 is specially designed to test the following relays: - Single and three phase directional relays (voltage source) - Remote protection (voltage source) - Sensors and three phase measuring systems - Min. or max. frequency relays - Min. or max. voltage relays - Frequency variation detection relays - Synchronisation relays - Automatic voltage regulation relays

Table 10: Calibration material with injection of I and U

7. MEASURING POWER

This device is (already) a museum piece, but you may have used one in a laboratory during your training to become an electrician.

This is not the type of device you should use on a site anyway

Figure 88: Laboratory Chauvin-Arnoux wattmeter

We will not come back to measuring device technology in this chapter, but we will take a closer look at the "after" methods and calculations for obtaining the 'right' result.

7.1. DIRECT MEASUREMENT OF ACTIVE POWER

This chapter refers to the device measuring this power (P), the Wattmeter. We will now focus on methods and calculations rather than measuring device technology.

7.1.1. Measuring principles

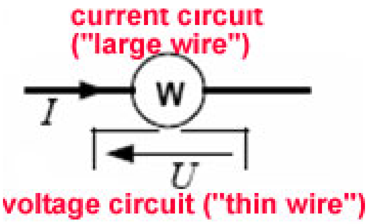


Figure 89: wattmeter connection principle

The wattmeter (single phase device) includes 4 connection terminals (+ the ground if applicable): 2 for the voltage circuit & 2 for the intensity circuit.

On flow charts, the intensity circuit is (in principle) the 'large wire', and the voltage circuit the 'narrow wire'.

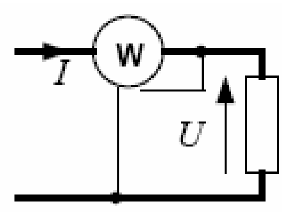


Figure 90: Circuit wattmeter connections

It is easy to connect an intensity circuit, simply make sure the polarity is right.

You have two possibilities for the connection of the voltage circuit;

- Downstream assembly, the voltage input is considered after the wattmeter.

- Upstream assembly, the voltage input is before the wattmeter.

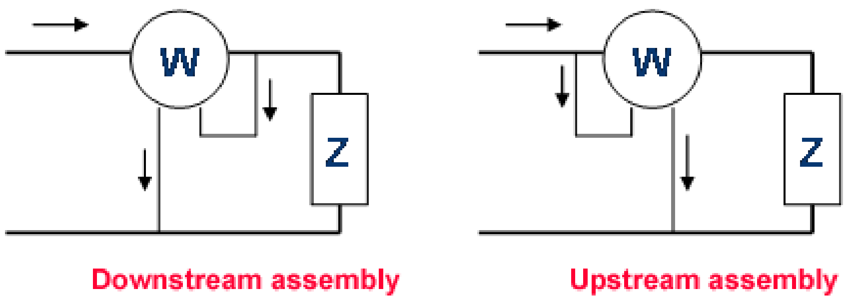


Figure 91: Upstream and downstream wattmeter connections

The 'Downstream' assembly is (in principle) more frequently used as it accounts for the voltage at the load terminals.

The Joule losses are (also) measured in the wattmeter in the 'Upstream' assembly.

The wattmeter (DC or AC) only measures the active power, i.e. the power dissipated by the 'R' component of the impedance.

$P_{WDC} = R \cdot I^2$ and $P_{WAC} = (Z \cdot \cos\varphi) \cdot I^2$ the wattmeter integrates the value of the power factor in its calculation.

Figure 92: Laboratory wattmeter

7.1.2. Power measurements in three phase regime

7.1.2.1. With a ground

Measurement to be carried out when the distribution network is unbalanced

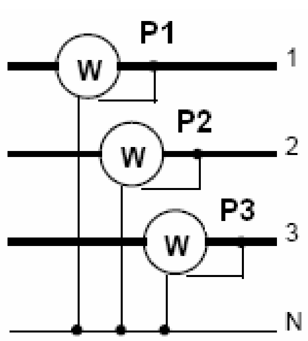


Figure 93: 3 three phase wattmeters with ground

The power absorbed by the network concerned is:

$$P = P_1 + P_2 + P_3$$

And if the distribution is balanced, this gives:

$$P = 3P_1 = 3P_2 = 3P_3$$

7.1.2.2. Without a ground

With the 2-wattmeter method, 2 measured currents, the voltage for each wattmeter being measured between "its" phase and the 3rd phase not measured for current.

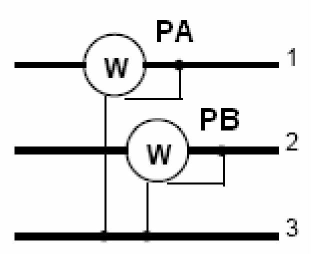


Figure 94: 2-wattmeter method, three phase, no ground

The 2 wattmeters can be connected to any of the phases, however, check you identify P_A and P_B correctly, corresponding to the phase order in the direction of rotation. (P_A is, in principle, higher on a "traditional" induction circuit).

The power absorbed by the network is **$P = P_A + P_B$ (in watts).**

The particularity of this assembly is that it also measures the reactive power where:

$$|Q| = \sqrt{3} \times |P_A - P_B|$$

The sign of Q will depend on the type of load ($Q > 0$ with induction loads, $Q < 0$ with capacitor loads).

Trigonometric verification

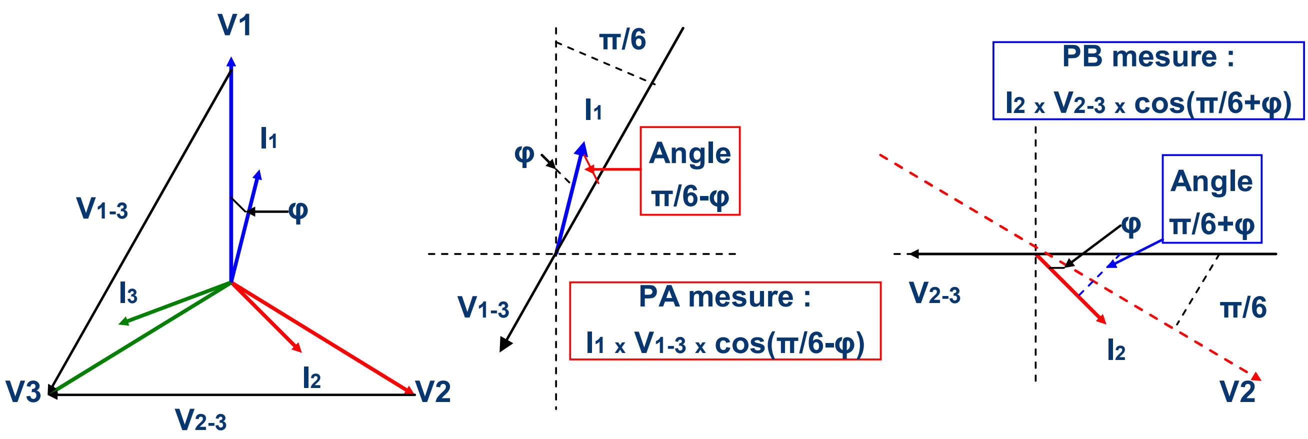


Figure 95: 2-wattmeter method - trigonometric checking

$$P = P_A + P_B = I_1 \times V_{1\text{-}3} \times \cos(\pi / 6 - \varphi) + I_2 \times V_{2\text{-}3} \times \cos(\pi / 6 + \varphi)$$

With a balanced three phase circuit: $I_1 = I_2 = I$ and $U = V_{1\text{-}3} = V_{2\text{-}3}$ therefore

$$P = P_A + P_B = I \times U\, [\cos(\pi / 6 - \varphi) + \cos(\pi / 6 + \varphi)]$$

$$Q = \sqrt{3}\,(P_A - P_B) = I \times U\, [\cos(\pi/6 - \varphi) - \cos(\pi/6 + \varphi)] \times \sqrt{3}$$

Let us check P by taking "φ" which is easy to calculate and change the 'π' into degrees "°":

For **φ = 0**, cosφ = 1 and **P** = U . I . $\sqrt{3}$ = $P_A + P_B$

= I x U [cos (30° - 0°) + cos (30° + 0°)]

= I x U ($\sqrt{3}$ / 2 + $\sqrt{3}$ / 2) = **U x I x** $\sqrt{3}$

For **φ = π / 6 = 30°**, cosφ = $\sqrt{3}$ / 2 and **P** = I x U [cos (30° - 30°) + cos (30° + 30°)

= I x U (cos 0° + cos 60°) = I x U (1 + 0.5))

= **1.5 x U x I**

Compared with P = U. I . $\sqrt{3}$. cosφ = U . I . $\sqrt{3}$ x $\sqrt{3}$ / 2 = 3 / 2 x I x U = **1.5 x U x I**

Let us check Q for the same values of φ

For **φ = 0**, cosφ = 1 and sinφ = 0 and Q = U x I x $\sqrt{3}$ x sinφ = 0

= $\sqrt{3}\,(P_A - P_B)$

= I x U [cos (π / 6 – φ) - cos (π / 6 + φ)] x $\sqrt{3}$

= I x U [cos (30° - 0°) -cos (30° + 0°)] x $\sqrt{3}$

= I x U ($\sqrt{3}$ / 2 - $\sqrt{3}$ / 2) = **U x I x (0)** $\sqrt{3}$ **= 0**

For **φ = π / 6 = 30°**, cos φ = $\sqrt{3}$ / 2 and sinφ = ½ = 0.5

Q = U x I x $\sqrt{3}$ x sin φ

Q = 0.5 (U x I x $\sqrt{3}$ **)**

Q = I x U [cos (π / 6 – φ) - cos (π / 6 + φ)] x $\sqrt{3}$

= I x U [cos (30° - 30°) - cos (30° + 30°)] x $\sqrt{3}$

= I x U [cos (0°) - cos (60°)] x $\sqrt{3}$

= I x U (1 – 0.5) x $\sqrt{3}$ = **0.5 (U x I x** $\sqrt{3}$ **)**

And with the 2 values (P_A and P_B) you can determine the apparent power and the power factor, because you now know P and Q.

$$S^2 = P^2 + Q^2 \Rightarrow S = \sqrt{P^2+Q^2} \text{ and } \cos\varphi = P / S$$

Or, without using S:

$$\mathrm{Tg}\,\varphi = Q / P \Rightarrow \mathbf{Tg}\,\varphi = \sqrt{3}\,\frac{PA-PB}{PA+PB}$$

And in case you did not know…..:

$$\mathbf{Cos^2}\varphi = \frac{1}{1+tg^2\varphi}$$

$$\mathbf{cos}\,\varphi = \sqrt{\frac{1}{1+tg^2\varphi}}$$

Trigonometry is such fun!

7.1.3. Measuring power with a hook-on multi-functional device

This chapter refers to measuring with a hook-on wattmeter

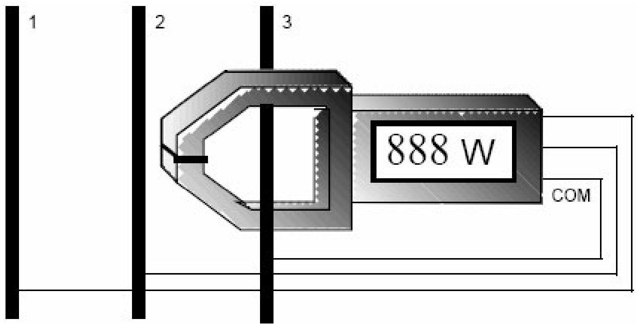


Figure 96: Use of a hook-on wattmeter

The voltage reference (COM input) is the phase to be used to measure the current:

These (numerical) hook-on devices have an integrated computer, and measuring one phase in a balanced three phase circuit is adequate to conclude the measurement. With a non-balanced circuit, refer to the instructions, the handling and outcome processing procedures vary between manufacturers.

A hook-on wattmeter (multi-function) can measure multiple parameters, refer to the list below and make your choice!

'VOLTCRAFT' - VC 609 True RMS hook-on wattmeter

The VOLTCRAFT ergonomic hook-on multimeter has been specially designed to measure electric power: peak factor and phase lag (cos Phi), apparent power, active power and reactive power.

Voltage and intensity can clearly be measured separately.

Figure 97: 'VOLTCRAFT' - VC 609 True RMS hook-on wattmeter

- *Measurement of up to 750 kW/kVA/kVAR 1.5% + 2 digits (frequency of 45-450Hz).*
- *Phase lag (cos Phi) of 0.3-1, resolution 0.001, precision 2% + 20 digits.*
- *Peak factor of 1 - 5, precision of the fundamental parameter 0.5%.*
- *AC voltage up to 750V, precision 1% + 3 digits.*
- *AC up to 700A, precision 1.5% +2 digits. Dim: 92 x 246 x 45mm.*
- *Fuel cell weight included: appr. 500g.*

Hook-on wattmeter, AC RMS TES 3079K

- *Brand: TES*
- *Measurement of range powers 60 / 600kW and kVA for single phase AC networks*
- *Measurement of TRMS currents and voltages*
- *Measurement of cosinus Phi and the frequency*
- *Measurement of resistance, capacity and temperature for torque K (-50/+900°C) Insulation test up to 100M Ohms*
- *Min / Max / Hold functions and AUTO stop*
- *IEC 1010 cat III 600V conformity*

Figure 98: Hook-on wattmeter, AC RMS TES 3079K

AC/DC PROVA 400 hook-on wattmeter

- *Brand: PROVA*
- *Large LCD screen, 3 3/4 digits +40-segment 'bargraph'*
- *Conductor diameter: 23mm*
- *Easy selection of functions using a turn knob*
- *Ranges and precision:*
    - *Power AC+DC 240K: 40KW/240KW Precision: ±2.5% ±3digits*
    - *DC: 400A Precision: ±1.5% ±3digits*
    - *TRMS AC: 400A Precision: ±1.5% ±3digits*
    - *DC voltage: 400A Precision: ±1.0% ±2digits*

- *AC voltage: 600A Precision: ±1.0% ±2digits*
- *Frequency: 100 to 1,000KHz Precision: ±0.8% ±2digits*

- *Supply from two 1.5V fuel cells*
- *Dimensions: 183x61.3x35.6mm*
- *Weight: 190g*

Figure 99: AC/DC PROVA 400 hook-on wattmeter

F27 Chauvin Arnoux (Metrix) hook-on wattmeter

- Reference: F27
- Diameter: 500mm
- Measurements: TRMS AC+DC
- VDC: 60 / 600 / 1,500V -
- VAC: 60 / 600 / 1,500V
- IDC / AC: 60 / 600 / 1,500V
- Active, reactive, apparent powers: 10W-600kW
- Frequency: 0.5 to 20kHz

Figure 100: F27 Chauvin Arnoux (Metrix) hook-on wattmeter

MX 240 METRIX (Chauvin Arnoux) hook-on wattmeter

- Reference: MX240
- Diameter: 40mm
- Measurements: TRMS AC+DC
- VDC: 600: 1,000V
- VAC: 400 / 750V
- IDC / AC: 20–200A
- Resistances: 200–2,000 ohms
- Active, reactive, apparent powers: 2 K / 20 K / 200 K
- Active energy: 20 / 200 / 2,000K
- Frequency: 20 / 200 / 2 kHz
- Particularities:
  - Measurement of cos
  - Optional mains supply
  - Retransmission of the values measured.
- RS232 output/ Analogue output for oscilloscopes and recorders

Figure 101: MX 240 METRIX (Chauvin Arnoux) hook-on wattmeter

The measurement of power as a routine verification is useful on a site, if you intend to measure the power on each phase of a motor, to give just one example… Having a "hook-on wattmeter" such as this one can be of great use, and enable the rapid detection of a "problem"….

And it measures amps too! As you need a "hook-on ammeter", pass this device off as a hook-on ammeter….

7.1.4. Counting - energy meters

An energy meter measures the energy consumed by the network user (EDF in France or any supplier): $W = Pa.t$.

This energy is proportional to the active power consumed ($kUI\cos\varphi$) and is generally expressed in kWh.

Under all circumstances, EDF (or another supplier) invoices the active energy consumed and only the active energy consumed for "basic" users, who are connected in single phase (one phase + ground), but, pay attention!

If energy is supplied as three phase (three phases + ground) both active energy (watts) and reactive energy (VARs) is metered. The watt rate is constant (*irrespective of off-peak hours, peak hours, or any other "marketing" consideration)* if VAR rates are progressive. The more VARs you consume, the more watt rates climb! (In price per kVAR). This is to dissuade electricity providers from having a low power factor (cos φ).
In France, EDF invoices reactive energy (using a reactive energy meter) if the power factor cos φ is less than 0.928 (⇔ tg φ = 0.4).

Reactive energy *is of no use*! Users with over-inductive installations are requested to offset their power factor with capacitor banks (refer to the course on "electric networks" and "electric panels".

On-site meters are now flowmeters which are integrated into the general surveillance and control system (control room). "Independent" flowmeters are fitted to sub-stations. These are "boxes" which are connected like wattmeters and varmeters and which meter kWh and kVARh; These boxes generally have a connection (RS232 or other) for transmission to the centralised system.

Figure 102 Local energy meters

7.2. INDIRECT MEASUREMENT OF POWER

This chapters refers to the calculation of W, VAR or VA rather than using devices which display the values directly.

7.2.1. Basic principles

This has all been mentioned in other courses, however repeating can never do any harm. Electricians measuring power must understand "Pythagoras" and the related applications.

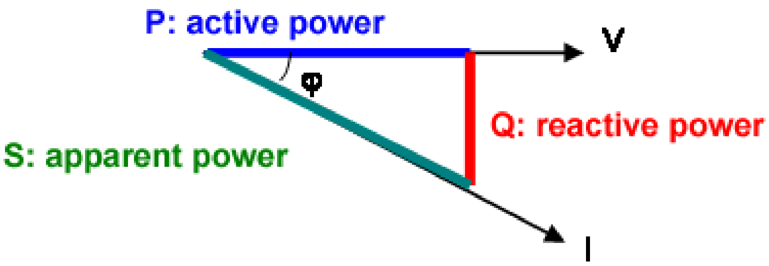


Figure 103: Powers and Pythagoras's triangle

Just like with R, L and C, we can identify a right handed triangle using Pythagoras theorems

P, active power is the power consumed by a resistance **R**

Q, reactive power is the power consumed by a reactance (**L + C)**

S, apparent power is the power consumed by the impedance **Z**

Cos φ = P / S

7.2.2. Measurement of single phase power using U and I

S: Apparent power

Apparent power is the product ***P = U x I*** of the RMS values measured by a voltmeter and an ammeter.

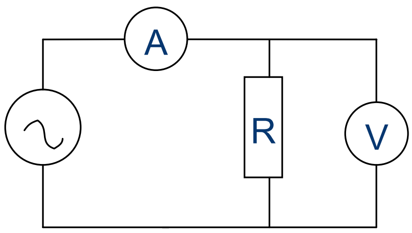


Figure 104: Apparent power

The unit is the **VOLT AMPERE: $\underline{S_{(VA)} = U_{(V)} \times I_{(A)}}$**

P: Active or True Power

Active power is the product *$S \times \cos\varphi$*; A 'phy-meter' or phasemeter must therefore be integrated in the measuring circuit.

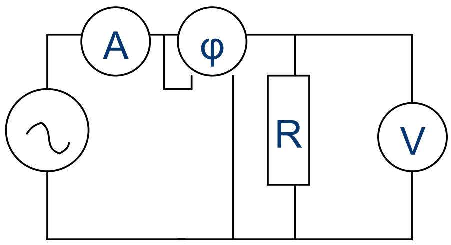


Figure 105: Active power

Figure 106: Phymeter

The unit is the **WATT:** **$P_{(W)} = U_{(V)} \times I_{(A)} \times \cos\varphi$**

Q: Reactive Power

Reactive power is the product *$S \times \sin\varphi$*; A 'phy-meter' or phasemeter must therefore be integrated in the measuring circuit.

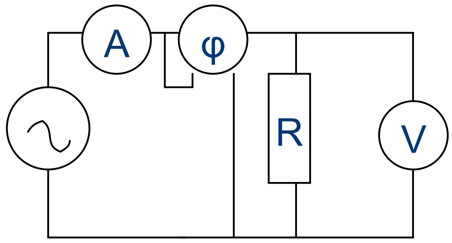


Figure 107: Reactive power

The unit is the **VAR (Volt Ampere Reactive)**: **$Q_{(VAR)} = U_{(V)} \times I_{(A)} \times \sin\varphi$**

Units generally have 'k' or 'M' prefixes giving kVA, kW, kVAR, MW, etc.…

7.2.3. Balanced three phase distribution

With $I = I_1 = I_2 = I_3$ and 'U' voltage between identical phases between the 3 phases

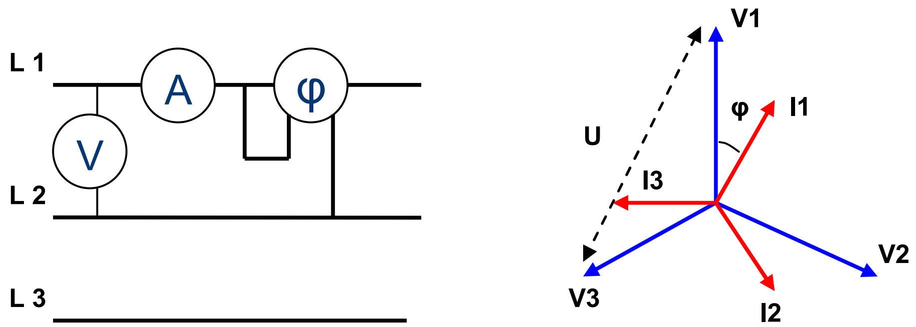


Figure 108: Measurement of power with a balanced three phase distribution

P in Watts = U x I x √3 x cos φ (U: voltage between phases)

Q in VAR = U x I x √3 x sin φ (U: voltage between phases)

S in VA = U x I x √3 (U: voltage between phases)

7.2.4. Measurement of power with an unbalanced three phase distribution

With an unbalanced three phase circuit:

$P = V_1 \cdot I_1 \cos \varphi + V_2 \cdot I_2 \cos \varphi + V_3 \cdot I_3 \cos \varphi$, sum of the measurements for each phase, where V is the voltage between the phase and ground.

And:

$Q = V_1 \cdot I_1 \sin \varphi + V_2 \cdot I_2 \sin \varphi + V_3 \cdot I_3 \sin \varphi$

$S = V_1 \cdot I_1 + V_2 \cdot I_2 + V_3 \cdot I_3$

A device measuring the "phase lag" between U and I is clearly required, i.e. a 'Phymeter' requiring current and voltage input.

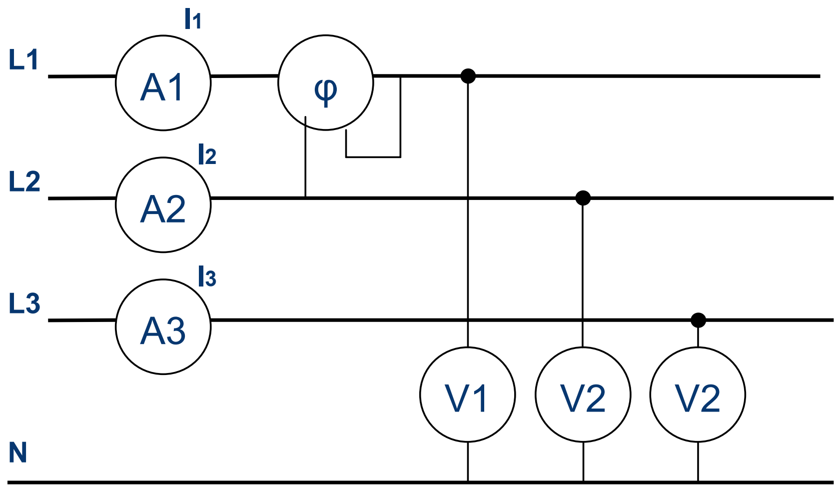


Figure 109: Measurement of power with an unbalanced three phase distribution

This assembly is used for e.g. main generators, currents from the CT and PT voltages.

W, VAR and VA are also calculated in the Schneider "SEPAM" type general protection relay (or equivalent). *See the "Electric protection" course.*

With regards powers metered in kWh, kVAh, or kVARh, the mean power consumed in 1h will be calculated per type of power.

7.3. APPLICATION OF 'W' AND 'VAR' MEASUREMENTS

The MW and MVAR indication is on the same device, with the same span as on the control panels of the (old) Solar Turbo generators. (TEG - Turbo Electric Generator).

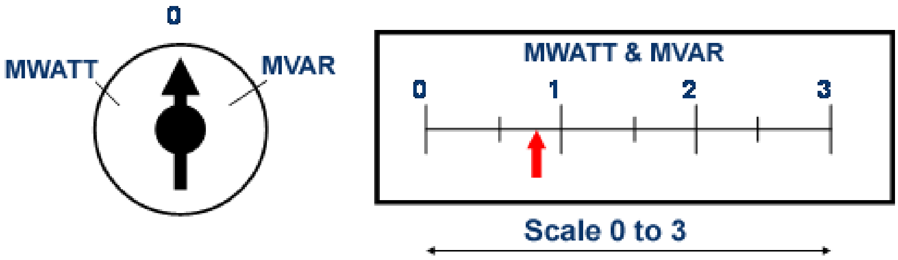


Figure 110: Solar TEG power switch and indicator

A 3-position switch determines the units shown on the single indicator (MW or MVAR). Let us consider the measuring method and "trick" used.

Characteristic of the 2.5-3MW turbine with 5.5kV (between phases) i.e. a maximum current of approximately 300A (possible with an overload).

Taking measurements: currents are measured via 400/5 CTs (ratio 80) and voltages via PTs, ratio $30\sqrt{3}$ i.e. (5500 / $30\sqrt{3}$) # 106V in the secondary circuit with nominal voltage in the primary circuit.

Reminders of typical PT and CT connections

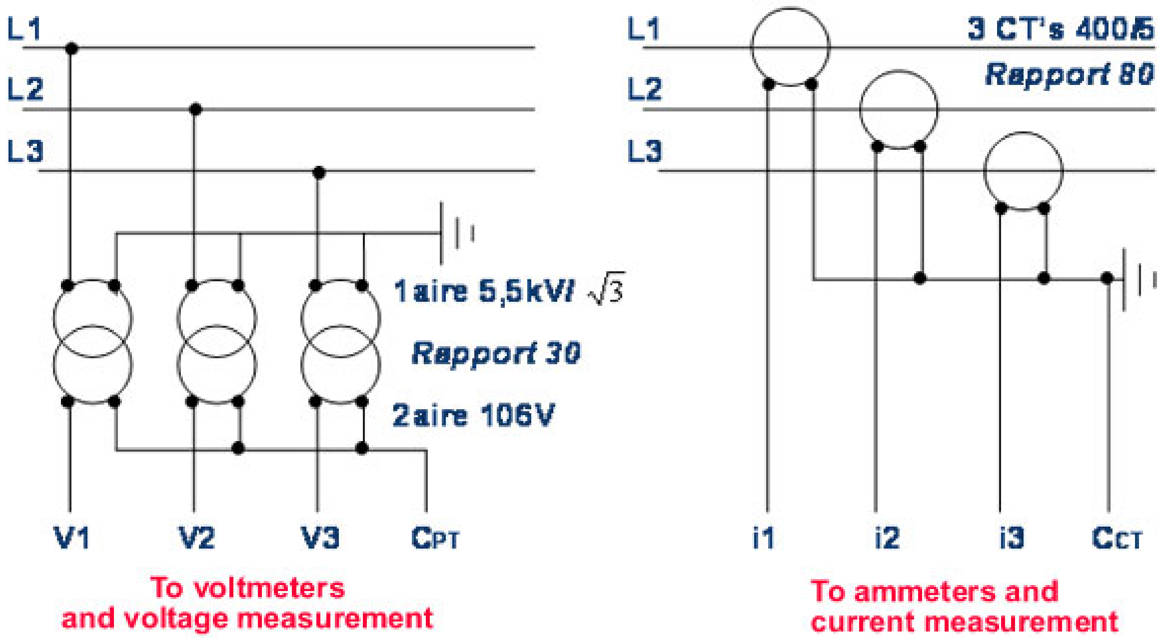


Figure 111: Typical PT and CT connections by creating a ground

Measuring device flow chart:

The assembly includes:

- The image of the 3 phase currents from the 3 CTs.
- The image of the 2 phase-ground voltages V1 and V3 from the PTs.
- A phase lag transformer (90° forward or back, gives the same result).
- A 3-position switch: '0' – 'MW' – 'MVAR'.
- A transmitter / transducer receiving the 3 currents and 2 voltages and transferring the component to the indicator.
- A panel indicator.

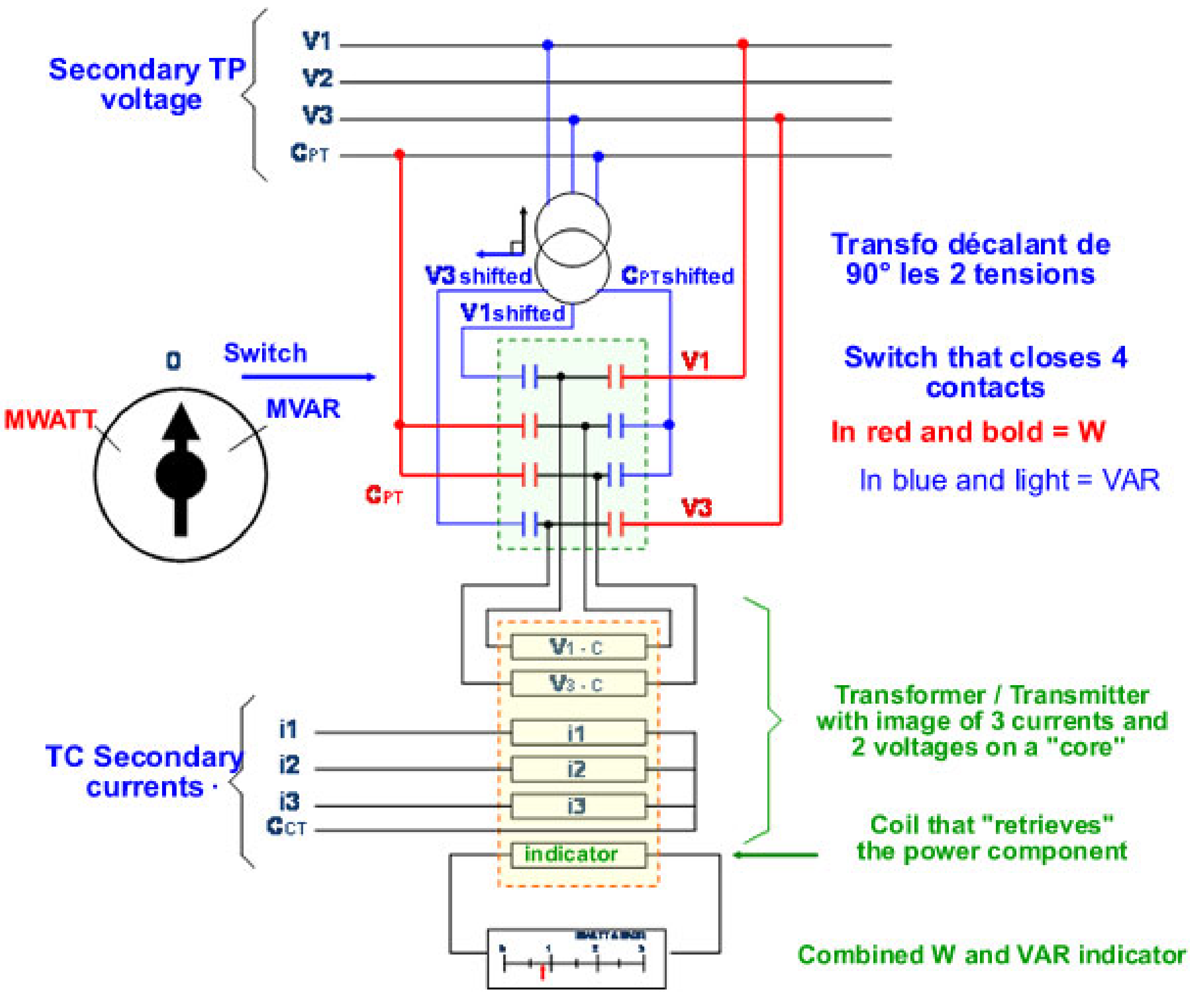


Figure 112: Simultaneous measuring principles for W and VAR on Solar turbines

Vector components for the 2 measurements:

The transmitter / transducer receiving the 3 currents and 2 voltages, combines all of this input, obtains a power with the product of U and I, applies a coefficient determined in calibration (factory and on site) and (above all, this is what we are interested in as a demonstration) integrates the phase lag between U and I to obtain the sinus in one direction and the cosinus in the other direction.

The phase lag angle is measured by "modifying" the image of the voltage in the transducer only. Let us consider the "direct" measurement and the "offset" measurement using vector 'i1' as a reference in both cases.

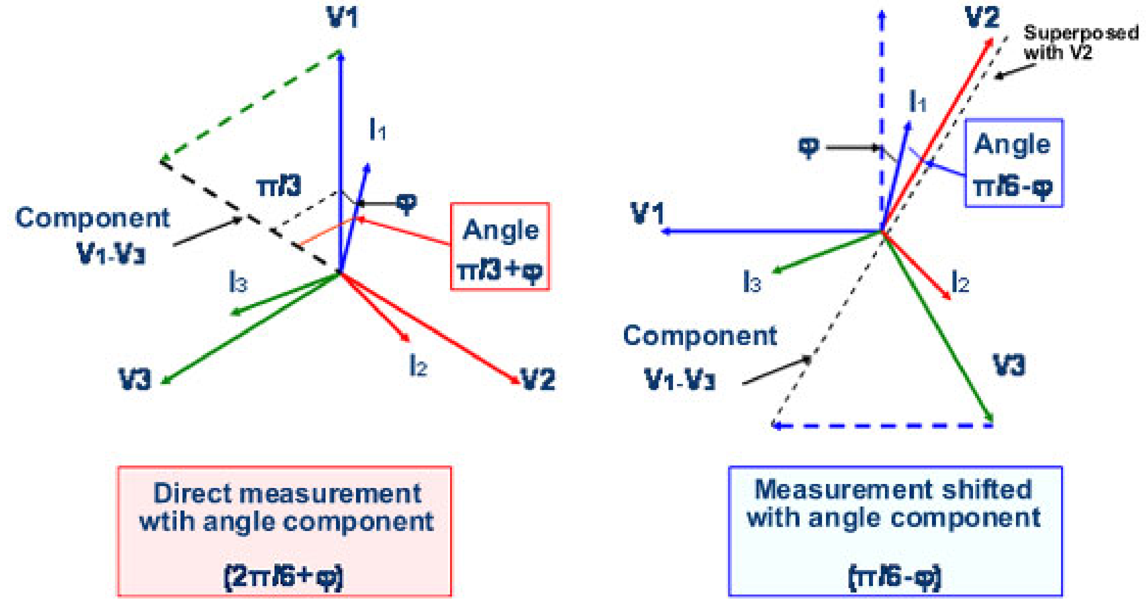


Figure 113: Vector components for the 2 measurements

A coefficient will be applied to the product of U and I calculated by the transducer, according to:

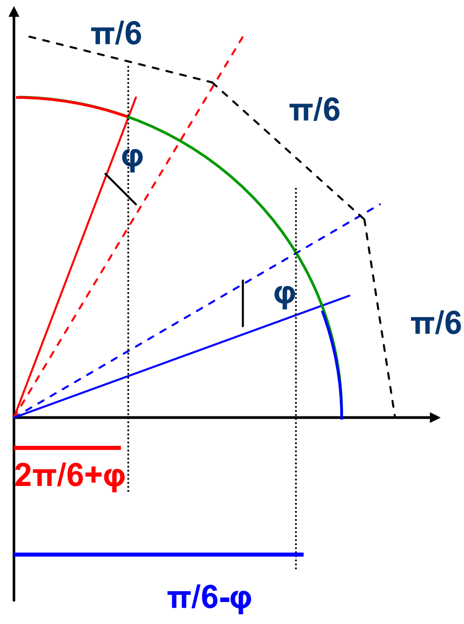
Angle (2π/6 + φ) as a direct measurement

Angle (π/6 - φ) as an offset measurement

However cos (2π/6 +φ) = sin (π/6 – φ)

or sin (2π/6 + φ) = cos(π/6 – φ)

As with the 2 switch positions, I (measure the same element (for U & I), the cosinus is used for one side and the sinus for the other, for the same angle. Measure P & Q.



You can carry out this "analysis" with the reverse offset, the result is identical

You will need a single phase wattmeter (to compare) generating 120V and 3.475 amps to calibrate the transducer (this is an electrician's job, and not that of an instrument expert). (417W) for the 2 voltage windings in parallel and the 3 current windings in series.

With the transformation ratios: P = 417 x (30 x $\sqrt{3}$) x (80 x $\sqrt{3}$) = 3 MW, cos phi is equal to 1. *The transducer uses the mean voltage value for calculations. The max. value of V_1 and V_3 may be 'injected' for calibration.*

8. SAFE MEASUREMENTS

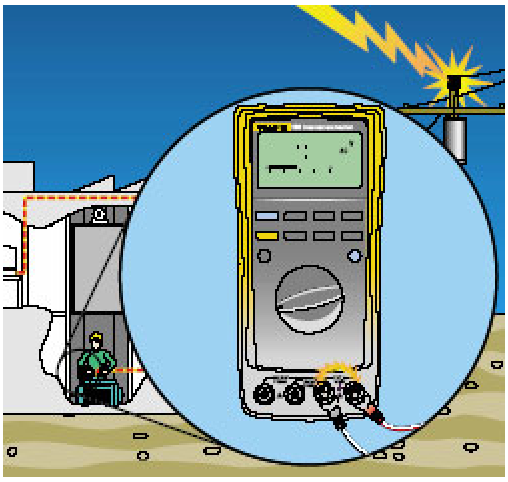
This chapter refers to 'Fluke' documents

I have always found the 'Fluke' equipment I have used to be satisfactory and precise for the entire range of measuring devices.

8.1. HOW TO ENSURE THE SAFETY OF ELECTRIC MEASUREMENTS

8.1.1. Do not neglect safety: you life depends on it

When safety is endangered, the same principles apply to electric testers as to motorcycle helmets: if your head is worth a fiver, then choose a helmet which is worth a fiver. If you plan on holding on to your head, buy a reliable helmet. While the dangers of motorcycles are clear, can the same be said of electric testers?



Are you not working safely as long as you select a tester with a sufficiently high nominal voltage? A voltage is a voltage, right?

Figure 114: "Surprise" voltage can turn up while measuring

No exactly. Engineers analysing tester safety often find that defective devices have been subject to a voltage far higher than the user thought to measure.

In some accidental cases, authorised low voltage testers (1,000V or less) were measuring intermediate voltages, e.g. 4,160V. The accident, a frequent incident, was not due to the incorrect use of the tester, but to an instantaneous *high voltage spike affecting* the tester input without warning.

8.1.2. Voltage spikes: an unavoidable danger

The risks of transient overvoltages increase with the growing complexity of distribution and load systems. Motors, capacitors and power converters such as speed regulators can generate substantial voltage spikes. The impact of lightning on external supply lines also leads to dangerous high energy transients. When you intervene on electric systems, these transients are 'invisible' and represent globally unavoidable dangers.

These spikes regularly occur on ***low voltage supply circuits***, and can reach maximum values of ***several thousand volts***. In these circumstances, your protection depends on the safety margin integrated into the tester.
The nominal voltage alone does not indicate if the tester is designed to survive high transient pulses.

The initial indications of the dangers relating to voltage spikes were identified in the applications involving measurements from the supply bus bar for electrified regional rail networks. The nominal voltage of the bus bar was only 600V, however multimeters authorised for 1,000V only resisted a few minutes when measurements were taken during the operation of the train.

More in-depth examination revealed that the starts and stops of the train caused spikes of 10,000V. These spikes left the input circuits of the initial multimeters with no chance. The lesson learned from this enquiry led to significant improvements in the input protection circuits of multimeters.

8.1.3. New safety standards

Safety must be integrated in test equipment to protect users against spikes.

What element of performance must you check if you need to work on high energy circuits? The definition of new safety standards for test equipment has been recently entrusted to the IEC (International Electrotechnical Commission). This body develops international safety standards for electric test equipment.

The industry designed equipment on the basis of IEC 348 for many years. This standard has been replaced by IEC 1010, and recently updated by IEC 61010 (EN 61010). The testers designed on the basis of IEC 348 have been used by technicians and electricians for many years, however, it must be admitted that the new standard EN 61010 provides a significantly higher safety level.

Let us consider why this is.

8.1.4. Protection against spikes

The circuit protection of measuring devices does not only depend on the voltage range in continuous duty, but on their ability to combine both their resistors to transient overvoltage and in continuous duty. Protection against spikes is crucial. When spikes circulate in high energy circuits, they are particularly dangerous as these circuits can generate high currents. If a spike causes an arc back, the high current may supply the arc, causing a plasma explosion or discharge when the ambient air becomes ionised and conductive. This will cause an arc flash, a disastrous event which causes more injuries due to electricity each year than electrocution, despite the latter being more well known. (See the "*Spikes: a hidden danger*" paragraph below.)

8.1.5. Measuring categories

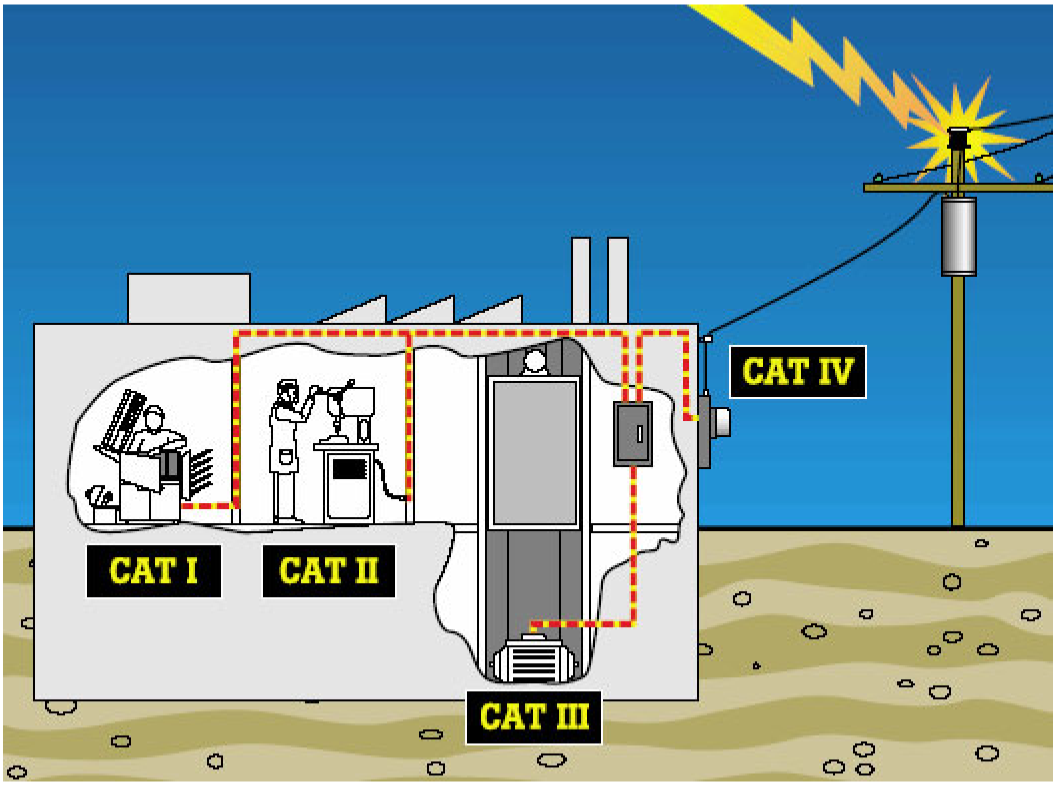


Figure 115: Measurement category = depending on location

The most important concept for the new standards is the measuring category.
The new standard defines 4 categories (I-IV), often shown as
CAT I, CAT II, etc. (see Figure).

The division of an electrical distribution system into categories is based on the fact that a dangerous high energy spike such as lightning will be attenuated or absorbed when crossing the impedance (AC resistance) of the system.

A higher CAT category will refer to an electrical environment marked by a higher available power and higher energy spikes. A multimeter designed on the basis of CAT III will resist high energy spikes far better than a CAT II multimeter.

Within each category, a higher nominal voltage implies a higher spike resistance, in other words, a CAT III-1,000V device provides better protection than a CAT III- 600V device. The understanding of this concept is important if a user selects a CAT **II**- *1,000V* device thinking that it is better than a CAT **III**- *600V device*. (See "*When 600V is higher than 1,000V"* below.)

Measuring category	***Overview***	***Example***
CAT IV	Three phase mains connection, all external conductors	Refer to the "origin of the installation", i.e. the location where the low voltage connection meets the mains lead. Electric meters, protection equipment with maximum primary current. Input of supply wires and external lead, service connection from the pole to the building, section between the meter and the electric distribution panel. Airborne lead to a separate building, underground line to a well pump.
CAT III	Three phase distribution, including single phase commercial lighting	Equipment for fixed installations, such as multi-phase motors and switch devices. Bus bars and supply of industrial sites. Supply leads and short voltage circuits, electric distribution panels. Lighting installations in large buildings. Plugs for electric devices with short connections to the supply wire input point
CAT II	Loads connected to single phase plugs	Devices, portable tools and other similar or household loads. Current plugs and long voltage circuits. Current plugs at a distance in excess of 10 metres (30 feet) from the CAT III source. Current plugs at a distance in excess of 20 metres (60 feet) from the CAT IV source.
CAT I	Electronics	Protected electronic equipment. Equipment connected to circuits (source) in which action is taken to limit transient overvoltages at an appropriate low level. An low energy source of high voltage, derived from a high winding resistance transformer, such as the high voltage section of a photocopier.

Table 11: Measurement categories

8.1.6. This is not simply voltage level

In the figure (measurement categories), a technician intervening on office equipment on a CAT I site may come across DC voltage far higher than the mains voltages in supply leads measured by the motor electrician on a CAT III site.

And yet, the spikes in CAT I electric circuits, irrespective of the voltage, are less dangerous as the energy available for an arc is limited.

This does not mean that no electrical risks exist for CAT I and CAT II equipment. The primary danger is from electric shocks and not spikes or arc flashes.

These shocks can be as deadly as an arc flash.

Let us take another example.

An airborne line section between a house and a separate laundry is certainly at 220V or 24 V, however, this section is technically a CAT IV section.

Why?

All external conductors are subject to very high energy spikes related to lightning. Conductors buried in the ground are considered as CAT IV conductors even if they are not hit by lightning as a nearby lightning strike could *induce* a spike due to the presence of high electromagnetic fields.

The location rule is applied when considering measuring categories: location, location, location, etc.

(For a detailed discussion of installation categories, refer to the following paragraph on the "Task-based application of categories"

8.1.7. Spikes: a hidden danger

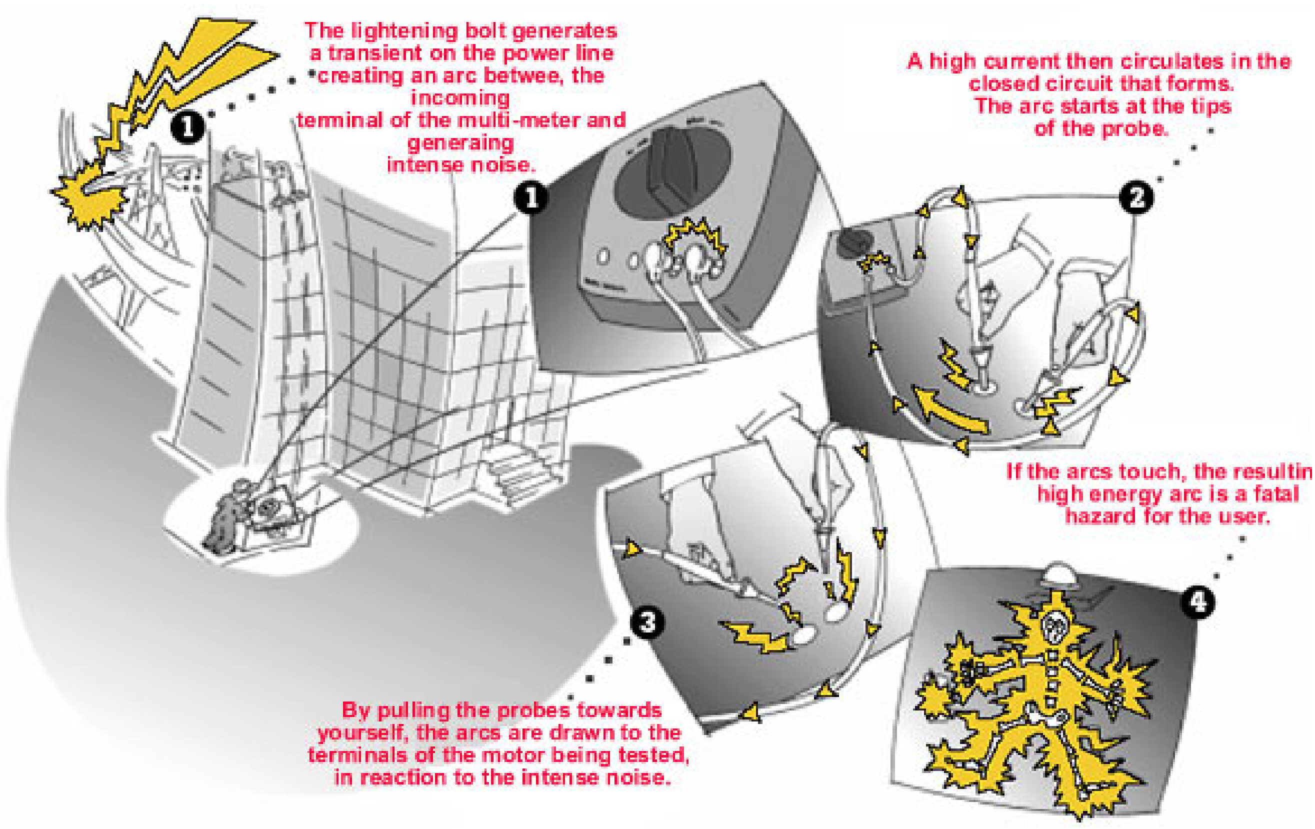


Figure 116: Scenario: potential sequence of an arc flash

Let us consider a worst case scenario in which a technician takes measures on a three phase motor control circuit using a multimeter, without taking the necessary safety precautions.

Several events may occur:

1. A lightning strike causes a spike on the supply lead, which subsequently hits an arc between the input terminals *inside the multimeter.* The circuits and components intended to prevent this event have failed or were absent. This was most certainly not a CAT III multimeter. Consequently, we have a *direct short-circuit* between the two measuring terminals via the multimeter and the measuring leads.

2. A high fault current, possibly reaching up to several thousand amps, circulates in the short-circuit created. This will occur in several thousand seconds. When the arc forms inside the multimeter, a very high pressure shock wave will cause a detonation *which will be heard as a gun shot or ignition return from the carburettor*. The technician will simultaneously see bright blue arc flashes at the ends of the measuring leads: the fault currents will overheat the probe ends which start to self-consume, while attracting an arc from the contact point towards the probe.

3. The natural reaction would be to step back and break the contact with the overheated circuit. However, the arc is attracted between the motor's terminal and each probe, while the hands of the technician retreat. If the two arcs meet up and form one single arc, *another short-circuit will be formed between the phases, directly between the motor terminals this time.*

4. The temperature of this arc may reach 6,000°C (10,000°F), i.e. higher than an oxyacethylenic welding blowpipe! As the arc extends, fed by the current available from the short-circuit, it overheats the ambient air.
An electric flash and a plasma fireball are produced.
If the technician is lucky, the blast of the explosion will throw him far from the arc and save his life even though he may be injured. If not, the technician will receive mortal burns from the intense heat of the plasma arc or flash.

All individuals working on live supply circuits must use an approved multimeter for the appropriate measuring category, but must also wear fireproof protective clothing, or, even better, a facial protection mask and insulated gloves.

8.1.8. Arc flashes and electric shocks

8.1.8.1. Use the right high energy fuses

Spikes are not the only possible sources of short-circuits and arc flashes. The widespread *incorrect use* of portable multimeters can cause a similar sequence of events.

Let us consider the following case. A user intends to establish current values for indication circuits. The operation involves selecting the ammeter mode, inserting the leads in the mA or A input terminals, opening the circuit and taking a measurement in series. With a circuit in series, the current will not change. The input impedance for the intensity circuit must be sufficiently low to not display the current of the circuit connected in series. The input impedance for the 10A terminal of a multimeter is 0.01Ω.

Compare this to the input impedance of voltage terminals of 10MΩ (10,000,000Ω).

If the measuring leads are *left in the intensity terminals, and then accidentally connected to the terminals of a source of voltage*, the low input impedance will become a short-circuit! It does not matter if the switch is set to volts: the leads are physically connected to a circuit with low impedance.* This is why the intensity terminals *must be protected by fuses*.

These fuses are the only barrier between a technical fault and a power disaster.

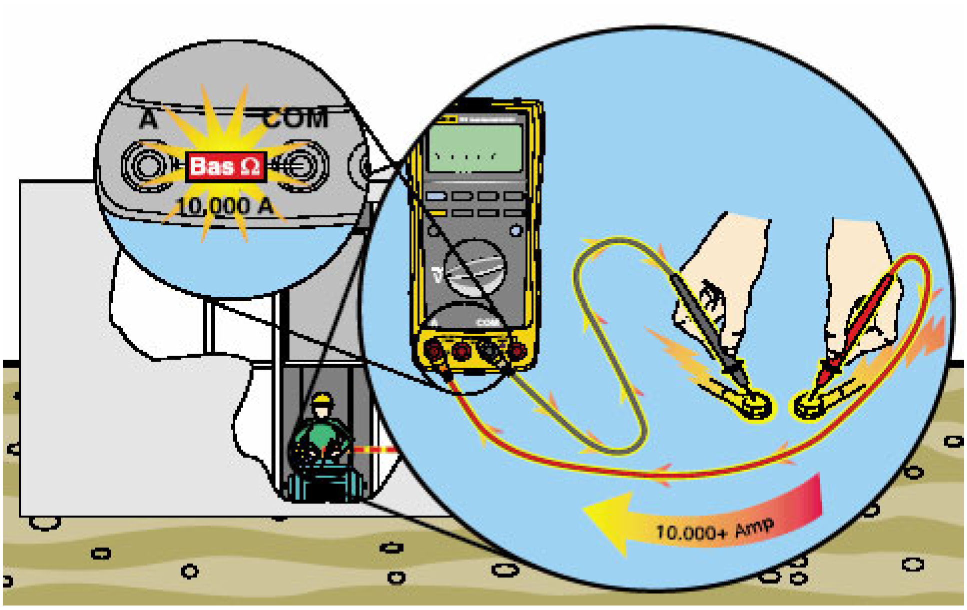


Figure 117: Incorrect use of a digital multimeter to measure current.

The multimeter must only be used when protecting the intensity terminals using high energy fuses. Never replace a melted fuse with a fuse of the wrong rating. *Only use the high energy fuses specified by the manufacturer.* These fuses are approved for one voltage and have the ability to stop short-circuits to ensure your safety.

8.1.8.2. Protection against overloads

Fuses provide protection against overcurrents. The high input impedance of volt/ohm terminals ensures that overcurrent is little probable, removing the need for fuses. Protection against overvoltage is however *necessary*. This protection is provided by a protection circuit which aligns the high voltages at an acceptable level. A heat protection circuit also detects overvoltage conditions, protects the multimeter until the elimination of the condition before automatically switching back to normal operation.

The main advantage of this device is that it protects the multimeter against overloads when the device operates in ohmic mode. The protection against overloads with automatic re-establishment is therefore installed for all measuring functions providing the leads are in the voltage input terminals.

8.1.8.3. Electric shocks

The approximate resistance under the skin when passing from one hand to another is 1,000 Ω. A voltage of *only 30V* (with *1,000Ω , in your hands*) would cause a current of 30mA.

Fortunately, the resistance of the skin is far more substantial.

The resistance of the epidermis, particularly of the outer layer of dead cells known as the "stratum corneum" protects the body. In humid conditions, or in the presence of a cut, this resistance drops radically. At approximately 600V, the resistance becomes non-existent. The skin is then perforated by the high voltage.

For manufacturers and users of multimeters, it is fundamental to prevent any accidental contact with live circuits at any cost.

Make sure you obtain:

- multimeters and measuring leads with double insulation.
- multimeters equipped with embedded input jacks and measuring leads equipped with reinforced input connectors.
- measuring leads fitted with protection collars and an anti-slip coating.
- multimeters and measuring leads of high quality, long-lasting and non-conductive materials.

8.1.9. Task-based application of categories

8.1.9.1. Rapid recommendations to understand categories

These few tips will assist you in applying the concept of categories in your day-to-day operations:

- One simple rule applies: the nearer you are to the supply source, the higher the category, and the higher the potential danger of spikes.
- Therefore, the higher the *short-circuit current* available in a given location, the higher the category.
- In other words, the higher the i*mpedance of the source*, the lower the category. The impedance of the source is quite simply the total impedance, including the impedance of the cabling between the point of the measurement and the supply source. This impedance is the element which smooths out spikes.
- Finally, you are familiar with spike overvoltage removers (*surge arrestors*), you are aware that if such a device is installed in the electric distribution panel, it must have a greater energy management ability than if it was installed on the computer. In CAT terms, the surge arrestor on the distribution panel is a CAT III application, while the computer is a load connected to an electric plug and consequently a CAT II installation.

As you can see, the concept of categories is neither new nor exotic. This concept simply completes the common sense which electricity specialists apply on a daily basis.

8.1.9.2. Multiple categories

A scenario profile can cause confusion for technicians who attempt to apply the categories to applications in the real world. One item of equipment may often incorporate several categories. To give an example, with office equipment, the 220V/240V circuit between the supply and the electric plug is CAT II. The electric circuit is however classified as CAT I.

With residential control systems, such as lighting control panels, or in industrial control equipment, such as programmable controllers, electronic circuits (CAT I) and supply circuits (CAT III) co-exist, often close to each other.

What should we do in this case?

Just like in other real situations, use your common sense. Use the approved multimeter for the highest category. Users cannot reasonably be expected to systematically attempt to define the category.

It is however far more reasonable and strongly recommended to *select an approved multimeter for the highest category that the user is likely to come across*. In other words, if you are going to estimate figures, round up!

8.1.10. Safety characteristics of a tester

8.1.10.1. Explanation of nominal resistance voltages

Test procedures EN 61010 integrate three main criteria: voltage in continuous duty, spike voltage at maximum pulse and source impedance.

These three criteria are combined to provide the true resistance to overvoltage at the multimeter.

8.1.10.2. When 600V is higher than 1,000V

The table below will help you to understand the true resistance to overvoltage for a device:

Measuring category	Service voltage (RMS VDC or VAC with ground)	Spike at maximum pulse (20 repetitions)	Test source (Ω = V / A)
CAT I	600V	2,500V	Source of 30 ohm
CAT I	1,000V	4,000V	Source of 30 ohm
CAT II	600V	4,000V	Source of 12 ohm
CAT II	1,000V	6,000V	Source of 12 ohm
CAT III	600V	6,000V	Source of 2 ohm
CAT III	1,000V	8,000V	Source of 2 ohm
CAT IV	600V	8,000V	Source of 2 ohm

Table 12: Test values for spikes for measuring categories
(The values 50V / 160V / 800V are not included)

1. *Within a* category, a higher "service voltage" (voltage for continuous duty) will be combined with a higher spike, as is to be expected. To give an example, a CAT III-600V multimeter, is tested with 6,000V spikes while a CAT III- 1,000V multimeter is tested with 8,000V spikes. All appears normal for the moment.

2. However, one element is harder to understand: the difference between the 6,000V spike for CAT III-600V and the 6,000V spike for CAT II-1,000V. They are not identical. This is where the impedance of the source comes in. Ohms law (amps = volts/ohms) states that the test source of 2Ω for CAT III represents *six times the current of the test source of* 12Ω for CAT II.

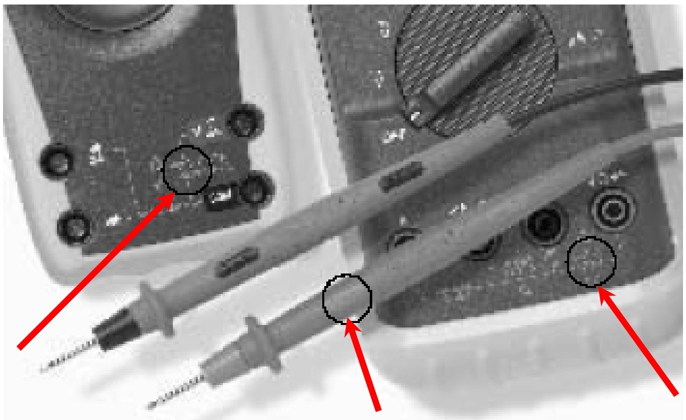
The CAT III-600V multimeter clearly provides better protection against spikes than the multimeter CAT II- 1,000V, although its "nominal voltage" appears lower. *The combination of the voltage in continuous duty (service voltage) and the category determines the total resistance voltage for the test device, including the nominal value of the spike resistance if high.*

Remark on CAT IV: Test values and design standards for category IV voltage tests are described in the second edition of EN 61010.

8.1.10.3. Slip and separation distance

Multimeters are tested in view of an actual surge, and EN61010 also demands that they show minimum "slip" and "separation" distances between internal components and circuit points. Slip measures the distance along a surface. Separation measures the distance directly. The higher the category and service voltage, the higher the internal separation characteristics. One major difference between the old standard IEC 348 and EN 61010 is the increase in separation required by the more recent standard.

8.1.10.4. To conclude



If you must replace your multimeter, do one simple operation before starting the search: analyse the worst case scenario for your work and determine the category you must use and the application concerned.

Figure 118: Identify the category and nominal voltages for multimeters and measuring leads.

Start by selecting a multimeter for the highest category you are likely to come across. Then search for a multimeter whose nominal voltage corresponds to the category matching your requirements.

Figure 119: Use instruments with the following indications: CAT III 1,000 V, CAT IV 600 V

In parallel, do not forget the measuring leads. EN61010 also applies to measuring leads: they must be certified for a category and voltage equal to or higher than that of the multimeter. With regards your personal protection, never let measuring leads be your weak link.

Figure 120: Safety equipment

To conclude, to get luck on your side, use protection equipment, and safety goggles and insulated gloves in particular.

See the "Electricity safety" course

8.1.11. Independent tests

The following chapter explains the meaning of the "strange" acronyms and signs you may see on devices.

8.1.11.1. Independent testing is decisive in ensuring compliance with safety requirements

Look for a symbol and the authorisation number of an independent testing laboratory such as UL, VDE, TÜV or any other recognised test body. (list in the equipment course, one copy should be displayed in at-risk areas).

Beware of expressions such as "Designed to meet specifications... " Design plans cannot replace a good independent test.

How can you identify if your device is a genuine CAT III or CAT II tester? This is unfortunately not always easy. Manufacturers may certify their own testers for CAT II or CAT III *without requiring independent checking*.

The IEC (International Electrotechnical Commission) develops and proposes standards, however it is not responsible for the *application* of these standards.

Look for a symbol and the authorisation number of an independent testing laboratory such as UL, VDE, TÜV or another recognised certification body.

Figure 121: Examples of signs for independent bodies

This symbol can only apply if the device has passed the verification tests for the agency based on national/international standards. e.g. UL 3111 is derived from EN 61010. These answers are not ideal, and this is your best bet for checking that the safety of the multimeter has been tested.

8.1.11.2. What does the CE symbol mean?

The CE sign (Conformité Européenne - European conformity) indicates that the product complies with certain essential requirements relating to health, safety, the environment and consumer protection, established by the European Commission and authorised by the usage of "directives".

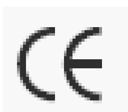


Figure 122: The official "CE" sign

These directives apply to many products, and products may not be imported into the European Union if they do not satisfy the applicable directives.

Product conformity with the directive may be obtained by proving its compatibility with the pertinent technical standard, such as EN 61010 for low voltage devices. Manufacturers are authorised to *certify that they have complied with these standards,* issue their own Declaration of conformity and apply the "CE" brand to the product *themselves*. *The CE brand is not therefore a guarantee of independent checking.*

Personal comment: There are (perhaps increasingly) electric devices with the CE brand (I am not just talking about measuring devices) which are clearly (a quick look suffices) far from compliant with safety standards – and they are freely available from supermarkets….

8.2. ERRORS TO BE AVOIDED

8.2.1. 10 errors to be avoided

… we have all done these at least once!

Personnel who work with electricity on a daily basis rapidly acquire a healthy distrust of any item even vaguely likely to contain current.

However, when working under pressure, people can become careless and even experienced electricians can be pushed to make serious errors. The following list is a quick summary of what must *absolutely be avoided* when taking electric measurements.

The following is a "report" drafted by a vendor. Some may find that, in some cases, we take things too far…. In terms of safety, particularly electric safety, we can never be too prudent and when accidents happen, as described above, it's a question of, more haste less speed... In addition, an electrician who has not yet burnt his fingers is not yet a "good" electrician, once bitten twice shy!

So, we all need to build up our own experience, to take a couple of light "hits" and to intervene carefully and safely….

8.2.1.1. Replace the original fuse of the tester with a cheap fuse.

If your digital multimeter satisfies current safety standards, its silica rated fuse has been specially designed to ensure the safety of your tester by melting before an overload reaches your hand.

If you change the fuse of your digital multimeter, make sure that the new fuse satisfies the manufacturer's specifications.

8.2.1.2. Use a small bit of electric wire or a small metal object to replace a molten fuse.

This may seem an effective means of finishing a job quickly if you have no spare fuses, however this missing fuse could well be the only barrier between you and a devastating voltage spike…

8.2.1.3. Use an inappropriate tester for a task.

It is important to use the right digital multi-meter for each task.

Particularly check that the CAT marking of your tester corresponds to your working environment – even if this forces you to juggle with several multimeters all day long.

8.2.1.4. Select the cheapest multimeter.

Nothing stops you from switching for a better model later, right?

Yes, something could stop you: being victim to a work accident because your cheap tester did not actually have the safety characteristics announced. Check that your device has been certified by an independent test laboratory.

8.2.1.5. Do not wear safety goggles.

It is essential to take your goggles out of your pocket and put them on.

The same applies to your protection gloves and fire-proof clothing.

8.2.1.6. Work on a live circuit.

Always disconnect the voltage from a circuit whenever possible.

If you absolutely have to work on a live circuit, use tools which are appropriately insulated, wear safety gloves, remove your watch or any other jewellery, work on an insulating mat and wear fire-proof clothing (and not your normal work gear).

8.2.1.7. Do not use the correct consignment and labelling procedures.

No comment

8.2.1.8. Keep your two hands near to the test point.

Don't do it! When working with live circuits, never forget that old electrician's saying: always keep one hand in your pocket. This will reduce the possibility of creating a closed circuit formed by your two arms, your heart and your chest.

Hang up or lay down the tester if possible. Attempt to avoid holding the tester to reduce the risks of personal exposure to the effects of spikes.

8.2.1.9. Neglect the importance of measuring leads.

Measuring leads are key components in the safety of your digital multimeter.

Check that your measuring leads correspond to the right CAT for the task. Select leads with double insulation, sheathed input connectors, finger guards and a non-slip surface.

8.2.1.10. Remain loyal to your trusty old tester.

Current testers have integrated safety characteristics **which** were unknown just a few years ago, and which make it more than worth investing in new equipment – which will cost less than a stay in hospital…

8.2.2. International safety standards

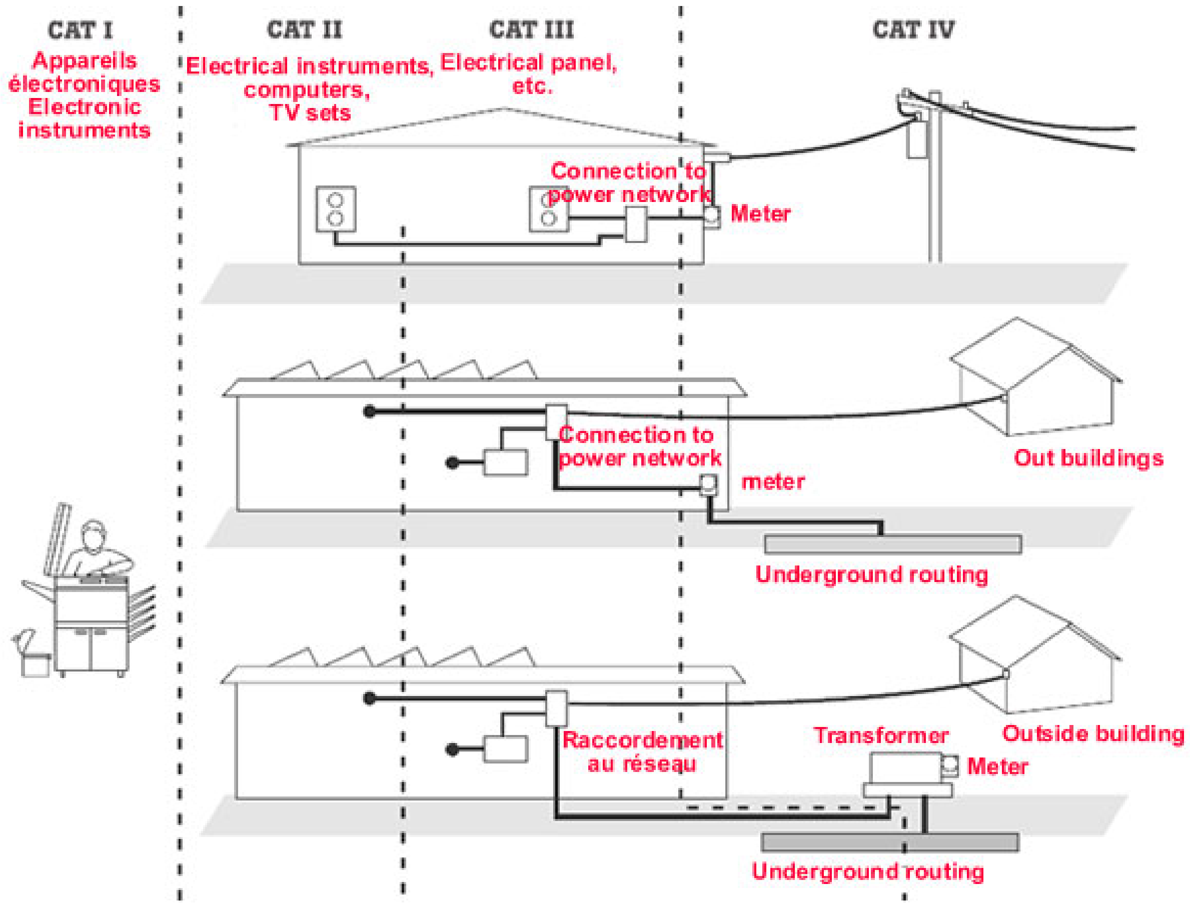


Figure 123: Safety standards for the use of measuring devices

CAT I

- Electronic equipment
- Low energy equipment with protection against limited spikes

CAT II

- Long branch circuits and plugs
- Any plug located more than 20m from a category II area
- Any plug located more than 20m from a category IV area

CAT III

- Supply leads and short branch circuits
- Distribution panel equipment
- Power take-offs with "short" connections to the network
- Lighting systems in large buildings

CAT IV

- External lines and network connections
- Pylon-building connection lines
- Cabling connecting a distribution panel and a meter
- External line to a secondary building
- Underground line to a water pump

The limit between category III and IV areas is arbitrary:

- At the meter or mains circuit breaker (ANSI/NFPA 70-1990(2), Article 230-70) for low voltage installations.
- At the secondary circuit of the sub-station for installations supplied with higher voltage.

8.3. TESTERS AND ACCESSORIES

8.3.1. Safety levels assigned per tester!

You have certainly previously seen voltage testers on electric sites. These portable devices can be slipped into a pocket and are frequently used to rapidly identify the presence of electric voltage. They are convenient for checking basic voltage and widely used by electricians.

However, they are not all identical: There are clear differences in terms of safety, reliability and ease-of-use.

Figure 124: Assortment of testers / voltage detectors

Tester or detector? With or without contact? Which brand? The image shows the following brands: Fluke, Chauvin-Arnous, Meterman, Standard Instrument, Sefram, Technotech, Kyoritsu, and Catu. Other brands could have been shown. Which voltage? The image shows DC/AC and AC only testers (and detectors) with a maximum voltage of 400–1,000V, with thresholds such as 440, 600, 690, etc.

Compare the different testers available and you will rapidly understand that two main categories exist: ***solenoid*** testers and ***electronic testers***.

Solenoid testers have long been used.
These were the first types of testers to flood the market and are still frequently used today.
Their operation is very simple: when the voltage exceeds a certain threshold, the tester indicates the presence of an electric voltage.
Should the voltage not exceed this threshold, the tester will not indicate any data.
However, the threshold will vary between categories, which may have a significant impact on safety and ease-of-use. Let us consider these two tester categories more closely. After this chapter, you will know which instrument to leave in the tool kit and which one to take with you.

But before we look at the "true" testers, watch out for these pocket testers/screwdrivers (certified by VDE) whose voltage interval is a maximum of 250VAC. Make sure you know where you are working, you are a human fuse….

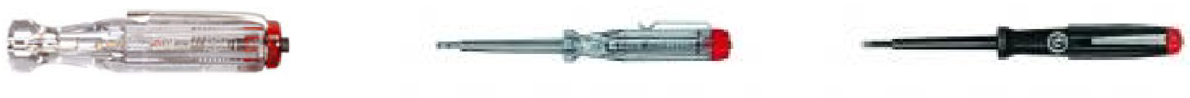


Figure 125: pocket screwdriver-type voltage detector

Figure 126: automobile voltage detector

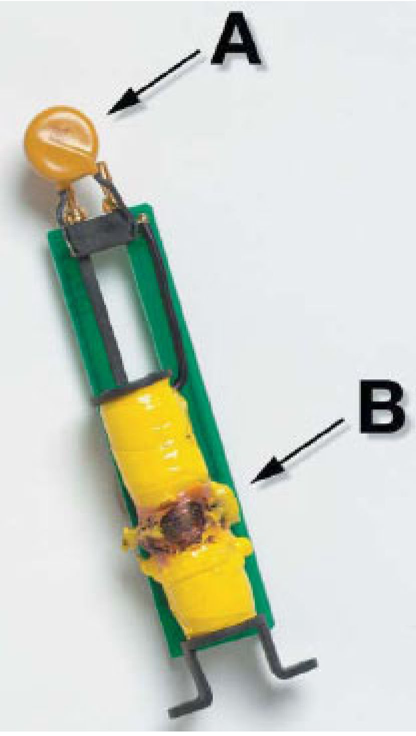
The automobile-type voltage detector is only used for DC and a maximum voltage of 24V DC.

8.3.2. Solenoid voltage testers

As indicated by their name, these devices operate using the solenoid principle. A solenoid valves responds to the movement of a ferrite core, which is subjected to the excitation and non - excitation of an electromagnetic coil.

The indication function of these testers therefore depends on a spring actuating a mechanical needle. The spring will retain the core, which will slide to one end of the chamber, depending on the energy present in the coil to oppose the core to the force of the spring. The quantity of energy required limits the sensitivity of solenoid testers.

The ability to measure higher voltages also restricts the ability to detect voltages less than approximately 100V due to the low dynamic properties of the magnetic elements, which is a specific weakness of solenoid testers. Test a solenoid tester on 24V or 48V control circuits. The effect would be the same for a stick of wood.



Another major concern for solenoid testers is their relatively low input impedance (10 kohms at the upper end, but often near to 1 kohm).

Figure 127: Defective voltage tester (A) Varistor and (B) overheated section

If you apply Ohm's law, you will note that solenoid testers may easily be perceived as loads in the circuit and, therefore, interfere with the operation of the latter. The relatively high current absorption of a solenoid tester leads to an increase in heat which is enough to overheat the tester, to the extent of damaging the latter if the voltage is measured for too long a period.
To conclude, if you use a solenoid tester, remember to provide for cooling time (around thirty seconds) between each measurement.

If your programmable controller stops and the supervisor blows a fuse at the idea of definitively losing part of production, remember what we just said. Even testing a plug can involve risks. You could also carry a few testers and use them alternately. However, the very reason for using a compact tester would then be rendered null and void!

8.3.3. Electronic voltage testers

As compared with early models, current electronic voltage testers have one undeniable advantage: their robust and compact design. They are easier to carry and less fragile.

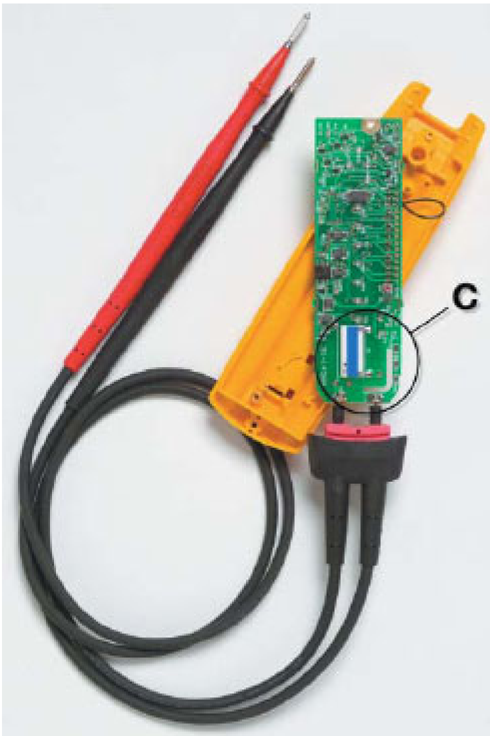


Figure 128: Electronic voltage tester with protection resistances

However, this argument is nothing compared to the major advantage in terms of safety due to the much higher input impedance of electronic voltage testers. Certain models have an input impedance of one megohm, i.e. 100 times the capacity of the best solenoid tester. Event at lower ends, you benefit from an impedance of 20 kilohms, i.e. a performance which is twice that of the best solenoid tester. Simply apply Ohm's law to clearly identify other benefits.

You will work with a much lower input current. This implies improved safety and a shorter cooling time between each measurement. These testers operate at lower voltages and generally provide better IEC-type safety levels. The figure demonstrates the input protection to the circuit making IEC certification possible. These testers solve a multitude of problems, with enhanced safely and rapidity.

The higher impedance has a down side: electronic testers can indicate the presence of an electric voltage for an off-load conductor (e.g. a "phantom" voltage). This can occur if a conductor induces a voltage in another parallel conductor. The indication of this voltage can represent an obstacle and display a false positive. However, this can also be a benefit. You are not given a false impression, i.e. that you are in the presence of an off-load and therefore safe conductor.

If we assume that the solenoid tester does not display the 80V for the wire and you take hold of this wire, what will happen?

8.3.4. Other considerations, leads, probes

Differences are not limited to testers.

In the same way, the selection of the type of tester (solenoid or electronic) is not the only problem on the table. Many other considerations must be taken into account when considering safety and working performances.

A frequent ***error*** in terms of test equipment involves attempting to ***making savings on measuring leads and probes***. These so-called savings can be very costly: badly manufactured, cheap input accessories leave the door open to the failure of equipment which is supposed to protect you. Never forget that you must hold these accessories when taking measurements.

Figure 129: Probes and leads must be quality equipment

If these accessories fail, the consequences can be very serious. It is important to select quality measuring equipment.

Select accessories which are suitable for your industrial applications, and attempt to identify any sign of wear or long-term damage. This will enable you to avoid any failure of measuring leads or probes, and the inherent consequences. Make sure you know the IEC certification level (e.g. CAT II, CAT III or CAT IV) of your tester and purchase measuring leads and other accessories which satisfy or exceed the requirements of this certification.

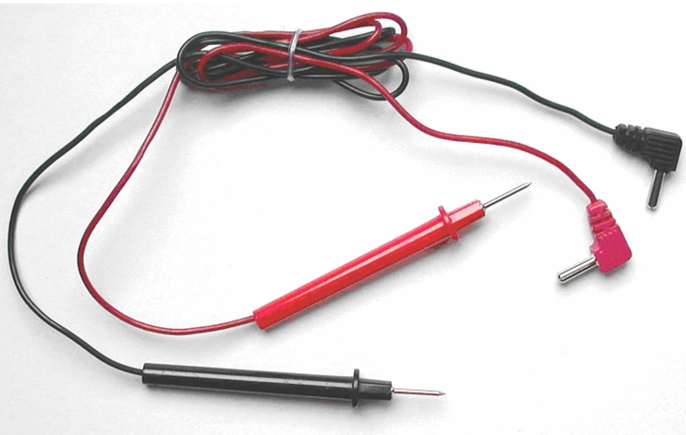
You can optimise your tester by adding other functionalities. However, do not forget that this implies an increase in weight and cost. If you absolutely need these functionalities, consider them from the moment you purchase the voltage tester.

8.3.5. Use of leads, plugs, probes and other accessories

Measuring leads consist of an insulated flexible conductor (generally black or red).

Figure 130: Measuring leads, "red and black"

Leads generally come in pairs, with one red lead (plus) and one black lead (negative).



A male banana plug of a diameter of 4mm will be connected to one end and may be protected by insulation which retracts when the multimeter is inserted.

Figure 131: Banana type leads + contact point

The other end of the lead will consist of a contact point with a long rigid conductor, protected by a plastic insulation duct in the same colour (red/black) as the lead, and fitted with a metal tip. .

Figure 132: Connection of banana plugs to the device

Figure 133: Banana plugs and traditional alligator clips

Standard 4mm ***banana plugs*** *are often used in electronic, for the leads of measuring devices (multimeters, laboratory supplies, circuit plates, etc.). They are also found in the high fidelity field behind amplifiers and loudspeaker enclosures, often the conductive section is plated with gold/silver/etc., while the rest is in plastic.*

Measuring leads with a banana plug at each end exist, enabling the use of single contact points, wire clips or alligator clips (standard 4mm).

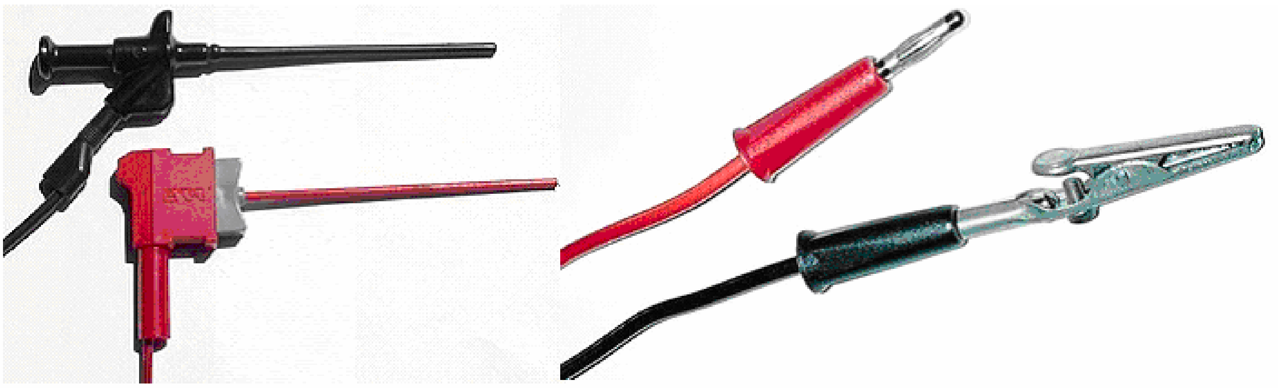


Figure 134: Wire clips and alligator clips

Measuring leads of differing levels of quality exist, it is preferable to select leads with silicone insulation which are more flexible.

Check that they satisfy optimal safety standards: Isolation Cat III, 1,000 Volts, Acceptable current, minimum 10A, safety banana plugs also exist (1,000V insulation) with a diameter of 4mm.

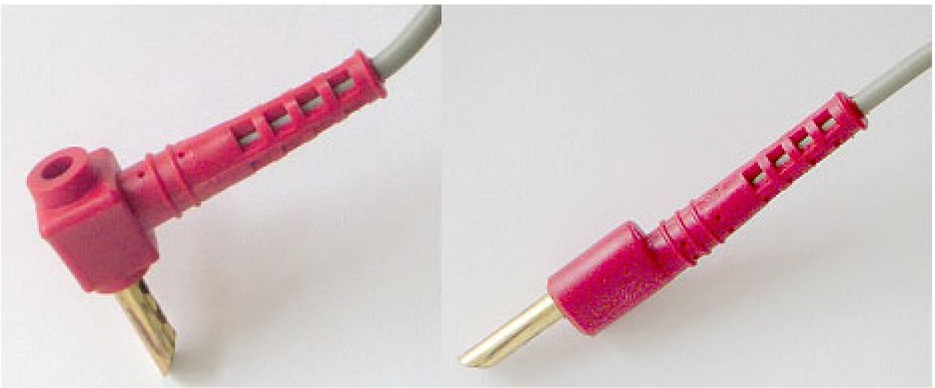


Figure 135: Banana plugs meeting the requirements of IEC 1010, U max. 100V

Insulation standard for contact points: standard IEC 1010 Cat II =300V Cat III =1,000V

For very high voltage measurements, divider type probes exist, which enable reading on a traditional multimeter (e.g.: 25,000 Volts = reading 25 Volts).

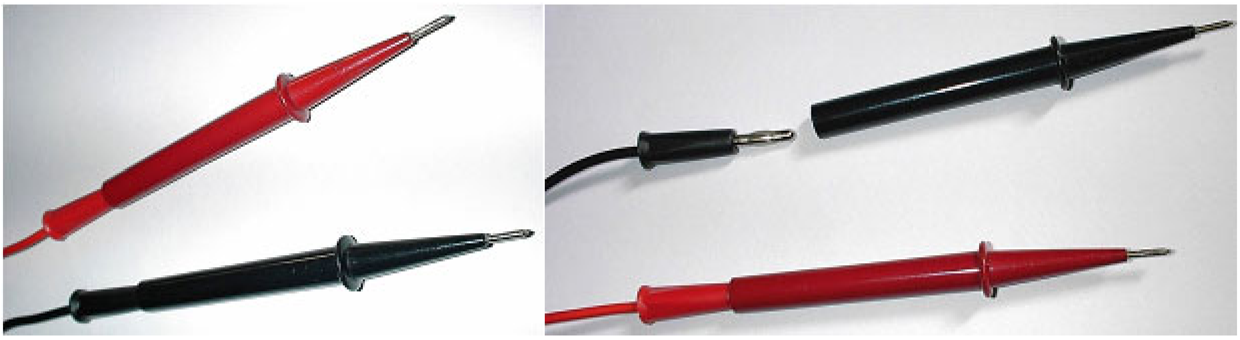


Figure 136: "Traditional" contact points

9. OTHER MEASURING DEVICES

This chapter refers to the measuring devices which electricians could use on site and which it is important to have "in reserve".

9.1. FAULTOGRAPH

AND/OR - REAL TIME FAULT ANALYSER

All or part of the installation triggers, the lists of alarms in the control room are impressive, and printers have come up with a whole series of events, but no final conclusion. There is no way of knowing what caused the "shut-down".

Everything (or almost everything) is planned for, the indications are there, but what was the initial source of this f…. shut-down! *Controllers are advanced machines, but they require a certain "scanning" time, and with several "embedded" controllers and a centralised control system which also takes time…, in some cases, it is impossible to conclude anything.*

The only solution is to initially locate (or estimate) the origin of the (possible) source of the failure on the basis of available information (it must come from there…), determine what we need to "catch out" (circuit breaker, alarm, switch, etc.), and install a "time -event recorder/analyser", i.e. a recorder which determines the sequencing of the faults. This not a rapid scanning multi-channel recorder, but rather a device which indicates the time of the appearance of the fault to the milli-second (or even micro-second) 13h 24min 06,127 s, on a printed strip and/or on a screen list.

I remember a contact opening for 4ms (pressure peak), i.e. long enough to activate the shut-down sequence, but not to trigger an alarm and therefore it was impossible to conclude that this was the source of the shut-down from the sequences. Only the "time event analyser" was able to save the day…

Production sites require a mixed device which can be a quality analyser for the electric network (an actual faultograph, for electricians), or an analogue or digital events detector (a "time event analyser", for instrument experts). And if only one device is required for a site, the device should be multi-functional, with multiple possibilities, as, to begin with, we have no idea if the problem is purely electrical, or other, it would be preferable to have several, complementary devices…

As we are currently considering electrical equipment, let us look at the faultograph and leave instrument experts to find their own time event analysers.

9.1.1. Faultograph operating modes

Analysis "a posteriori"	● Resolution of a complex fault for which other control equipment is not sufficient (identification and resolution of the fault: initial analysis). ● Verification of the performance of the various items of equipment during the incident (subsequent analysis). ● Location of the line fault. ● Compilation of statistics on network performance and/or the maintenance of protection.
Operational use	● Regular control measurements ● Continuous recording
Preventive study	● Use of actual recordings for the validation of new protection models. ● Validation of mathematical models for network simulation.

Table 13: Operation of the faultograph

The faultograph is installed within the sub-stations, it is itself subject to all induced and/or controlled electromagnetic perturbations which can be substantial, particularly in case of an incident.

If we compare the faultograph to the "black box" of an aeroplane, this device is essentially required to operate correctly in critical environmental conditions. It must have excellent immunity to perturbations.

Standards (IEC 6100-4-x) specifically describe the levels of perturbation to which faultographs must be subjected and the expected reactions.

Figure 137: Example of a portable faultograph

A faultograph is characterised by the **number of input channels**. Therefore, depending on its size, it could detect signals for one lead (generally 3 voltages and 3 or 4 currents, plus the associated protection contacts) or for several leads on one single high voltage station, enabling the comparison of instantaneous signals.

With electrical plants, it can record dozens of values for the operating of a generator.

The faultograph also enables the recording of **values derived** from the physical input values, such as the active and reactive powers deducted from input voltages and currents, homopolar voltage deducted from voltage for the three phases, the network frequency, etc.

The sampling rate (time resolution) will be adapted depending on the **type of perturbation** to be detected. The most powerful devices enable the detection of several types of perturbations at different speeds within the same item of equipment.

9.1.2. What use is a faultograph for an electrician

Symptoms	Possible sources																
	Flicker	Voltage drop	Undervoltage	Overvoltage	Harmonics	Interharmonics	Homopolar harmonics	Micro power cut	Rapid cut-out	Long and very long cut-outs	HF spikes:	Transient overvoltage	DC component	Three phase unbalance	Frequency regulation	Excess reactive energy	EMC
Malfunctioning of processes		●			●			●									
Random production stops		●	●														
Process stops					●					●	●						
Broken equipment					●	●					●		●	●			
Heating and noise in equipment			●	●	●	●	●							●		●	
Malfunctioning of motors			●		●									●	●		
Vibrations and abnormal motor noises			●		●	●								●			
Motor stops									●	●			●				
Electronic malfunctioning					●			●					●				●
Electronic power malfunctioning								●			●	●		●			●
Erratic functioning of protection				●			●					●		●		●	
Erratic triggering of protection													●				
Triggering of arcs							●			●	●						●
Screen disturbance	●																●
Radio communication disturbance											●						●
IT perturbations				●	●			●	●		●						●
Destruction of electronic cards				●				●			●						●
Destruction of IT equipment					●			●			●	●					
Lighting flicker	●								●								
Electrocution							●										

Table 14: Symptoms of perturbations and possible causes

9.1.3. Which device?

You must decide depending on your requirements. Obtain technical information on devices which could be appropriate. The following is a list of manufacturers with the main references and characteristics.

The aim is to obtain information, identify what material exists and realise that this equipment costs very little as compared with the cost of an extended production stop because you cannot identify the source of the problem.

Things will run much more smoothly if you have the right equipment.

Portable devices

Constructor	Model	Main characteristics
Alpes technologies	Alptec 2000	4U/41 – Samp. at 10.2 kHz/channel – EN 51160 – Measurement of P.Q.R.S.PF, tang, etc – 32 Mo - 512 Mo memory – No screen – 37.6 x 13.2 x 38cm
Chauvin Arnoux	Qualistar CA8332	Voltage P-N(600V) – 3I – Samp. At 12.8 kHz 6, ENS1160 parameters plus power – Pst – 2 Mo - Very compact (24 x 18 x 5.5cm)
	Qualistar CA8334	Idem CA8332 but with 4 Mo of memory and recording of spikes for 80ms
	Qualistar CA8352	Voltage P-N(600V) -4I – Samp. At 4.6 kHz – Option 10 analogue channels and 2 E TOT – ENS1160 parameters plus power – Pst & Plt – Order 50 harmonics – Alarm trigger – Recording of spikes for 10 s- 10 Go on hard disk – 36 x 30 x 15cm
Dewetron (Dimelco)	PNA600	4U/4I – Offset 10'' screen – EN50160 measurement parameters, power measurements, flicker Pst & Plt – Spike acquisition (samp. 200 k samp./s) – Extension of 16 analogue channels 20 Go – 31 x 34 x 6cm
Dranets BMI (MB electronic)	PX 4400	4U/4I – Samp. 12.8 kHz/16 bits – All parameters, flicker Plt and Pst , U, I & W harmonics (order 63) – Standard IEC 61000 – '-30 class A – 32 - 128 Mo memory – Touch screen – 30 x 6.4 x 20.3cm
	PX5	As PX 4400 but may be used on a 400Hz network – Analysis of spikes (samp. 1 MHz/14 bits)
Fluke	1650/01 and 03	4U/5I – 6.4 k samp./s for 14 bits – No screen – EN50160 parameters, power, energy, PF – Detection of spikes 130 µs – Storage of 96000 events – 21.25 x 30 x 7.5cm
	1650/111 and 113	Idem above with 2 M. samp./s and detection of 50ns spikes
	430	4U/4I – 200k. samp./s – EN50160 parameters plus transient energy, start-up current – IEC61000 – 4-30 – Display of 8 simult. curves. – 50 screen shots in memory – 25.6 x 16.9 x 6.4cm
HT Italia (Dimelco)	GSC57	LV single/three phase network analyser according to EN 50160 – 2Mo/1,000 recordings of 63 parameters – Electric tester (circuit breaker, ground, etc) – Measurement of physical values – Screen 128 x 128 pixels)
LEM	Analyst 3P	3U/3I – Samp. At 10.24kHz – Measurement of harmonics (order 40), power, energy, PF – Recorder of perturbations – 24 x 18 x 11cm
	Analyst 3Q	Idem Analyst 3P, with 3 or 4I and measurement of the parameters defined by EN50160
	Analyst Q70	Single phase analyser – EN50160 parameters – 3 Mo memory – 22.5 x 10.5 x 7.2cm
	Memobox 808	3U /4I – Samp. at 10.24kHz – No screen – Software for the display of EN50160 parameters and power – 8 Mo memory – 28.2 x 21.6 x 7.4cm
	Topas 1000	Top of the range – 8 voltage/current input elements - No screen – Samp. Up to 10 MHz for 16 bits – Measurement of EN50160 parameters, power and energy
Megger	PA-9Plus	3U /3I – Samp; at 12.8 kHz – Display: 240 x 64 pixels – EN50160 parameters – Measurement of power, energy, harmonics (order 63), flicker – 128 Mo
Metrel (Dimelco)	M12192	3U/3I – EN50160 parameters plus power – Order 63 harmonics – Oscilloscope – 2 Mo

Yokogawa (MB electronic)	PZ4000	Modular power analyser – Up to 4U/4I – BP of CCF at 2MHz – 5 M.samp./s – FFT and analysis of harmonics up to order 500 – Input for the torque and speed sensor (for the regulator unit) – 100 k.samp. memory with 4 M.samp/channel – TFT 640 x 480 screen – 42.6 x 17.7 x 45cm
	WT3000	Ultra precise power analyser (basic precision: 0.02% of the reading) – up to 4U/4I – BP 0.1Hz-1MHz – Harmonics up to order 50 – Screen 640 x480
	DL750	16-channel recording oscilloscope with optional electrical analysis – 10 M/Samp./s, 1 Gpoint memory
	DL7480	8-channel recording oscilloscope with optional electrical analysis -2 G/Samp./s, 16 Mpoint memory
Zimmer (Aeroflex)	LMG500	4U/4I (optional 200%) – Power analyser, plus (option) harmonics and flicker – High precision (0.03%) – 3 M.Samp./s – Oscilloscope function – 43.3 x 14.7 x 40cm

Table 15: List and references for portable faultographs

Rack and fixed devices

Constructor	Model	Main characteristics
Alpes technologies	Alptec 2000	12 and 19-inch rack versions, 4U/4I – Samp. At 10.2 kHz/channel – EN51160 – Measurement of P,Q, R ; S, PF, tang, etc – 32 Mo - 512 Mo memory
Enerdis (Chauvin Arnoux)	MAP500	19-inch or 1/2 rack (possibility to place 2 devices side by side in one rack) – 4U/4I – samp. at 12.8 kHz – TOR 4In/4out, analogue 4in/4out– 8 - 32 Mo
	MAP5200	19-inch rack - 4U/4I – Samp. at 12.8 kHz (1 MHz for spikes) – 8 - 16 TOR in, 4 - 8 TOR out, analogue 4 in and 4 - 16 out – 8 - 32 Mo
	MAP6000	Idem MAP5000, with samp. at 37.5 kHz]
Fluke	1951/1952	4U/5I – 6.4 k samp./s for 14 bits – All EN50160 parameters plus power, energy, PF – Detection of spikes 130 µs – Storage of 96,000 events -31.5 x 29.4 x 15.2 cm
	1958/1959	Idem above with 2 M. samp./s and detection of 500 ns spikes
LEM	QWave Power	3U/3I – Samp. At 12.2 kHz/channel – EN51160 – Measurement of P,Q, R; S, PF, cos, etc – 4 Mo - 20 Mo memory
	QWave Silver	19-inch rack - 3U/3I - 6U6I (to control 2 transformers) – EN51160 – Measurement of P,Q, R; S, PF, cos, etc – 4 Mo - 20 Mo memory
	BEN 6000	Device used to control electric current transport networks

Table 16: List and references for rack or fixed faultographs

9.2. OSCILLOSCOPE

Electricians may need to use this device, mainly to check the signal shape, and to check the presence and condition of harmonics (on regulators, inverters, etc); Some faultographs have an integrated oscilloscope, but it is preferable to have a separate device

Figure 138: Philips GM5655 oscilloscope

This device is fitted with first generation lamps and a trace. It would be preferable to have something "more modern" on site….

• *Adjusting oscilloscopes:*

Irrespective of the oscilloscope, the following adjustments are almost always required.

Refer to the figure with its references and explanations.

This is a description of an oscilloscope and includes advice for use. Now you simply have to actually use the machine for measurements to gain familiarity with this type of device.

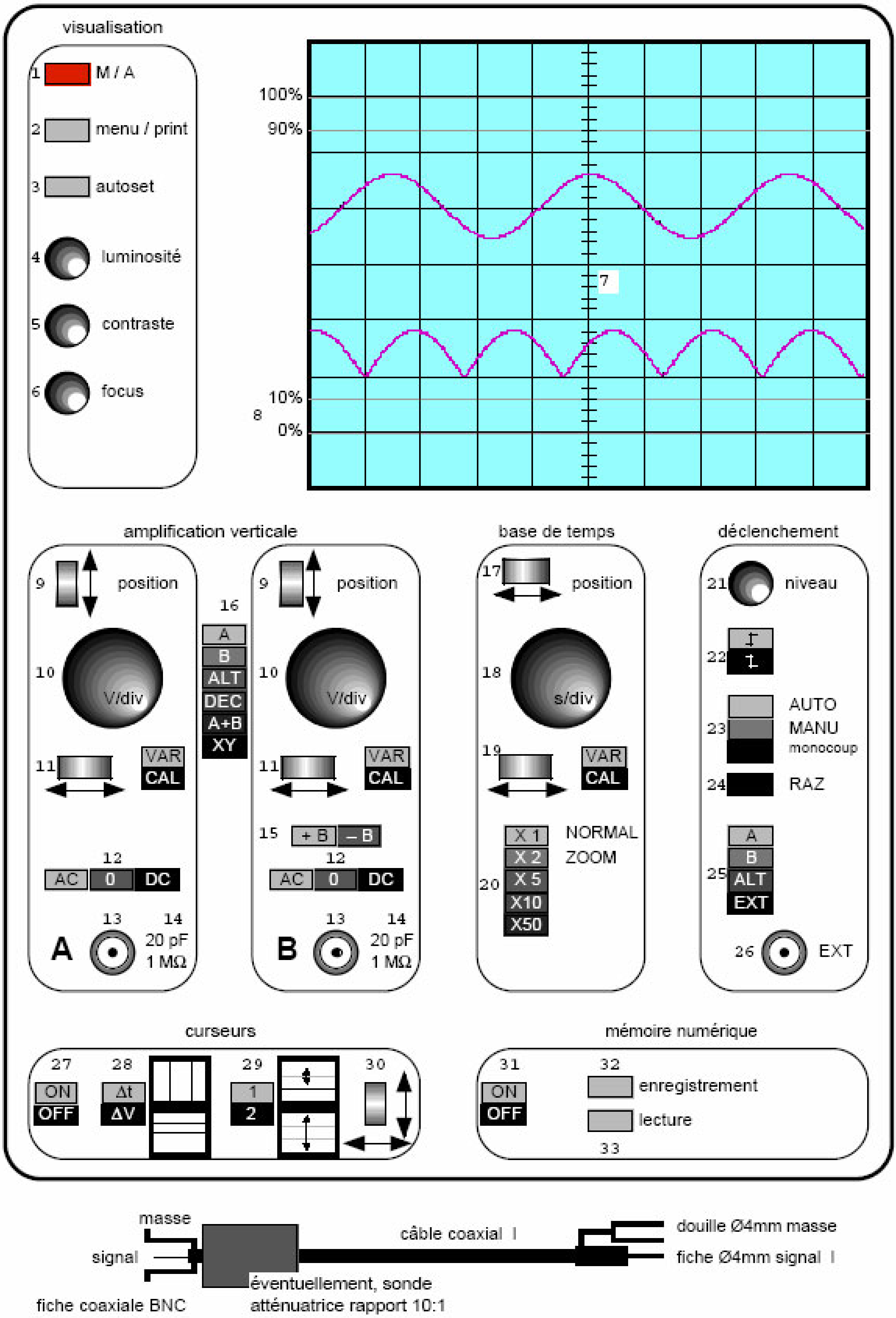


Figure 139: Oscilloscopes and settings

Display:

1. Start/Stop.

2. "User" menu for customised settings, resetting of the serial link to the PC, printing.
..
3. Automatic resetting of the trace display (detects the signals present in A & B and automatically adjusts amplification, time base, synchronisation, etc.). *Autoset*.

4. Trace luminosity.
⚠ Always check the luminosity setting before starting: the screen will remain desperately empty if the luminosity is low, or zero!

5. Contrast (LCD screens only).

6. Trace sharpness.
.
7. Screen with graduated reticle (in general, one division = one cm)
.
8. Dotted lines traced on the screen, enabling the measurement of the rise time of an impulsion between 10 and 90% of its final value, after having positioned the trace between the 0% (minimum) and 100% (maximum) lines. It is generally necessary to adjust 11.

Vertical amplification:

9. Setting of the vertical position of the traces.

10. Selection of vertical amplification (in V/division): ordinate scale.
.
11. VAR position (variable) ⇒ adjustable vertical amplification, between two 10 positions.
⚠ Always check that the switch is set to the CAL position before starting (calibrated).

12. DC: normal input; AC: AC component only; 0 (or GND: *ground*)
⚠ An oscilloscope generally uses DC coupling. The AC input is only used in certain particular cases (e.g.: examination of the residual ripple of a DC signal, measurement of phase lag, etc.)

13. Coaxial input (BNC socket).
⚠ With a tabletop device, the input ground is connected to the electric supply ground for the oscilloscope.

14. Input impedance.

15. Inversion of the channel B signal sign.

16. Trace A only, or B only, or A & B alternating, or A & B with *CHOP, or* A+B, or B depending on A (B = y axis, A = x axis: Lissajous figure, etc.). NB: A–B can also be displayed by selecting A+B after having activated 15.

⚠ To display two traces simultaneously, DEC mode is generally selected, except with high frequencies where the ALT mode is required to avoid showing the trace chop. ALT mode should not be used for low frequencies for visual convenience.

Time base:

17. Setting of the horizontal position of the traces.

18. Selection of the time base (in s, ms or µs / division): x axis scale.

19. VAR position (variable) ⇒ adjustable time base, between two 18 positions.

⚠ Always check that the switch is set to the CAL position before starting (calibrated)

20. Zoom (or enlargement); sometimes provided by a 2nd, rapider, time base.

⚠ Always check that the switch is set to the x1 position before starting (no zoom)

Synchronisation:

21. Trigger level: determines the start of the trace (on the left margin of the screen), when the signal reaches this voltage level.

Figure 140: Start of scanning on the oscilloscope screen

⚠ In manual mode (switch 23 in MANU position), trace stabilisation is only possible if Vmin < level < Vmax (where Vmin and Vmax are peak signal values).

22. Determine if the start of the trace increases (first value) or decreases (last value).

23. Automatic, manual (21) or single sweep (one single screen scan) synchronisation.

24. Resetting after a single sweep (23).

25. Synchronisation according to channel A, or B, or A & B alternating, or an external signal (26).

⚠ When synchronisation is set to A & B alternating, it is as if we were using two separate oscilloscopes (one per channel). The advantage of this synchronisation mode is the ability to display two asynchronous signals (independent signals with independent phases). The drawback of this mode is, precisely, that it does not generally account for the phase difference existing between two asynchronous signals ⇒ always check that the switch is not set to ALT before starting.

26. External synchronisation input using a third signal, neither A nor B. E.g.: 50Hz network signal.

Cursors:

25. Start/stop of the display of cursors on the screen.

26. Selection of vertical cursors (measurements of time intervals) and horizontal cursors (measurement of voltage).

27. Selection between moving one single cursor or both at once.

28. Movement of cursors.

Numerical memory:

29. Start/stop of the numerical memory (if the oscilloscope is digital/numerical...).

30. Save.

31. Display of the most recent recordings.

Check List

List of settings and checks to be carried out before starting:

1) Connect a signal to channel A, after having checked that peak voltage does not exceed the maximum acceptable voltage for this channel.

2) Luminosity (4) in max. position, potentiometers in the vertical position (9) at the mid-point.

3) Vertical amplifications and time base calibrated (11 & 19 on CAL).

4) DC coupling (12), and switch (16) input for DEC.

5) Zoom not active (20 set to NORMAL).

6) Automatic synchronisation (23 set to AUTO), for channel A (25).

7) Numerical memory not active (31 set to OFF).

8) If necessary: *autoset* (3).

9) Check the settings proposed by the *autoset*. Modify if necessary.

The most ‘realistic’ approach is now to practice with a "true" oscilloscope…

Forget spectrum analysers, energy analysers, harmonic analysers, etc. for the time being…

10. GLOSSARY

11. FIGURES

12. TABLES