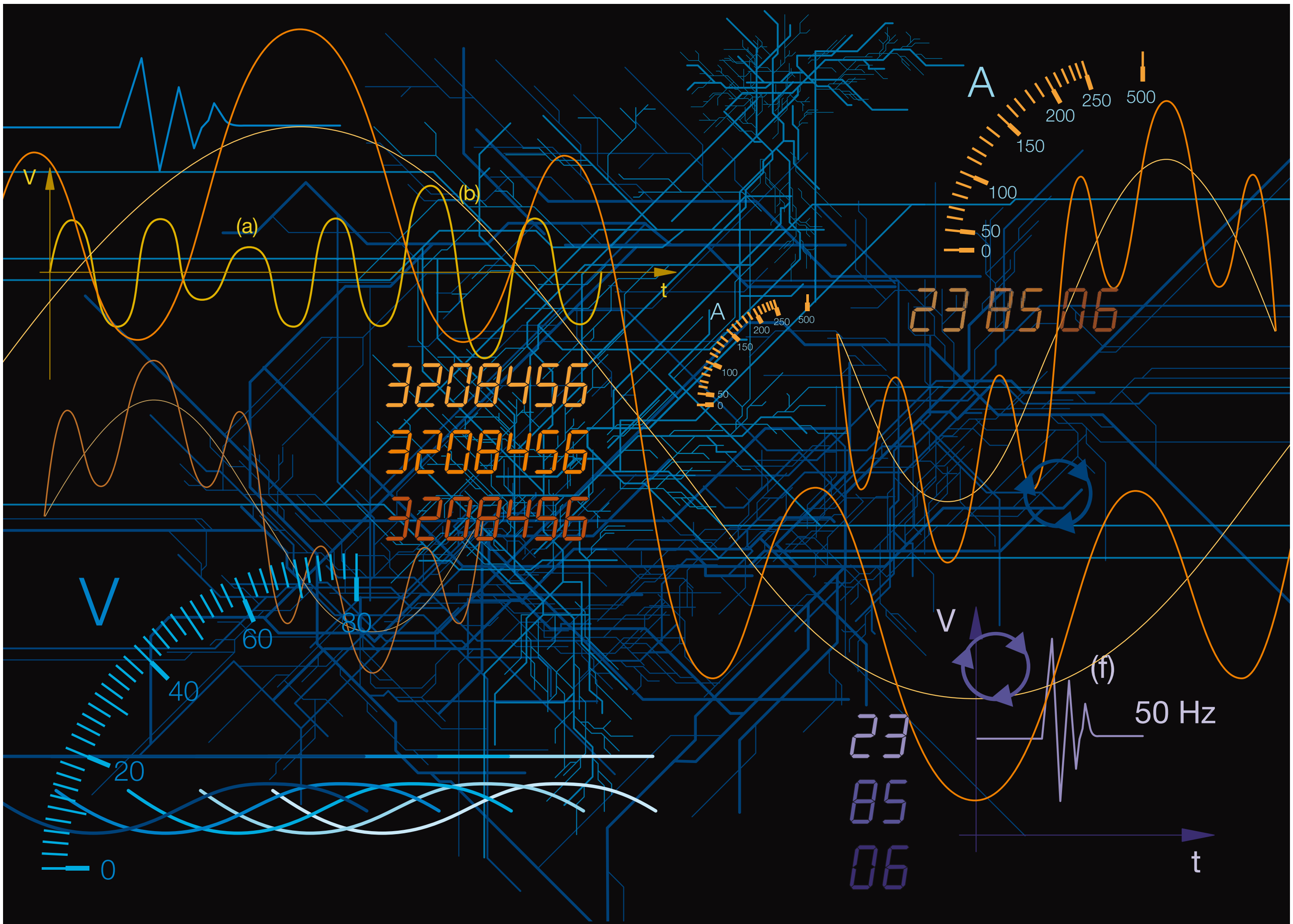


Made to measure.
Practical guide to electrical measurements in low voltage switchboards

Made to measure. Practical guide to electrical measurements in low voltage switchboards

table of contents

Made to measure. Practical guide to electrical measurements in low voltage switchboards

Electric measurements

Measurement: ratio between one quantity and another that is homogenous to it, which is conventionally a unit.
Nevertheless, in the electrical field it is not always easy to find samples to compare, especially for measurements conducted outside equipped laboratories.
In practice, calibrated instruments are therefore used that do not compare the electrical quantity under examination with an electrical sample but with another type of quantity (for example, in analogue instruments, the force exerted by a spring).
The general definition of the measuring concept makes it important to define the units of measurement, which must be invariable and in general reproducible.
The correct units of measurements that have to be used are those indicated by the SI (Système International); Table 1.1 shows the fundamental (or basic) units of measurement of the SI.

Table 1.1 Basic SI unit

Quantity	Unit	
	Standards	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Current	ampere	A
Thermodynamic	kelvin	K
Quantity of substance	mole	mol
Light intensity	candle	cd

Table 1.2 shows the electric and magnetic quantities that are most often encountered and which need to be measured.

Quantity	SI Unit		Dimensional expression
	name	symbol	
- Electric current	ampere	I	A
- Quantity of electricity (load)	coulomb	C	s · A
– Electric potential • potential diff. • electromotive force • voltage	volt	V	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
- Electric capacity	farad	F	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
- Permittivity	farad per metre	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
- Resistance • impedance	ohm	Ω	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
- Resistivity	ohm per metre	Ω · m	$m^3 \cdot kg \cdot s^{-3} \cdot A^{-2}$
- Conductance	siemens	S	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
- Conductivity	siemens per metre	S/m	$m^{-3} \cdot kg^{-1} \cdot s^3 \cdot A^2$
- Inductance	henry	H	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
- Electric field	volt per metre	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
- Load density	coulomb per metre^2	C/m^2	$m^{-2} \cdot s \cdot A$
- Current density	ampere per metre^2	A/m^2	$m^{-2} \cdot A$
- Frequency	hertz	Hz	s^{-1}
- Induction flow	weber	Wb	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
- Magnetic induction	tesla	T	$kg \cdot s^{-2} \cdot A^{-1}$
- Magnetic field	ampere per metre	A/m	$m^{-1} \cdot A$
- Magnetic potential	weber per metre	Wb/m	$m \cdot kg \cdot s^{-2} \cdot A^{-1}$
- Dielectric constant	farad per metre	ε	$m^{-1} \cdot kg^{-1} \cdot s^4 \cdot A$
- Magnetic permeability	henry per metre	μ	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
- Power	watt	W	$m^2 \cdot kg \cdot s^{-3}$
- Energy	watt per second	J	$m^2 \cdot kg \cdot s^{-2}$

Table 1.2 Main electric and magnetic quantities

1.1

Why is it important to measure?

As article 2 of European Directive 374 of 25 July 1985 states that 'also electricity' is a 'product', equating it with any other type of 'movable goods', the first, immediate answer is: to be able to market the product elctricity.
Using a more sophisticated argument, even if it is limited to the management aspects of a power plant (thus ignoring all the technical and scientific questions), there is a clear need in today's market to contain and reduce costs and ensure continuity of service. It has thus become vital to thoroughly familiarise oneself with the operation of an electric plant in order to be able to optimise: consumption, load curves, harmonic interference, voltage disturbances, etc, i.e. all the elements that contribute to increase efficiency, improving competetitivity, and, an important factor today, reducing harmful emissions in the environment.
Lastly, still from the management point of view, measuring and monitoring electrical quantities enable fault prevention to be optimised and maintenance to be scheduled owing to early identification of problems that results in greater protection not only of the plants but also of the objects connected to them.

1.2

Applicational contexts

An efficient system of measuring and monitoring electrical quantities is important for ensuring the success of all initiatives that require:
- energy costs to be contained;
- quality energy supplies;
- continuity of service of the plants.

Specifically, achieving the above objectives requires the activities to be implemented that are set out in the flow chart in Fig. 1.1.

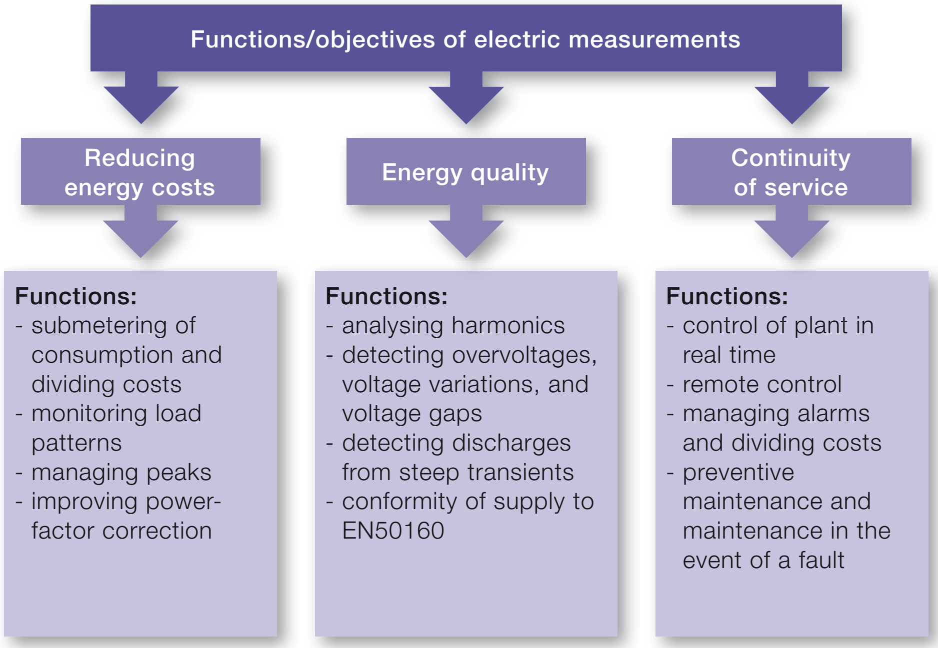


Fig. 1.1: Functions and objectives of electric measurements

ABB measuring instruments are analogue and digital network analysers and energy meters that optimise the above functions in the most varied applicational contexts:
- residential and commercial buildings
- industries
- shopping centres
- garages
- colleges and campuses
- trade fair sites, exhibition venues
- tourist ports
- hotels and camp sites

All the ABB instruments, both of the DIN rail and panel front type, are distinguished by the superiority and excellence of their properties, and last but not least, they enable low voltage power panels and cabinets cabled into the power centres to be enhanced and their aesthetic appeal to be approved.

1.3

Problems connected with energy networks

In order to define the features of the power supply at the delivery points, a distinction must be made between normal and emergency operation of an electrical system.

An electrical system is running normally when it is able to meet the load supply, eliminate faults and resume operation with ordinary means and procedures if there are no exceptional conditions due to external influences or significant critical situations.

Emergency operation occurs when, owing to insufficient generation capacity or because of situations having a grave impact on the system, or owing to events that are beyond the control of the power provider (deliberate destruction, disasters, strikes, acts of the public authorities, etc), it becomes necessary to interrupt or limit the

service.
The three-phase voltage supplied to the delivery points by the public distribution system during normal operating conditions has the following features (see also Table 1.3):
- frequency
- amplitude
- wave form
- symmetry of the three-phase voltage system.

The distributing body can also impose low voltage signals on the voltage that have the aim of transmitting information on operation.
These features are subject to variation during normal operation of the electrical system due to load fluctuations, disturbances generated by certain types of user equipment or plants and the occurrence of faults, which are mostly due to external events that may cause temporary interruptions to the supply.
As a result, these characteristics are changeable over time, if referred to a specific delivery point; they are changeable in space if at a given moment all the delivery points in a distribution network are considered. Consequently, in both cases, they must be described in statistical terms; Fig. 1.2 shows the different types of variation of voltage amplitude due to transistor and pulse phenomena.
Table 1.4 lists the main disturbing devices, i.e. machines and equipment of the user that may introduce electromagnetic disturbances. They are listed by type of application to show how the same type of device may simultaneously generate several disturbances. For example, a resistance welding unit may generate: dissymmetry and unbalance, voltage fluctuation, voltage variations, respectively indicated in the columns on the right of Table 1.4 by the letters SQ, VF, VV.

Characteristic	Phenomenon	
	Type	Description
Frequency	Variation	% deviation from nominal value
Amplitude	Slow variations	% deviation from nominal value with duration of variation > 10 s
	Rapid variations	% deviation from nominal value with duration of variation < 10 s
	Overvoltages	Rises in voltage measured as instantaneous absolute value or as percentage of nominal value
	Holes	Partial decreases below 90% of rated voltage and duration comprised between 10 ms and 60 s
	Short interruptions	No voltage for ≤ 180 s
	Long interruptions	No voltage for > 180 s
Wave form	Harmonics	They are sinusoidal voltages or currents with a frequency equal to a complete multiple of the basic frequency, the presence of which causes a distortion to the wave form of the supply voltage
	Interharmonics	They are voltages or currents that may be single sinusoidal components with a frequency that is not an entire multiple of the basic frequency or may be an extended spectrum of sinusoidal components
Symmetry of the three-phase system	Dissymmetry	Inconsistent amplitude and/or angle between the measured phases as a degree of dissymmetry

Table 1.3 Voltage characteristics

Key:
a) Voltage gaps:
duration from 10 ms to 60 s, if the voltage is completely cancelled the interruptions are known as short interruptions
b) Non pulsed overvoltages:
the opposite of voltage gaps
c) Slow variations:
amplitude variations in relation to the nominal value with duration > 10 s
d) Pulsed voltages of long duration:
duration comprised between 0.1 ms and some ms originating from faults or manoeuvres
e) Pulsed voltages of medium duration:
duration comprised between 1 and 100 µs of atmospheric origin or from action of switches or circuit breakers or from tripped fuses
f) Pulsed voltages of short duration:
duration < 1 µs originating from actions of switches or circuit breakers in special cases
g) Communication transients:
originating from converter devices and rectifiers

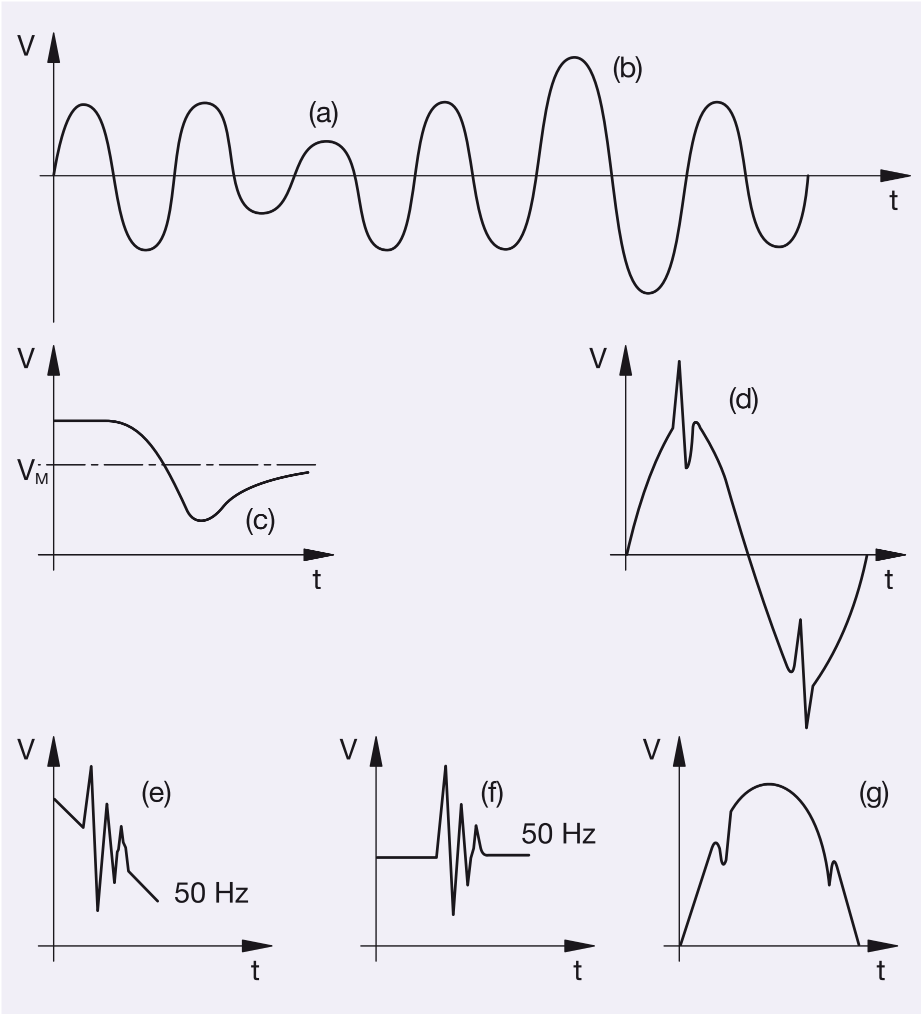


Fig. 1.2: Schematisation of types of variation of voltage amplitude

Key:
SQ = dissymmetries and unbalance
VF= voltage fluctuations
VV = voltage variations
AR = harmonics
SF = spurious frequencies
RE = radioemission
(1) if single-phase
(2) at insertion, when power is not low compared with the power of the short-circuit power of the network
(3) if remote control

Table 1.4 Disturbing devices

Devices	Power	Disturbances generated					
		SQ	VF	VV	AR	SF	RE
Resistance heating	1-40 kW	(1)		(2)	(3)		
Domestic ovens - microwave ovens - infrared ovens	 1-2 kW	 (1) (1)		 • •		 •	 •
Industrial kilns - induction - HF - UHF - plasma - arc	 10-2,000 kW 10-600 kW 10-100 kW some MVA 1-100 MVA	 •	 •	 • • • •	 • • • •	 • • • •	 • • •
Welding machines - resistance - arc	 0.1-2 MW 1-300 kW	 •	 • •	 • •	 (3)		
Motors - asynchronous (e.g. compressors) - variable speed	 < 10 MVA -20 MVA	 • •	 • •	 •	 • •		
Transformers	< 100 MVA			•	•		
Converters -ac/dc -ac/ac and cycle converters	 < 10 MW < 30 MW			 • •	 • •	 •	
Electroerosion	10-30 kW			•			
Discharge lamps				•			
Televisions				•	•		
Radiology				•	•		

The same device may also generate several different types of disturbance at the same time.
Emission levels for the various disturbances are calculated in the following manner:
- the emission level of the single devices is calculated;
- the total emission level of the user is calculated as a composition of the emission levels of the single devices;
- the total emission level of the user is compared with the permitted emission level; this emission level is generally defined by the distributor on the basis of criteria that ensure control of the compatibility levels.

The emission levels are generally measured at the 'common coupling points' that are deemed to be of particular interest: point of common coupling with the national grid (PCC) and internal points of common coupling with the user distribution network (PIC).
The disturbances that occur most frequently and that have to be assessed and contained are:
- harmonics;
- rapid voltage variations;
- flickers.

The latter are voltage fluctuations that have a modulation frequency between 0.5 and 35 Hz and give rise to the phenomenon of flicker, i.e. the sensation of fluctuations in the intensity of the light of the lamps.

1.4

Reducing consumption

The rising cost of electric energy is a significant problem and is one of the parameters that is increasingly coming under scrutiny in order to contain the general costs of a business. Statistics drawn up both nationally and internationally show that every single company can reduce its energy bill from 10% to 30%.
This savings percentage varies according to the evaluation of the consumption made during the power plant design phase and even more for older plants in terms of the consumption analysis and the relative solutions adopted to manage consumption.
The steps required to achieve a good result are summarised in Fig. 1.3.

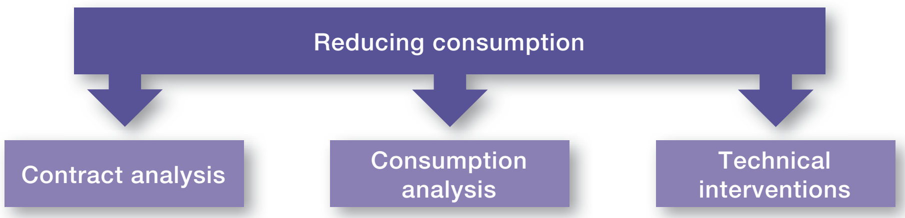


Fig. 1.3: How to reduce consumption

1.5

Table of charges

The analysis of the supply contract for electric power reveals a series of useful pieces of information:

- the power used, i.e. the maximum value of available power that is limited or must not be exceeded in order not to incur penalties;
- the table of charges that can be fixed or may vary according to the time of day;
- the peak or excessive power that exceeds the contractually agreed supply.

The committed power is the maximum usable value that, for contracts for levels of power that are not particularly high (generally up to 35 kW) is managed by a current limiter that interrupts the energy supply when consumption exceeds the committed value.

The power commitment is set during the design stage on the basis of the effective power required for simultaneously running loads during peak consumpton periods.

Each kW committed has a fixed cost and it is therefore advisable to assess actual needs to avoid paying for unnecessary power.

The contract must be signed after an assessment of the most appropriate user network architecture, taking into account the following of the most important parameters:

- number of connection points;
- low or medium-voltage delivery or several low voltage delivery points;
- creating an emergency plant;
- making consumption forecasts on the basis of the actual consumption and not on the sum of the nominal power of the loads (to define available power).

During the course of the supply contract the user should periodically examine the consumption stated in the electricity bills and make analyses/records with suitable instruments; hence the importance of measuring and monitoring energy consumption over time.

1.6

Absorption peaks

For power above 37.5 kW the power provider uses energy meters that measure absorption over time, recording average consumption every 15 minutes (Fig. 1.4).

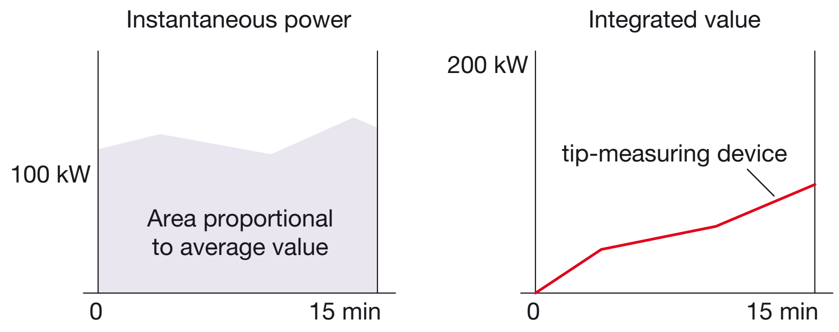


Fig. 1.4: Graphic representation of average consumption

If, for example, the contract is for 100 kW, the peak value is deemed to be within the contractual value if the average value of maximum consumption is 100 kW in 15 minutes, which may be the equivalent of average consumption of 200 kW in 7.5 minutes with 0 kW consumption in the following 7.5 minutes.

In order to avoid penalties, it is important to control and manage absorption peaks so as to never exceed the available power average.

A correct analysis of consumption enables the suitability of the type of contract to be checked against the user's use parameters, thus slashing company costs and avoiding a high price adjustment at the end of the year; for example recording energy consumption at different times of day enables all the power consumption of the day or month to be monitored, thus providing a complete picture of the energy situation.

1.7

Dividing consumption

If it is fundamental to know consumption to optimise energy saving, it is just as important to use the energy available under the contract rationally in order to avoid interruptions to the supply and penalty charges.

In residential or tertiary-sector environments, where the available power is limited and load needs change continuously over the day, it is important to know momentary consumption and to be able to disconnect less important installations if the maximum power level is reached.

For example, if in a domestic environment several machines are working such as: a washing machine, dishwasher, vacuum cleaner, etc that exceed the contractual power, the limiter in the electricity meter of the provider interrupts the supply and disconnects power to the entire system. In simple cases such as this one a load management switch may suffice (for example the LSS1/2 switch), whilst in more complex environments such as industry and the tertiary sector, it is possible to use ABB energy meters of the ODINsingle and DELTAsingle single-phase meters, and ODIN and DELTAplus three-phase meters (see chapter 5 below) to monitor continuously consumption and make contingency plans for cases in which the maximum set value is reached (for example by disconnecting only the installations that are considered to be less important, maintaining the supply to the main installations).

1.8

Power Factor Correction and Maintenance

The power factor or cosφ (which is the phase angle between the phasors of the voltage of the current), must be maintained at a value that is as near as possible to 1, to avoid unnecessary inductive currents that overload the line of the supplier company. As is known, the user devices, which mostly have inductive loads (for example): motors and transformers), need magnetising current to operate that does not produce work but loads the lines, reducing their capacity.

For this reason, the suppliers of electric power apply a penalty when the power factor cosφ is less than 0.9.

It is thus important to measure the power factor and if it does not fall within the contractual limits, power-factor correcting capacitors must be fitted to the out-of-phase lines.

Measuring and recording consumption thus becomes an important indicator for scheduling maintenance, in particular in industrial environments, because identifying the most used lines and devices enables the interventions to be controlled and established in a scheduled preventive maintenance programme.

1.9

Remote and historical reading of information

In order to conduct a thorough analysis of electric parameters and of events, it is important for the measuring instruments to have a system for storing measured data and to be able to transfer remotely such data in order to compare and analyse them. Remote reading and storing information are used especially in plants with a great extent and in the presence of heavy loads, such as, for example, in the large chain stores and in industry.

2 Technical reference standards

In any technical environment and in particular in the electrical sector, in order to make 'workmanlike' devices, all relevant legal and technical standards must be complied with. Knowledge of standards and distinguishing between legal standards and technical standards is thus the basis for a correct approach to measuring-instrument questions that involves not only technical aspects relating to accuracy and safety but also tax and accounting matters.
Legal standards are all those governing the behaviour of parties subject to the authority of the state, including the European directives that are normally enacted in national legislation through legislative decrees.
Technical standards are all the prescriptions on the basis of which the machines, devices, materials and plants have to be designed, built and tested to ensure their operating efficiency and safety.
The technical standards set by national and international bodies (CEI, CENELEC, IEC) have been drawn up in a very detailed manner and can have legal significance when this is assigned to them by a legislative measure.

2.1

IEC standards

Three committees are specifically responsible for measuring instrumentation.
- TC85 "Measuring equipment for electrical and electromagnetic quantities"
- TC66 "Safety of measuring, control and laboratory instruments"
- TC13 "Electrical energy measurement, tariff and load control".

The first committee draws up and publishes the reference standards for all the instruments (voltmeters, ammeters, wattmeters, etc) of both analogue and digital type and provides the prescriptions for the instruments and the sample equipment (batteries, resistors, recording instruments, etc).
Committee 85 is also responsible for a series of standards, all of which are European in origin (from IEC EN 61557-1 to IEC EN 61557-10), dedicated to electrical safety in low voltage distribution systems. These standards also contain some safety prescriptions and the functional features required for the instruments for the tests, measurements and controls of low voltage electric plants such as, for example: earth resistance measuring instruments, instruments for measuring impedance of fault loop, instruments for testing continuity of protection conductors, insulation measuring instruments, etc.
These are therefore particularly important standards for defining the required characteristics of the measuring instruments to be used for the tests prescribed by standard IEC 60364 that governs low voltage electric plants.
Committee 66 deals with the safety prescriptions for electrical measuring devices that must be met by the manufacturer to ensure the safety of the operator.

Lastly, Committee 13 is entirely dedicated to publishing the standards governing active energy and reactive energy measurements and the relative devices: meters, integrated units, devices of different types. In this connection the following standards have particular importance for the purposes of tests on energy meters: EN 50470-1, EN 50470-2, EN 50470-3, which set the test prescriptions both for electromechanical active energy meters and for static meters.
Fig. 2.1 summarises the standards to which measuring instrumentation is subject.

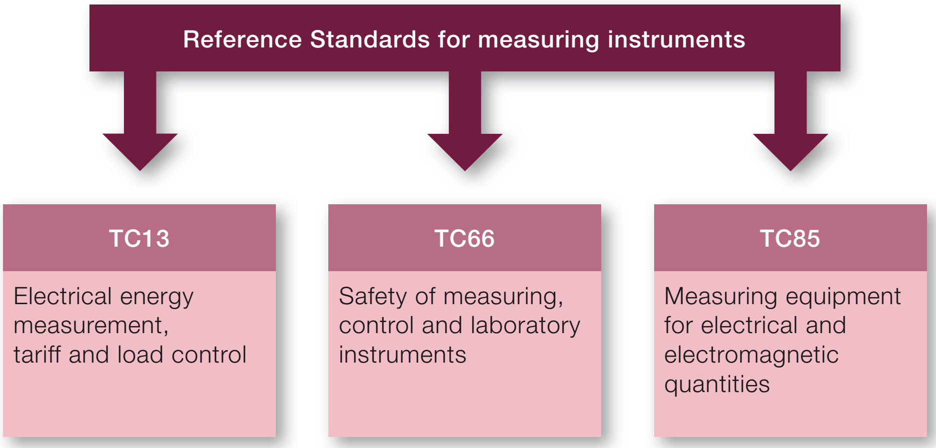


Fig. 2.1: Reference Standards for measuring instruments

2.2

MID Directive

European Directive 2004/22/EC of 31 March 2004 introduced a Community framework law governing devices and systems with measuring functions relating to common consumer goods: water, gas, fluids in general and, in particular, *"active electric energy meters and measuring transformers"*, which are identified in the directive by MI-003.
The directive states that the measuring instrument must conform to '*the particular requirements which are applicable to the instruments in question*'; for the active electric energy meters, the annex defines specific requirements in terms of: accuracy, operating conditions, maximum tolerated errors, procedures for ascertaining conformity.
The directive applies to all electric energy meters, whether they belong to the utility company or to private individuals, that are installed for any reason in plants for measuring and/or metering electric energy; it is also specified that the meters can be used in combination with external transformers.
The significance of the directive is considerable, not only because it proposes eliminating all unreliable measuring instruments that have not been constructed in conformity to the product standard and sometimes do not even have CE marking, but also because it enables instrumentation to be used (provided that it conforms to the directive) also to meter energy for tax purposes.

3 Measuring instruments

For the last few decades both analogue and digital measuring instruments have existed alongside one another.
The former are devices in which the information is associated with physical quantities that are continuously variable whereas in digital instruments (that emerged later in the 1970s and 1980s with the arrival of electronics and IT) the quantities have discrete values (as in the word 'digit').
These instruments consist of an A/D transducer-converter system for transforming any non electric input quantity into an outlet analogue electric quantity (generally voltage) and subsequently converting into digital form, and of a counter system for providing information on the number of pulses.

3.1

Analogue instruments

In Fig. 3.1 a block diagram shows the initial configuration of an analogue instrument.

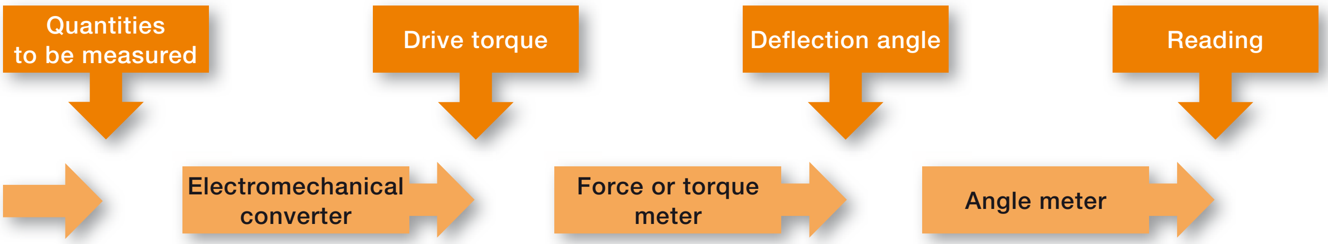


Fig. 3.1: Block diagram of an electromechanical analogue instrument

These instruments exploit phenomena for which the interaction of electric or magnetic quantities gives rise to mechanical force or torque. These instruments consist of a movable part that has an initial rest position, on which a driving torque acts in function of the electric or magnetic quantities on which the associated phenomenon depends.
The driving torque is opposed by restoring, normally elastic, torque, which, depending on the movement, tends to return the movable part to the initial position when the action produced by the driving torque ceases.
From the balance of the two torques an angular deviation is obtained that is proportional to the quantity to be measured.
An index fixed to the movable part rotates along a scale. In general, the manufacturer places on the dial of the instrument certain conventional symbols that characterise not only the unit of measurement but also the operating principle, the connection network (direct or alternating), the accuracy rating, operating position (horizontal, vertical) and safety prescriptions (test voltage).
The conventional symbols that are generally used are summarised in Tables 3.1. and 3.2.

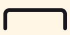
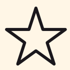
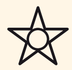
Circuits in which it can be inserted			
Circuit	**Symbol**	**Circuit**	**Symbol**
Direct current		Three-phase alternating current with a current circuit and a voltage circuit	
Alternating current		Three-phase alternating current with two current circuits and two voltage circuits	
Direct and alternating current		Three-phase alternating current with three current circuits and three voltage circuits	
Arrangement of the instrument			
Arrangement	**Symbol**	**Arrangement**	**Symbol**
Instrument to be used with vertical dial		Instrument to be used with tilted dial	
Instrument to be used with horizontal dial		Angle of tilt (optional)	
Test Voltage			
Voltage	**Symbol**	**Voltage**	**Symbol**
Test voltage 500 V		Test voltage 5,000 V	
Test voltage 2,000 V		Instrument exempt from voltage test	

Table 3.1 Identification of the instruments and symbols shown on the dial

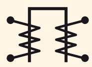
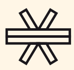
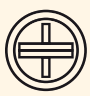
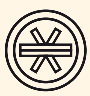
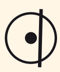
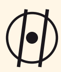
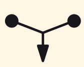
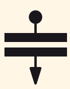
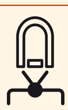
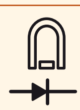
Instrument	Symbol	Instrument	Symbol
Fixed magnet and moving coil		Fixed magnet and moving coil as ratio measuring device	
Movable iron		Movable iron as ratio measuring device or as differential instrument	
Electrodynamic		Electrodynamic as ratio measuring device	
Electrodynamic with iron		Electrodynamic with iron as ratio measuring device	
Induction		Induction as ratio measuring device or as differential instrument	
Hot-wire thermal overload fuse		Bi-metal blade thermal overload fuse	
Electrostatic		Vibrating blades	
Movable thermocouple reel		Movable reel with rectifier	

Table 3.2 Identification of the instruments and symbols of the operating principle

Digital instruments

The operating principle of digital instruments is based on analogue-digital conversion techniques; decoding and display devices are always associated with them, as are very often sample frequency oscillators and decimal count circuits. The block diagram is shown in Fig. 3.2.

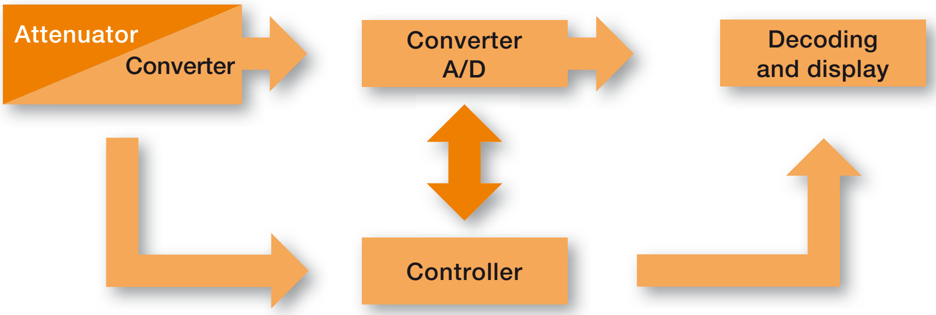


Fig. 3.2: General configuration of a digital instrument

The digital instruments are essentially voltmeters for direct currents; nevertheless, using usual conversion systems from VAC to VDC (especially thermocouple conversion systems) and introducing direct-current sources, they can become universal instruments for also measuring high-frequency voltage up to a few hundred kHz and resistences.

If these measuring instruments are in place they can be used to store and subsequently call up measuring values, and process them and control them remotely, as they can be interfaced with microprocessor systems until automatic measuring structures of great functional versatility are obtained.

Two particular aspects must be borne in mind when constructing and using digital instruments in order not to compromise operation and safety:

- electromagnetic inference;
- earth sockets.

The manufacturer of the instrument protects it directly against electromagnetic interference by providing the instrument with an electrostatic screen (a non ferrousmagnetic metal) that is also effective against high-frequency electromagnetic fields.

This screen can be connected to one of the measuring terminals or it can constitute a third terminal in its own right.

In the first case so-called 'unbalanced' measurements are obtained as one of the two terminals has to be connected to the measurement earth, so that only two voltage measurements are possible that refer to the earth potential.

On the other hand, in instruments with three terminals, two are dedicated to measuring and one that is dedicated to shielding is earthed. In this case potential differences can be measured also between the two points that are both outside earth and the type of measurement is known as 'balanced'.

Earth connections are defined as a point the potential of which remains constant and which is assumed to be a reference potential; this is obtained through an earth connection with very low impedance.

In electronic/digital instruments it may be necessary to have several reference points to which distinct parts of the circuits of the instrument belong; these points are known as mass connections and are ohmically isolated from one another (the capacitive coupling must also be minimised).

The symbols that are most commonly used for earth and mass connections are set out in Fig. 3.3.

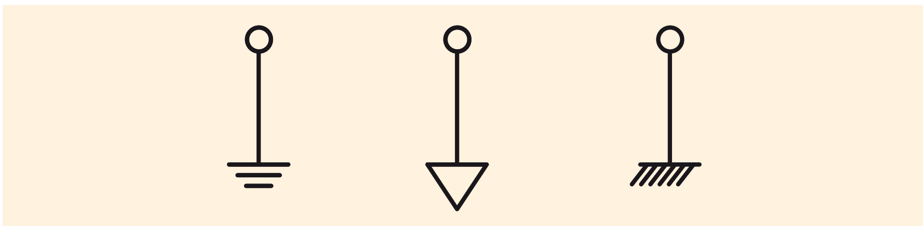
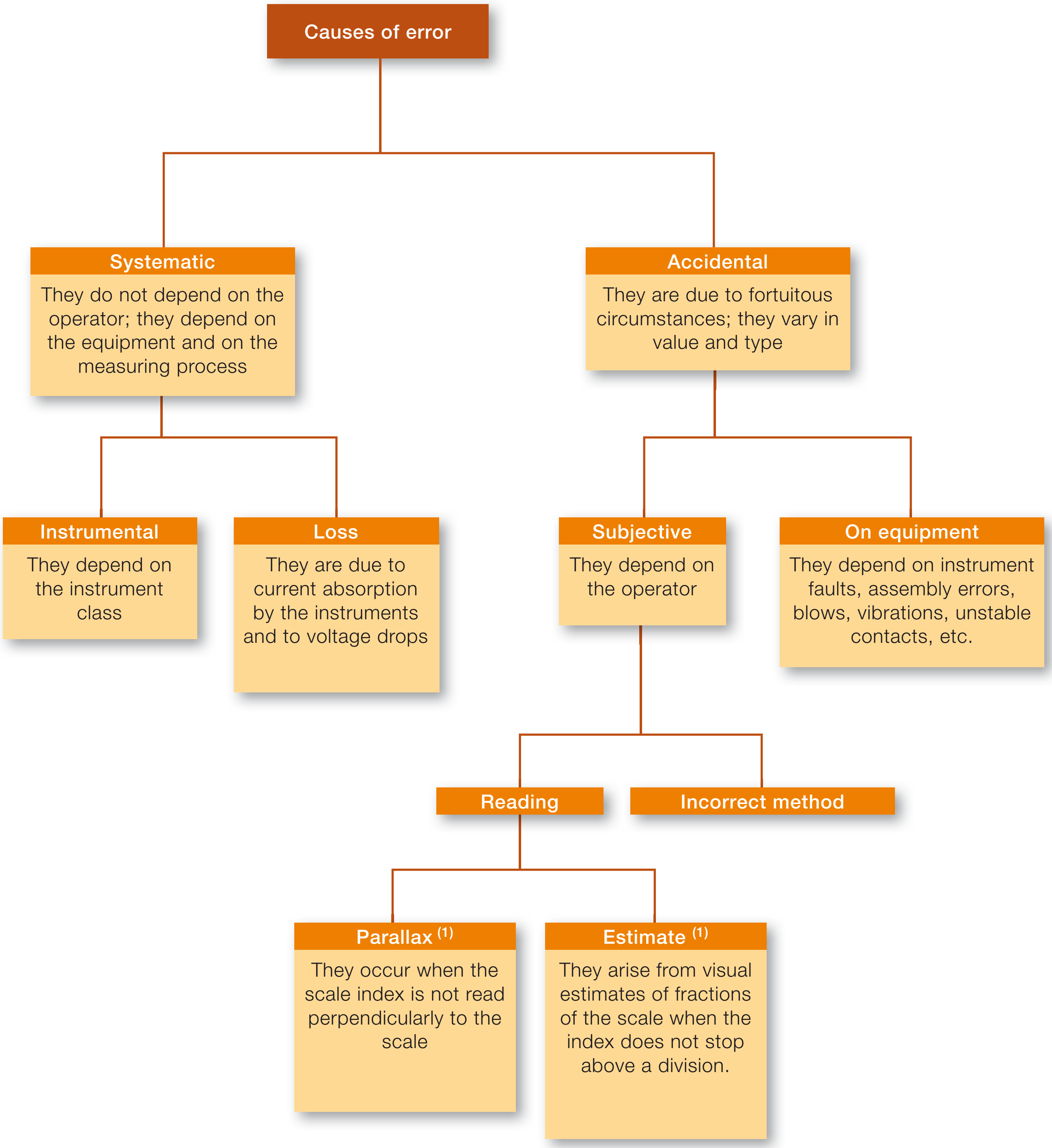


Fig. 3.3: Symbols most commonly used for earth (a) and mass (b, c) connections

Measurement errors and accuracy ratings

No measurement can be considered exact. The limits must therefore be established each time within which the value of the measured quantity falls, thus defining the margin of error of the measurement.
Errors may arise in a measuring operation for many reasons and have various origins. Apart from the errors due to major mistakes (e.g. fitting an instrument incorrectly), it is possible to divide the types of error into two categories: systematic and accidental, as explained better in the block diagram in Fig. 3.4.



(1) Parallax and appreciation errors are typical only of analogue instruments

Fig. 3.4: The main causes of error in electric measurements

Regardless of the causes of the error, an absolute error is defined as ε_a of the measurement of any quantity, the difference between the value V_m supplied by the measurement and the true value V_V of the quantity under examination. This is thus formulated as:

$$\varepsilon_a = V_m - V_V$$

In practice people prefer to talk of a relative percentage error that is obtained by dividing the absolute error ε_a a by the true value (V_V) of the quantity, all multiplied by 100:

$$\varepsilon_r\ \% = \frac{V_m - V_V}{V_V} \cdot 100 = \frac{\varepsilon_a}{V_V} \cdot 100$$

The formula shows that the percentage error decreases as V_m increases, i.e. by the measured value. As the absolute error does not in general depend on V_m, it is deduced that the relative error is less when the value on the instrument is towards the full scale. In fact, if, for example, there is an absolute value of 0.5 V with a voltmeter that in one case reads 50 V and in the other case 100 V, the errors are:

$$\varepsilon_r\ \% = \frac{0.5}{50} \cdot 100 = 1\ \% \qquad \varepsilon_r\ \% = \frac{0.5}{100} \cdot 100 = 0.5\ \%$$

In other words, in the second case there is a relative error that is the half of the first error. This fact must be borne in mind when choosing the measuring instrument, as in analogue instruments the reading should always be taken towards the end of the scale.
It is equally important to know the accuracy rating of an instrument, to know a priori the absolute errors that will be made and thus evaluate whether the accuracy of the measurement can be considered to be satisfactory.
Electrical instruments are in fact divided on the basis of their accuracy rating into the following categories in conformity to IEC standards:

0.05 – 0.1 – 0.2 – 0.3 – 0.5 – 1.0 – 1.5 – 2.5 - 5

These numbers represent the absolute errors in relation to nominal capacity and are stated as a percentage of nominal capacity.
This means that a 0.5 rating voltmeter with nominal capacity of 200 V must not have at any point of the scale an absolute percentage error that is greater than ± 0.5%. In other words, its margin of absolute error is:

$$\varepsilon_a = \frac{\pm 0.5 \cdot 200}{100} = \pm 1\ V$$

Thus, whatever the voltage value that is read on the instrument, this read value must not be more than 1 V higher or lower than the real value.
The class of an instrument thus coincides, as a numeric value, with the relative error evaluated at full scale, which in the case of the example is:

$$\varepsilon_r = \frac{1}{200} \cdot 100 = 0.5\ \%$$

In the case of digital instruments the percentage error of the read error (with respect to the true value of the measured quantity) is normally indicated with a double index, as in the example shown in the next page.
In particular, the indication with which the error is stabilised is shown by a series of abbreviations and numbers and is generally shown in the instrument's technical data.

Example

Declared error:	±1% rdg. ±4 dgt.;
where:	rdg. is the abbreviation of reading and dgt. is the abbreviation of digit.
Chosen capacity of the instrument	300 V
Resolution	0.1 V
Read value	30 V

To assess the measurement error, proceed as follows:

- maximum error of read value	±1% di 30	= ±0.3 V
- error due to movement of the last digit	±4 digits	= ±0.4 V
- maximum possible error	0.3 + 4	= ±0.7 V

All other things being equal, if instrument resolution were 1V instead of 0.1 V, the measurement error would be:

- maximum error of read value	±1% di 30	= ±0.3 V
- error due to movement of the last digit	±4 digits	= ±4 V
- maximum possible error	0.3 + 4	= ±4.3 V

In digital instruments particular attention must also be paid when the instrument is used to measure alternating current; in this case it is important that the instrument is able to detect the effective true value (TRMS) of the quantity. Many instruments (multimeters, amperometric sensors, etc) have been built and calibrated to measure only quantities with a sinusoidal shape and network frequency (50 Hz).

If these instruments are used in plants with non-linear loads or in the presence of harmonics (user devices such as computers, dimmers, photocopiers, microwave ovens, inverters, televisions, etc) very great reading errors can be made (up to 50% less than the true effective value). In order to include the influence of harmonic currents in the measurement, instruments with a wide frequency response (at least up to 1000 Hz) must be used.

When voltmeters are used to measure voltage in environments with strong magnetic fields (in transformer rooms, in the presence of large engines, near high-voltage lines, etc), great attention must be paid to the influence that these electromagnetic fields may have on the instrument.

The voltmeters that are normally used to conduct voltage measurements in the electrotechnical-plant sector are generally voltmeters with high internal impedance. The high internal impedance of a voltmeter, which is typical of digital instruments or of instruments with an electronic input, is the feature that enables voltage measurements with high resolution to be conducted, i.e. enables small voltage values or small variations to be appreciated even with little energy available. For this instrument also the connecting cables can cause measuring errors due to the presence of strong electromagnetic fields.

In fact, the cables inserted into an electromagnetic field are the seat of induced electromotive forces.

The longer and more extended measuring cables and the higher the internal impedance of the voltmeter, the higher the induced (disturbance) voltage value comprised in the measurement. These voltmeters can indicate voltage values above 100 V with one test probe connected to earth that is not carrying voltage and with the other test probe in the air.

Comparison between the two categories of instruments: advantages and limits

Analogue instruments were the only ones that existed until a few decades ago and they performed (and still perform) their functions outstandingly well; in particular in panel instrumentation their toughness and reliability are still valid and appreciated.

Digital instruments objectively offer many advantages over the corresponding analogue devices, in particular: they are easy to read, as there is no interpolation between two contiguous divisions and the calculation of the constant of the scale, there is greater accuracy and high resolution, low noise level, high measuring speed, the possibility of even direct insertion into an automatic measuring complex controlled by a computer.

The choice of instrument type must be made by assessing real instrument requirements with regard to the electric plant, the panel or the measuring circuit where it has to be inserted: if on the one hand it is pointless to require functions that will never be required, for example, from a voltmeter that has to be inserted into the shopfloor power panel of an engineering company for the sole purpose of indicating the presence of voltage, it should still be remembered that electronic instruments that can store and process the values of the measured quantities are almost indispensable in plants where monitoring the quality of the energy and/or cost reduction (for example for monitoring the pattern of loads) are prime objectives.

4 Direct and indirect measurements: CTs, VTs, converters and accessories

In order to measure electrical quantities, the measuring instruments must be connected to the lines safely, with maximum simplicity and convenience.
Generally, the fundamental parameters to be detected are voltage and current, which respectively require a parallel connection and a serial connection to the line on which the measurement is taken.

4.1

Direct measurements

The direct connection to the line defines a direct measurement of the quantity as the instrument is connected in the measuring point without the interposition of adapters.
The direct measurement is possible only when the quantity to be measured has a level that is within the instrument's capacity.
For example, if 230 V voltage has to be measured, the instrument must have a capacity that is greater than this value (for example 300 V).
This also applies to the current measurements: if currents up to 5 A have to be measured, an instrument with at least 5 A capacity and 0-5 A input is required.
Panel and cabinet instruments for direct measurements generally consist of intruments with very limited capacity (measurement of small current and voltage values) with one or several additional resistances inserted inside for the voltmeters and/or one or more shunts for the ammeters.
When the capacity resistances are inserted into the instrument, the instrument can be connected directly to the lines where the measurement is conducted.

4.2

Indirect measurements

When the quantity to be measured is larger than the capacity of the measuring instrument, a transformer must be interposed that reduces the quantity and supplies the quantity to the instrument with values that are compatible with its capacity. This methodology is defined as indirect measuring.
The measurement conducted via a measuring transformer is defined as an indirect measurement because it does not take place directly on the line under examination.
For example, if a current up to 100 A has to be measured with an current that has a capacity of 5 A, a current transformer (CT) has to be interposed with a transformation ratio of 100/5.
If the current transformer is of the wound primary type, it is connected directly serially to the conductor on which the current has to be measured. On the other hand, if it is of the type with a through primary, the insulated or bare conductor is inserted inside the hole of the device.

The current transformer has an outlet that will supply a current that is reduced by 20 times the current that circulates in the conductor being measured, to which the current with 5 A capacity is connected.
In current transformers the primary winding is intended to be connected serialy to the circuit traversed by the current to be measured, whilst the secondary winding supplies one or more measuring instruments (all serially connected to each other). The wiring diagram in Fig. 4.1. shows these transformers.
Compared with the operating principle of a normal transformer, the CT is designed to make the magnetisation current I_0 negligeable that is required to produce the flow Φ in the core.
In these conditions, the primary and secondary currents are in exact phase opposition and their respective effective values are in a ratio to one another that is inverse to the number of coils N_1 and N_2. In other words:

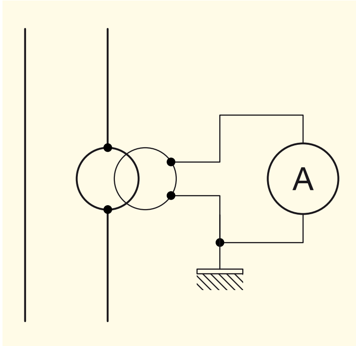


Fig. 4.1: Wiring diagram of current transformer (CT)

$$\frac{I_p}{I_s} = \frac{N_2}{N_1} = n$$

from which:

$$I_p = n\, I_s$$

The coil ratio n between the secondary and primary winding is thus the ideal transformation ratio between the primary and secondary current.
In fact, the magnetic core of the transformer cannot have nil reluctance and IEC 38-1 standards define, for every single transformer, the primary and secondary reference currents, which constitute the nominal currents I_{Pn} and I_{Sn} of the transformer. The ratio between these two currents is the nominal ratio:

$$K_n = \frac{I_{Pn}}{I_{sn}}$$

which is indicated by always specifying the numerator and denominator: the current transformer is, for example, said to have a nominal ratio of 75 to 5 A and is written for the sake of brevity as CT 75 A / 5 A.
Table 4.1 shows the ratio and angle errors (phase difference between the primary and the secondary current) permitted by IEC standards for current transformers.

Accuracy rating	Current as % of nominal value	Ratio errors %	Angle errors	
			in arc minutes	in hundredths or percentages
0.1	10 10 100 120	± 0.25 ± 0.2 ± 0.1 ± 0.1	± 10 ± 8 ± 5 ± 5	± 0.3 ± 0.24 ± 0.15 ± 0.15
0.2	10 20 100 120	± 0.5 ± 0.35 ± 0.2 ± 0.2	± 20 ± 15 ± 10 ± 10	± 0.6 ± 0.45 ± 0.3 ± 0.3
0.5	10 20 100 120	± 1 ± 0.75 ± 0.5 ± 0.5	± 60 ± 45 ± 30 ± 30	± 1.8 ± 1.35 ± 0.9 ± 0.9
1	10 10 100 120	± 2 ± 1.5 ± 1 ± 1	± 120 ± 90 ± 60 ± 60	± 3.6 ± 2.7 ± 1.8 ± 1.8
3	50 120	± 3 ± 3	no prescription	
5	50 120	± 5 ± 5	no prescription	

Table 4.1 CT ratio and angle errors permitted by IEC standard.

When there is the problem of measuring high voltages or voltages that are greater than the capacity of the instrument, voltage transformers are used (indicated by the letters VT), the primary of which is supplied with the U_P voltage to be measured whilst the transformers use the secondary to supply the measuring instruments (all parallel to one another) at the U_S voltage.
The wiring diagram in Fig. 4.2. shows these transformers.

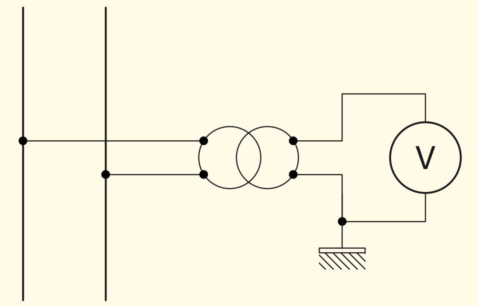


Fig. 4.2: Wiring diagram of voltage transformer (VT)

Similarly to the current transformers, the theoretical ratio n between the number of coils of the two windings (ideal transformation ratio) is given by the formulas

$$\frac{U_P}{U_s} = \frac{E_P}{E_s} = \frac{N_P}{N_s} = n$$

However, in practice the falls in ohmic and inductive voltage of the two windings mean that the ratio U_P/U_S differs from the coils n ratio, giving rise to a ratio error η_V %. Accordingly, for every single transformer, the manufacturer sets the nominal primary and secondary voltages, which correspond to a set load condition: the two defined voltages constitute the nominal voltages of the transformer, which must be indicated respectively by the symbols U_{Pn} and U_{Sn}.
The ratio between these two voltages is the nominal ratio of the transformer:

$$K_n = \frac{U_{Pn}}{U_{sn}}$$

which must be indicated by always specifying the two terms: the voltage transformer is, for example, said to have a nominal ratio of 10,000 to 100 V and is written for the sake of brevity as VT 10,000 V / 100 V.
Also for the VTs Table 4.2 shows the ratio and angle errors specified by the IEC standard.

Table 4.2 VT ratio and angle errors permitted by IEC standard.

Classes	Ratio errors %	Angle errors	
		in arc minutes	in hundredths
0.1	± 0.1	± 5	± 0.15
0.2	± 0.2	± 10	± 0.3
0.5	± 0.5	± 20	± 0.6
1.0	± 1	± 40	± 1.2
3.0	± 3	no prescription	no prescription

To conclude this discussion of voltage and current measuring instruments, we remind the reader that when the margin of error of the measurement is evaluated, the error of the instrument must always be added to the error of the transformer; e.g. if the accuracy rating of the instrument is 1.5 and the accuracy rating of the transformer is 0.5 the margin of error can be ± 2% of the read value (accuracy rating 2).

4.3

Shunts for direct current

When the capacity of an instrument is less than the current to be measured, shunts are used: these are additional resistors that are connected parallel to the instrument to shunt part of the current to be measured and to limit the current that passes through the instrument to an acceptable value.
Fig. 4.3 shows the wiring diagram of a shunt for measuring a direct current via a millivoltmeter.
In order to reach the desired capacity, the shunt must be proportioned (or selected) according to the current divider; in the Fig. 4.3 we have:

$$I \frac{R_s}{R+R_s} I' = \frac{1}{m} I'$$

from which:

$$I' = m\, I = K'_A\, n$$

being $m = \frac{R+R_s}{R_s} = \frac{I'}{I} I'$

the multiplying power of the shunt, n the number of divisions read on the scale, and K'_A the new reading constant of the instrument, expressed by the product $K'_A = m\, K_A$

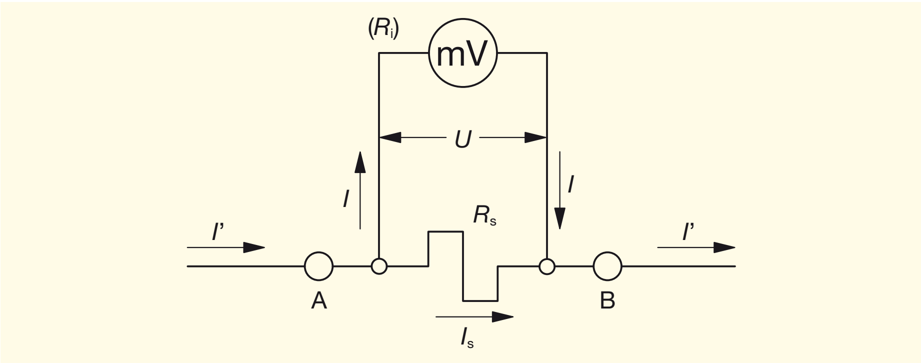


Fig. 4.3: Measurement of direct current with millivoltmeter and external shunt

4.4

Converters and accessories

The converters are devices that, if they are connected to electric networks with an alternating current signal, are able to provide a direct current or voltage signal that is proportional to the input signal, regardless of the load.
They are particularly suitable for acquiring highly reliable and accurate data and are not affected by temperature variations and vibrations.
The converters generally have several outputs that can be selected to adapt to various needs.
In addition to the CTs, VTs and to the converters, the measuring accessories are:

- the interchangeable scales to adapt analogue instruments to the desired capacities;
- the current and voltage switches for switching readers on several current and voltage phases;
- the transducers, which are necessary for the direct insertion of the analogue power-factor meters.

Current and voltage converters converters produce a direct current or voltage output signal that is independent of the load that is directly proportional to the input voltage or current signal.
Their electronic circuit ensures their reliability and operating accuracy, the extension of the measurement field, insensitivity to temperature variations and vibrations, and limited absorption of power from the circuit being measured. Their rapid centralised acquistion of data, even over great distances and the availability of different types of selectable outlets by acting simply on the adjusting minidips, makes them suitable for being installed in plants that require particular attention in production, distribution and use of electric power.

Fig. 4.1 – Current and voltage converters

5

Overview of ABB range

The measuring instruments for installation inside industrial switchboards for primary and secondary distribution of medium and low voltage are an ideal complement to ABB devices with which to configure the panel as an integrated functions system.
The range comprises about 1000 products in the basic versions but engineering/ standardisation of the components also makes many special versions available in order to satisfy any type of plant need.
Both analogue and digital instruments are available: in the former the reading function is provided by movement of a movable index along a graduated scale, which enables the detected values to be read immediately; the digital versions are, on the other hand, equipped with 3 or 4 digit display LEDs, depending on product type.
In both versions, the operating temperature is between -10 °C and +55 °C, with the possibility of operating in even more difficult conditions without substantial alterations to the accuracy rating.
The resistance to vibrations and the IP protection grade are particularly high.

5.1

Analogue instruments

In addition to normal devices for measuring electrical parameters (volt meters, ammeters, power-factor meters) the range of analogue ABB instruments comprises special instruments (meters) and a series of accessories, including the current transformers, which extend their operating range.
There are two distinct product ranges: the DIN rail products, which are snap-fitted onto an ordinary DIN rail and have dimensions, compactness and design that perfectly suit the command and protection devices of the System pro *M* compact®, System series and the panel front instruments that can easily be mounted in the medium and low voltage primary and secondary industrial distribution panels. They are fitted by means of screw brackets that enable the device to be placed both in a horizontal and vertical position, thus optimising space occupied and rationalising access from the front of the panel.

5.1.1

DIN rail analogue instruments

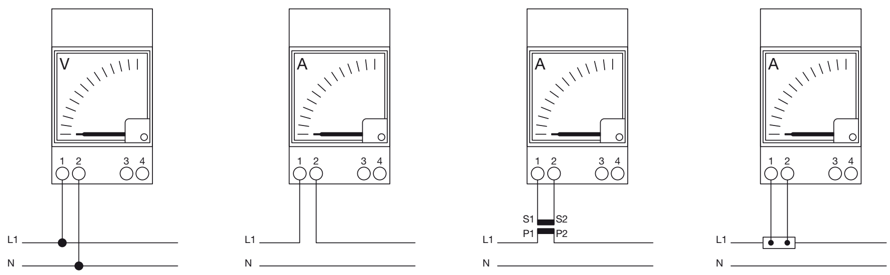
Table 5.1 summarises the characteristics of DIN rail ABB analogue instruments; for complete information on the technical characteristics of the devices, see the technical catalogue System pro *M* compact®.

ABB analogue measuring instruments	
AC	**DC**
- Direct voltmeters - Direct ammeters - Ammeters without scale for CT - Frequency meter 45-65 Hz - Power-factor meter with scale for transducers (1 mA input)	Direct ammeters Ammeters without scale for shunt

Technical characteristics			
Rated voltage Un		[V]	AC 300, 500; DC 100, 300
Rated alternating currents	direct reading indirect reading	[A]	full scale values 5...30 full scale values 5...2500
Rated direct currents	direct reading indirect reading	[A]	full scale values 0.1...30 full scale values 5...500
Frequency		[Hz]	50/60
Overloadability		[%]	20 compared to rated voltage or current
Accuracy rating		[%]	1.5 (0.5 for frequency meters)
Dissipated power		[W]	see System pro *M* compact® catalogue
Modules		[n°]	3
Standards			EN60051

Table 5.1 ABB DIN rail analogue measuring instruments

Both the direct insertion instruments and those that are insertible via CT or shunts (see figure 5.1 for insertion methods) do not require an auxiliary supply.
For the former it is sufficient to connect after choosing the rated voltage or current; for the others:
- choose the nominal measurement (current, voltage, ...);
- select the current or voltage transformer, shunt or transducer;
- select the appropriate scale;
- connect the instrument.



Direct insertion Insertion via CT Insertion via shunt

Fig. 5.1: Insertion method (direct, via CT and shunt) of the analogue instruments

5.1.2

Analogue instruments on front of panel

The range includes voltmeters, ammeters, power-factor meters and frequency meters with a fixed or movable reel, depending on versions.
With the passage of current in the devices provided with a fixed reel, the torque produced by the electromagnetic field moves a piece of iron along the quadratic scale, the iron being connected to the display index.
Owing to their particular resistance to current peaks, fixed reel devices are more suitable for alternating current. With the passage of current in the devices provided with a fixed reel, the torque produced by the electromagnetic field moves a piece of iron along the quadratic scale, the iron being connected to the display index.
The clockwise movement of the index depends on polarity, which means that these devices can be used for direct current only. The voltmeters and the ammeters, which are available both in the version for alternating current and in the version for direct current, are supplied in three standard dimensions of 48 mm x 48 mm, 72 mm x 72 mm and 96 mm x 96 mm (special versions available on request).
For ammeters without a scale, the interchangeable scale code with which accessorise them is indicated. The range of front panel measuring instruments is completed by power-factor meters and frequency meters for applications on single-phase and three-phase

alternating current lines in the three standard dimensions of 48 mm x 48 mm, 72 mm x 72 mm and 96 mm x 96 mm.
Fig. 5.1 shows some of these instruments and the technical specifications are set out in Table 5.2.
For a complete description of the instruments, the type and the code for ordering, see the technical catalogue 2CSC400002D00209 System pro *M* compact®.

Fig. 5.2: Analogue measuring instruments on front of panel

Technical characteristics		
Max. rated insulation voltage	V	650
Test Voltage	V	2000 effective (50 Hz/1 min)
Accuracy rating		1.5 (0.5 for frequency meters)
Overloadability[1] :		
- ammeter windings		up to In x 10/<1 sec.
		up to In x 2/permanent
- voltmeter windings		up to Un x 2/<5 sec.
		up to Un x 1.2/permanent
Operating temperature	°C	-20…+40
Storage temperature	°C	-40…+70
Average and max. relative humidity (DIN 40040)[2]		65% (annual average) 85% (+35°C/60 days per year)
Vibration resistance (IEC 50-1)	g (9.81 m/s)	0.08-1.8 (0.35 mm/10-55 Hz; 3 axes/6 h)
Protection class		IP52 for interior
		IP00 on terminals (IEC 144, DIN 40050)
		IP40 with the terminal covers
Manufacturing material:		
- cases and front edge		self-extinguishing thermoplastic material conforming to UL94 V-0, resistant to fungi and termites
- display indices (DIN 43802)[3]		moulded aluminium
- terminals		brass
Assembly		vertical/horizontal by means of screw brackets[4]
Dimensions L x H x D (DIN 43700/43718)	mm	48 x 48 x 53 72 x 72 x 53 96 x 96 x 53
Reference Standards		IEC EN 61010-1

(1) In instruments with insertion by CT, the overload may be greater because the transformer contains the peaks of secondary current within 10 In.
(2) Tropicalisation enables values up to 95% max. relative humidity to be tolerated (+35 °C/60 days). DIN 40040 requires them to be protected from humdity penetrating inside them. Terminals, screws, washers, bolts and magnets are galvanically protected against rust whereas the electrical circuits are coated with special Multicolor PC52 paint.
(3) The damping time for the display indices is 1 second. The detected values are reset by means of the appropriate adjustment.
(4) With panels that are 0.5 mm – 19 mm thick the screws must be fitted in the fixing position that is nearest the front edge of the measuring device. The panels that are 20 mm - 39 mm thick are fixed by screws in the position that is furthest away from the front edge.

Table 5.2 Technical characteristics of front panel analogue measuring instruments

Advantages

Analogue ABB measuring instruments are distinguished by their reliability and stability in indicating the measured value, thus making even remote reading simple; they also have the following features, which are much appreciated during the installation phase:
- reduction of overall dimensions;
- complete range for panel front instruments (48 x 48, 72 x 72, 96 x 96 mm);
- do not require auxiliary supply;
- are able to provide multiple readings thanks to the selectors.

It is very convenient for the fitter and wholesaler to have a single instrument with ample capacity (from 5 A to 2500 A), complete with a wide range of accessories and accompanying devices for insertion, which include the DIN rail switches (fig. 5.3).

Fig. 5.3: DIN rail switches and front panel switches

A final note on the type of scales available that are interchangeable to extend the reading scope of electrical measurements detectable with analogue measuring instruments.

For example, in figures 5.4a and 5.4b two different types of dials for scales are shown: the first has a traditional 90° full scale, the second has a 78° full scale plus an extra scale, which can be usefully used when, during the measurement, peak currents that could exceed the full scale are detected (for example during the startup phase of an asynchronous motor).

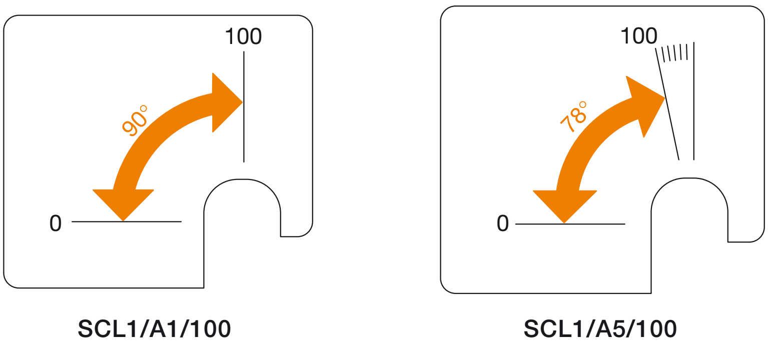


Fig. 5.4: a – 90° full scale
b – 78° full scale with extra scale

5.2

Digital instruments

The range of ABB digital instruments is particularly wide: alongside traditional measuring instruments (voltmeter, ammeter, frequency meter), both in the DIN rail and in the panel front version, there are:

- the multimeters of the DMTME series that not only enable the main electrical quantities to be measured but also store the maximum, minimum and average values of the main electrical quantities and count active and reactive energy;
- MTME and ANR series network analysers that not only monitor the quality of the energy in real time but are also able to disconnect loads and send alarm signals;
- energy meters;
- temperature measuring units.

In addition, a wide range of accessories make these instruments universal for electric plants and networks in the following range:

- voltage up to 600 V
- current up to 999 A
- frequency: from 40 to 80 Hz

It should lastly be noted that the absence of parts subject to wear through friction ensures a longer operating life and particularly high regulating accuracy.

5.2.1

DIN rail digital instruments

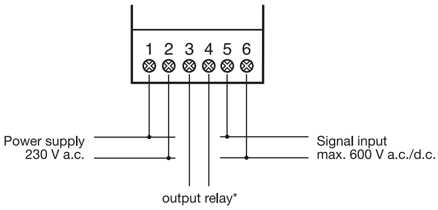
Table 5.3 summarises the characteristics of ABB DIN rail digital instruments; for complete information on the technical characteristics of the devices, see the technical catalogue System pro *M* compact®.

Table 5.3 ABB digital measuring instruments

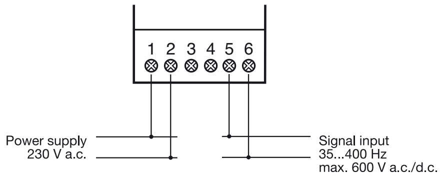
All the instruments offer high measuring accuracy (0.5 rating) and easy and accurate reading of the measured values: the range is completed by instruments with an internal relay which display and monitor a measurement and when a programmable threshold is exceeded they trip a relay contact and display the alarm condition. The alarm threshold can be programmed as a minimum or maximum threshold. The minimum and maximum recorded peak values are saved in the instrument's permanent memory. The relay action is programmable. The factory setting is normally open contact that closes only in the event of an alarm. In programming mode the instrument can be configured in such a way that the relay works with positive safety: in this case the relay will close during correct operation and will open in the event of an alarm or power failure. The instrument with the realy can be used alternatively either as a minimum realy or as a maximum realy but not simultaneously for both alarms. The intruments also enable the minimum and maximum measurement value to be stored and displayed.

Wiring diagrams for digital instruments, both DIN rail and front panel

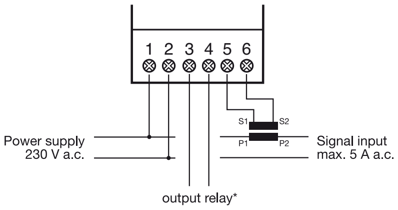
VLMD-1-2 and VLMD-1-2-R
VLMD P and VLMD-R P



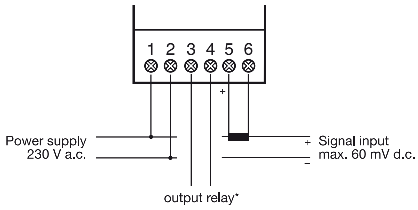
FRZ-DIG



AMTD-1 and AMTD-1-R
AMTD-1 P and AMTD-1-R P



AMTD-2 and AMTD-2-R
AMTD-2 P and AMTD-2-R P



*Only for instruments with output relay

Fig. 5.5: Insertion method of different ABB digital instruments

5.2.2

Front panel digital instruments

These instruments are provided with three-digit red LEDs displays to indicate immediately the electrical values detected.
A few simple operations enable the multiscale function to be accessed that enables the range of displayable quantities to be varied or extended.
The product range comprises voltmeters, ammeters for direct or indirect measurements using device transformers and shunts and temperature measuring units. The application can be run in both alternating and direct current.
The absence of mechanical parts that are subject to wear makes these instruments very reliable and durable.
Fig. 5.1 shows some of these instruments and the technical specifications are set out in Table 5.4.
For a complete description of the instruments, the type and the code for ordering, see the technical catalogue 2CSC400002D0208 System pro *M* compact®.

Fig. 5.6: Panel front digital measuring instruments

Technical characteristics		
Power supply	[V]	230 V CA
Rated frequency	[Hz]	50÷60
Ammeter full scale value	[A]	5, 20, 25, 40, 60, 100, 150, 200, 250, 400, 600
Voltmeter full scale value	[V]	300, 500
Frequency meter range	[Hz]	35...400
Tripping delay	[s]	1, 5, 10, 20, 30
Hysteresis	[%]	5, 10, 20, 30 set threshold
Output pins	[V]	3-4
Output relay	[A]	NO
Rated voltage relay	[In/Vn	230 V CA
Rated current relay	[%]	AC1 16, AC15 3
Relay configuration		NO relay closes in alarm status
		NC relay opens in alarm status, positive safety
Overload	[In/Vn]	1, 2
Accuracy class	[%]	±0,5 full scale ±1digit at 25 °C
Max. signal input value for ammeters	[°C]	5 A CA/60 mV DC
Display	[°C]	3 digit LED display
Operating temperature	[VA]	-10…+55
Storage temperature	[mm]	-40...+70
Protection degree		IP20
Power consumption		4
Modules		3
Overall dimensions front panel devices		36x72x61.5 (51.5 depth inside the switchboard)
Standard		IEC EN 61010

Table 5.4 Technical characteristics of digital measuring instruments on front of panel

5.2.3

DMTME multimeters

The instruments of the DMTME series are digital multimeters that enables the main electrical quantities to be measured (TRMS) in 230/400 VAC three-phase networks, the maximum, minimum and average values of the main electrical quantities to be stored and the active and reactive energy to be counted.
The multimeters of the DMTME series enable the same instrument to act as a voltmeter, ammeter, power-factor meter, wattmeter, varmeter, frequency meter, active and reactive energy counter, hour counter. This permits significant savings because both the size of the panel and wiring time are reduced.
Fig. 5.7a shows a DMTME DIN rail (6-modules) multimeter that can be inserted via CT .../5 A for measurements on 230/400 VAC lines (displayable measurements: V-I-W-VA-Hz-kWh-kVARh); the DMTME-I-485 version is provided with two digital outlets that can be programmed as alarm thresholds and pulse outlets for remote control of energy consumption and a serial door RS485.
Fig. 5.7b shows the multimeters to be installed in the front of the panel in the two versions: traditional 96x96 mm and 72x72 mm in the more compact version that is ideal for installation in power centres in which compact dimensions are required. From the serial port RS485 several multimeters and other digital instruments can be connected to the network via the Modbus RTU protocol. All the versions are supplied with a CD containing the instruction manuals, technical documentation, communicaion protocol and DMTME-SW tool.

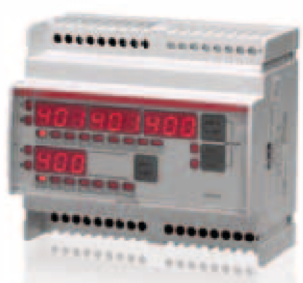


Fig. 5.7a DIN rail multimeter DMTME

Technical characteristics			
Rated voltage	[V rms]	230 +15% - 10%	DMTME-72 and DMTME-96
	[V rms]	240 +15% - 10%	DMTME-72 and DMTME-96
	[V rms]	400 +10% - 10%	DMTME-72
	[V rms]	400 +10% - 10%	DMTME-72
	[V rms]	115 +15% - 10%	DMTME-96
	[V rms]	120 +15% - 10%	DMTME-96
Frequency	[Hz]	45…65	
Power input	[VA]	< 6	
Safety fuse		0.1 A	
Voltmeter inputs			
Range	[V rms]	10…500 V (L-N)	
Non destructive max.	[V rms]	550	
Impedance (L-N)	[MW]	> 8	
Current inputs (only CT .../5 A external)			
Range	[A rms]	0.05…5	
Overload		1.1 permanent	
Measurements accuracy			
Voltage		±0.5% F.S. ±1 digit in range	
Current		±0.5% F.S. ±1 digit in range	
Active power		±1% ±0.1% F.S. from cosj = 0.3 to cosj = -0.3	
Frequency		±0.2% ±0.1Hz from 40.0 to 99.9 Hz	
		±0.2% ±1Hz from 100 to 500 Hz	
Energy count			
Maximum counted value per single phase		4294.9 MWh (MVarh) with KA = KV = 1	
Maximum counted three-phase value		4294.9 MWh (MVarh) with KA = KV = 1	
Accuracy		Class 1	
Max. power consumption		1.4 for each input (with Imax = 5 A rms)	
Digital outputs			
Pulse duration		50 ms OFF (min)/ 50 ms ON	
Vmax on contact		48 V (peak DC or AC)	
Power consumption		450 mW	
Maximum frequency		10 pulses/sec	
Imax contact		100 mA (max DC or AC)	
Insulation		750 Vmax	
Configurable parameters			
VT transformation ratio		1…500	
CT transformation ratio		1…1250	
Free hour counter	[h]	0…10,000,000, resettable	
Countdown	[h]	1…32,000	
Operating temperature	[°C]	0…+50	
Storage temperature	[°C]	-10…+60	
Relative humidity		90% max. (without condensation) a 40°C	
Overall dimensions	[mm]	96x96x103	DMTME-96
	[mm]	72x72x90	DMTME-72

5.2.4

MTME and ANR network analysers

The MTME series network analysers (Fig. 5.8a) enable the main electrical quantities to be measured as true effective values in 230/400 VAC three-phase networks, the maximum, minimum and average values of the main electrical quantities to be stored and the active and reactive energy to be counted on total or partial counters.
Owing to the THD (total harmonic distortion) measurement as an absolute and percentage value, it is possible to monitor in real time the quality of the energy of the plant and to prevent damage to the devices.
MTME network analysers are also able, depending on the version, to manage and disconnect loads to save energy and optimise consumption and to send alarm signals relating to 34 quantities via two relay outlets.

Fig. 5.8a Network analyser MTME-485-LCD-96

Versions with an RS484 port enable all the quantities of an instrument or of a network of instruments to be read and montored locally or remotely.
The local display of the quantities is shown on an LCD display with high-visibility back lighting. The following features are also available:
- automatic recognition of the direction of the CT (selectable)
- programmable main screen
- access password
- frimware that is updatable via PC

All the versions are supplied with a CD containing the instruction manuals, technical documentation, communicaion protocol and DMTME-SW software.

Main characteristics of the MTME-485-LCD-96 network analyser			
Rated voltage		[V rms]	230 +15% - 10%
		[V rms]	240 +15% - 10%
		[V rms]	115 +15% - 10%
		[V rms]	120 +15% - 10%
Frequency		[Hz]	45…65
Power input		[VA]	< 6
Safety fuse			T0, 1A
Voltmeter inputs			
	Range	[V rms]	10…500 V (L-N)
	Non destructive max.	[V rms]	550
	Impedance (L-N)	[MΩ]	> 2
Current inputs (always use CT .../5 A)			
	Range	[A rms]	0.05…5
	Overload		1.1 permanent
Measurements accuracy			
	Voltage		±0.25% ±0.3% F.S.
	Current		±0.25% ±0.3% F.S.
	Active power		±0.5% ±0.1% F.S. from cosj = 0.3 to cosj = -0.3
	Frequency		±0.2% ±0.1Hz from 40.0 to 99.9 Hz
			±0.2% ±1Hz from 100 to 500 Hz
Energy count			
	Maximum counted value per single phase		4294.9 MWh (MVarh) with KA = KV = 1
	Maximum counted three-phase value		4294.9 MWh (MVarh) with KA = KV = 1
Digital outputs			
	Pulse duration		50 ms OFF (min)/ 50 ms ON
	Vmax on contact		48 V (peak DC or AC)
	Power consumption		450 mW
	Maximum frequency		10 impulsi/sec
	Imax contact		100 mA (max DC or AC)
	Insulation		750 Vmax
Configurable parameters			
	VT transformation ratio		1…500
	CT transformation ratio		1…1000
Operating temperature		[°C]	0…+50
Storage temperature		[°C]	-10…+60
Relative humidity			90% max. (without condensation) at 40°C
Overall dimensions		[mm]	96x96x103

If even more advanced analysis functions are requested, the range of ABB panel instruments, and ANR network analysers enable network, information and alarm parameters to be measured and recorded by routing the data to supervision and monitoring systems.
The SW01 software with which they are provided manages the programming, display and recording of the measurement data and of the alarms.
Performance is top level:
- it is possible to measure, record and analyse over 60 electric parameters;

- the voltage and currents are measured as true and effective values (“true RMS”) with 0.5 rating accuracy;
- communcations are provided on: programmable analogue outlets, digital outlets for controls, pulses and alarms, status and/or non-electric parameters acquisition, Modbus, Profibus, ASCII, Ethernet protocols;

The ANR network analysers are available in the 96 x 96 mm recessed format or in the 144 x 144 mm version (the latter have expansion cards) and have graphic back-lighted 128 x 128 pixel graphic LCD displays.
Their use permits extremely efficient monitoring of the quality of the energy in both single-phase and three-phase distribution networks via instantaneous and historical variations of voltage, of supply interruptions, of microdisturbances and of harmonic components up to the thirty-first order and wave shapes, and optimisation of energy costs through prompt and historical analysis of consumption over four periods in a day that are freely selected, with monitoring and disconnection of loads.

Fig. 5.8b: Network analyser ANR 144-230

Main characteristics: ANR 144-230 network analyser			
Packaging			
Overall dimensions	[mm]	96 x 96 x 130 - 144 x 144 x 66	IEC 61554
Max setion of wires	[mm²]	2.5	
Protection class		IP52 frontal-IP20 terminal boards	EN 60529
Weight	[g]	430	
Display			
Graphic LCD		128x128 points with adjustable contrast with LED back lighting	
Display dimensions	[mm]	ANR96: 50 x 50-ANR144: 70 x 70	IEC 60529
Voltage (TRMS)			
Direct measurement	[V]	10 - 600	
Transformation ratio range kTV	[V]	0.01 - 5000,00	
Permanent overload		750, above this value a voltage transformer must be used	
Consumption	[VA]	0.2	
Input resistance	[MW]	> 2	
Current (TRMS)			
3 insulated inputs with internal CTs .../5 A	[A]	0.01 - 5	
Minimum current measurement	[mA]	10	
Consumption	[VA]	0.2	
Display			
Overload	[A]	10 (100 A for 1 second)	
Transformation ratio range kCT		0.01 - 5000,00	
THD			
Voltage and current		Up to 31st harmonic	
Frequency			
	[Hz]	30 - 500	
Accuracy			
Current	[%]	< 0.5	EN 61036
Voltage	[%]	< 0.5	
Power	[%]	< 1	
Power factor	[%]	< 1	
Active energy	[%]	< 1	IEC 62052-11
Reactive energy	[%]	2	IEC 62053-23
Separate power supply			
ANR96-230, ANR96P-230, ANR144-230	[V]	85 ÷ 265 AC/DC	
ANR96-24, ANR96P-24, ANR144-24	[V]	20 ÷ 60 AC/DC	
Internal fuse		5 x 20 mm 315 mA 250 V Fast	
Conditions of use			
Operating temperature	[°C]	-10 ÷ +50	
Storage temperature	[°C]	-15 ÷ +70	
Relative humidity	[°C]	90% non condensated	

continues **5**.2.4

Insulation		
Insulation voltage		3700 V AC rms for 1 minute
Serial output		
RS485		
Programmable Baud rate	[bps]	1.200 - 19.200
Communication protocols		Modbus RTU, ASCII
Internal memory		
For ANR96 and ANR144	[kbyte]	128 (usable 80)
For ANR96P	[Mbyte]	1
Type of memory		Permanent data memory using internal buffer battery
Data storage period		5 years at 25°C
Internal clock		
RTC clock		IEC EN 61038
Accuracy	[ppm]	5
Digital outputs		
Max setion of wires	[mm²]	0 ÷ 2.5
External pulse voltage	[V]	12 ÷ 230 V AC/DC
Max. current	[mA]	150
Digital inputs		
Voltage	[V]	12 - 24 DC

5.2.5

Temperature measuring units

They are used to monitor temperature levels and the ventilation functions of electric machines, transformers, motors, etc. Preventive control of temperature enables malfunctions and overloading to be avoided.
PT100 and RTD probes are used to measure temperatures. For each measurement channel, two alarm levels (tripped alarms) can be set that trip two output relays to remotely signal if a critical temperature level has been reached. The recorded values and possible alarm statuses are displayed on the 3-digit double display on the front of the device, from which the adjusting functions of the devices can be accessed via the 5 programming keys. In addition, the control units enable the maximum values to be stored, each intervention to be stored and ventilation inside the panel to be controlled.
Fig. 5.9 shows the panel front control unit TMD-T4/96

Fig. 5.9 – TMD-T4/96 unit

Main characteristics of the TMD-T4/96		
Auxiliary supply voltage	[V]	100 … 125, 220 … 240, 380 … 415/50-60 Hz
Max. consumption	[VA]	4
Measuring inputs		2 RTD Pt100
Measuring range	[°C]	0…+220 ±2 °C
Trip delay - hysterisis		5 s/2 °C
Measurement display		LED display, 7 segments, digits
Outputs		1 12 V DC, 3 NA-C-NC relay, 8 A resistive load
Outlet functions		alarm, trip, ventilation, autodiagnosis
Programmable functions		ALARM, TRIP, HOLD, FAN, T. MAX
Connections		extractable screw terminal boards, max. section 2.5 mm²
Insulation	[Vrms]	2500/50 Hz - 1 min
Protection class		IP52 on front panel can be increased to IP65 with optional protection cap code 2CSG524000R2021
		IP20 on back panel
Operating temperature	[°C]	-10...+55, max. humidity 90%
Storage temperature	[°C]	-25 ... +80
Standards		IEC EN 50081-2, IEC EN 50082-2, IEC 14.1, IEC EN 60255

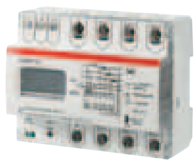
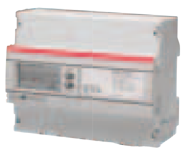
Electronic energy meters

The wide range of DIN rail ABB energy meters for measuring energy is summarised in Table 5.5. For a description of the specific technical characteristics of every single device, see catalogue System pro *M* compact®. Every electricity meter made by ABB is type approved, verified and issued with a certificate of compliance according to MID requirements, Measuring Instruments Directive. ABB has chosen type approval according to Annex B and initial verification according to Annex D. the product must fulfill relevant parts of EN 50470 and be assessed by a Notified Body that then issues a certificate for that product. ABB use NMi, an independent expert for metrology testing, certifying and calibrating, for any task.

The energy counters can be profitably used in both residential/tertiary environments and in industrial environments. A typical example of the first case is the interior of a shopping centre where local energy consumption can be measured, a record of consumption can be established, the building can be managed remotely and be integrated with a management system owing to different protocols chosen by the customer Modbus RTU, M-bus, LonWork and Ethernet, GSM/GPRS, EIB/KNX thanks to the serial adapters.

As the current direction is recognised automatically, the counters also ensure safe and error-free installation.

Equally significant are the installation advantages of the energy meters in industrial plants, where certain specific features of the device are immediately reflected in economic advantages and reliability, as shown in Table 5.6.

Single-phase energy meters		Three-phase energy meters	
ODINsingle	**DELTAsingle**	**ODIN**	**DELTAplus**
			
Direct measurement up to 65 A	Direct measurement up to 80 A	Direct measurement up to 65 A indirect by CT (5/5-900/5 A/A)	Direct measurement up to 80 A indirect by CT (1-999 A)

Tab. 5.5 – DIN rail electronic energy meters

5.3

Accessories for measuring instruments

5.3.1

Serial communication adapters

They permit serial communication of data between energy counters and the remote supervision system; they have reduced dimensions (2 DIN modules) and can easily be installed on the DIN section and can be coupled with the energy counter as shown in Fig. 5.10.

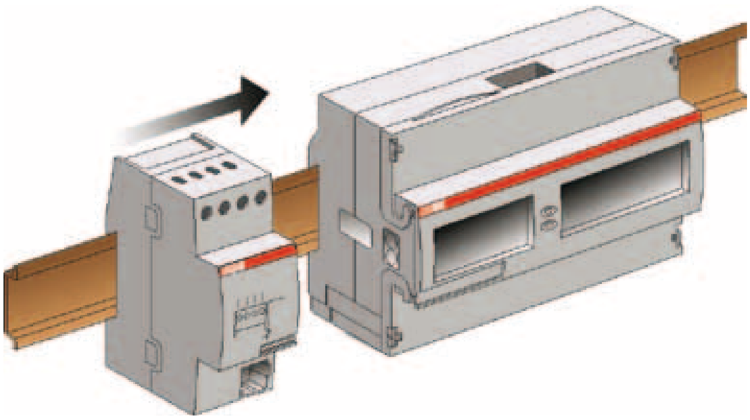


Fig. 5.10: Coupling energy meter-adapter

Their main function is to convert optical signals coming from the counters in the powerline serial communication means, pair, etc and in the selected protocols (Modbus RTU, Meter-bus, TCP/IP, KNX/EIB, GSM/GPRS).

Serial converter RS485 / RS232

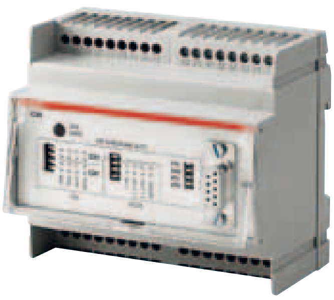


Fig. 5.11 – CUS serial converter

The multifunction serial converter CUS (fig. 5.11) is used in all cases in which it is necessary to convert or manage the serial lines EIA -232 (RS-232), EIA-485 (RS-485) and EIA-422 (RS-422). The connection between devices that use these types of communication bus (such as for example PLCs, measuring and control instruments, connection between devices and computers with specific application software installed, etc) often requires the type of serial line to be converted, the signal on the line to be amplied, different parts of the communication network to be insulated etc. The CUS converter is thus used widely, as it has broad applicational scope with different adjustments and settings that enable it to be used in the most widely varying applications.

CUS ensures the galvanically insulated conversion between the RS-232, the RS422-485 side and the supply source.
The versatility of the device allows different operating modes:
- RS-232 conversion to RS-422 full duplex
- RS-232 conversion to single RS-485 half duplex
- RS-232 conversion to double RS-485 half duplex
- RS-485 repeater (and monitor function on RS-232)

The main applications are:
- networks for multipoint data transmission
- long-distance serial connections
- galvanic separation of peripherals
- extension of RS-485 lines

Main characteristics of serial converter RS485 / RS232		
Supply voltage	[V]	230 V AC ±20%
Frequency	[Hz]	50-60
Power input	[VA]	7 max
Dissipated power	[W]	3.5
Line fuse		500 mA internal
Dimension, supply terminals	[mm^2]	2.5 max
Dimension, RS485-422 terminals	[mm^2]	2.5 max
Connection RS232		Sub-D 9-pole female (DB9)
Length, max. RS232 line	[m]	15
Length, max. RS485-422 line	[m]	1200
Units that can be connected in multidrop mode		Max 32
Operating temperature	[°C]	-20…+60
Storage temperature	[°C]	-20...+80
Modules	[n°]	6

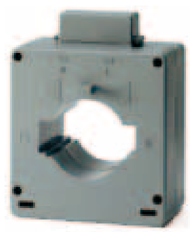
5.3.2

Current transformers

They are used to transform primary currents (max. 6000 A) into low-current secondary currents .../5 A supplying indirectly analogue and digital measuring instruments. They are available with both a wound winding and a through winding. In the first case they are supplied together with the bar or primary terminal; in the second the have a hole in which to insert the bar or cable that constitutes the primary.
The range is very comprehensive: for a description of the specific technical characteristics of every single device, see the technical catalogue System pro *M* compact®. System For example, in figure 5.12 three current transformers with different features are shown:
1) DIN rail transformer.
2) transformer, with wound primary, primary current on bar, 25 mm, secondary on terminals;
3) transformer with through primary: for primary current from cable, from horizontal bar or from vertical bar;

Current transformer range





DIN rail transformer TRFM	Transformer with wound primary	Transformer with through primary

Fig. 5.12: Example of current transformers

		Choice of primary						
		CT3	**CT4**	**CT6**	**CT8**	**CT8-V**	**CT12**	**CT12-V**
Section conductor [mm]	○	21	25	50	2x30	2x35	2x50	2x35
	▭	30x10	40x10	60x20	80x30	-	125x50	-
	▯	20x10	40x10	-	-	3x80x5	-	4x125x5

5.3.3

Voltage transformers

They are used to transform primary voltages up to 600 V into secondary voltages of .../100 V max with which supply indirectly all measuring instruments, both analogue and digital.

They are available in the case made of self-extinguishing rating 1 plastic (Fig. 5.13 a) or in a 0.5 rating metal case (Fig. 5.13 b). They can be installed in three-phase networks, with or without neutral. For the selection of the single devices, see the catalogue for the System pro *M* compact®.

Examples of voltage transformers	
	
a) in plastic case	b) in metal case

Fig. 5.13: Examples of voltage transformers

5.3.4

Fig. 5.14: Direct current shunt

Shunts for direct current

The shunts have 60 mV voltage and must be used with a maximum load of 0.25Ω in combination with the DC measuring instruments for measuring current.

The two-pole cable with which they are fitted is 1 m long and has a 1.4 mm^2 section that is equal to a resistance of 0.025Ω.

To ensure that the shunts operate correctly, check that:

- assembly can be both horizontal or vertical (the horizontal position enables the heat to be dispersed better);
- the contact surface must be used completely and be clean; after connecting, cover with a specific grease;
- the screws and bolts must be correctly tightened;
- the shunts must be sufficiently ventilated; as they are not insulated, they must be protected against accidental contacts.

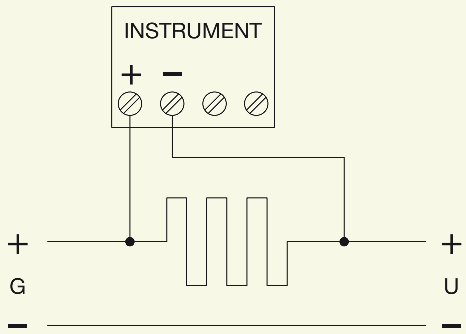


Fig. 5.15: Method of insertion of shunt into measuring circuit


3.98
3.97
4.00
3.99
MAX
MIN
on
off
MS
0.8
0.90
0.7
0.63

6 The measurements

6.1

TRMS Measurements

6.1.1

Linear loads

When the electricity is generated by the electric power utility, the wave form of the voltage is sinusoidal.

The traditional loads are, for example:

- incandescent lamps and heaters (resistive loads);
- motors and transformers (inductive loads), absorb sinusoidal current if they are connected to a sinusoidal voltage source.

The current absorbed by a purely resistive or inductive load has the same pattern and thus the same wave form as the voltage that supplies it. Thus, in linear loads the wave form of the current is the same as the voltage wave form (both are sinusoidal) and there are no harmonics.

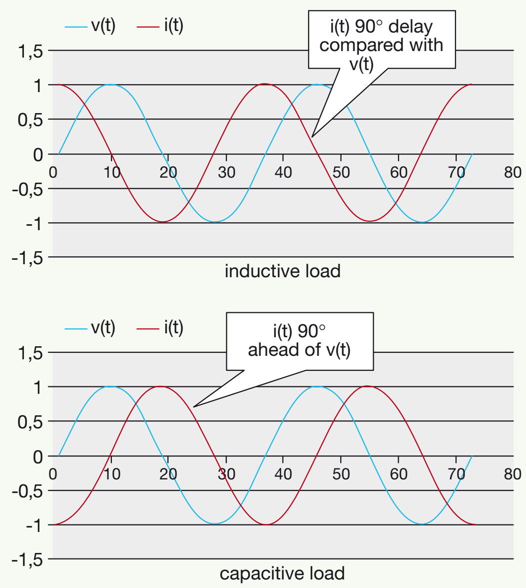


Fig. 1: Sinusoidal linear voltage v(t) and current i(t) pattern

6.1.2

Non linear loads

Technology and the need to reduce consumption, which is increasingly requested by the market, have led to new high-performance loads being developed that are able to operate with less energy absorption.

The introduction of sophisticated control logics by means of static AC/DC converters has enabled alternating-current motors to be obtained that provide dynamic responses and performance that are similar to those of direct-current motors.
The wave form of the current absorbed by a device supplied by a converter is not sinusoidal but is a non sinusoidal alternating period wave shape with an amplitude and frequency within the period that is the equivalent to the sinusoid.
Its wave form is very distorted compared with a sinusoidal wave and for this reason, when a load is supplied by such a type of source, the supply is said to be a non linear or a distorting load. In non-linear loads the absorbed current has a distorted wave form that differs from the wave form of the voltage applied to the load.

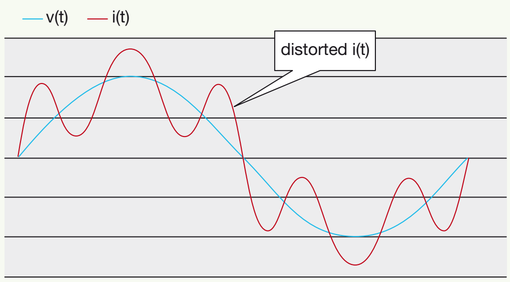


Fig. 2: Non sinusoidal pattern of a non-linear load

The following are examples of non-linear loads:
- computers, printers, monitors;
- UPS;
- AC/DC, AC/AC static converters;
- induction kilns;
- electronic regulators;
- switching supply units (also in domestic appliances):
- illumination systems controlled by SCR/Triac;
- variable speed drives;
- X-ray machines;
- magnetic-resonance machines

6.1.3

Problems connected with TRMS measurements

Measuring instruments can be of two types:
- instruments that measure the effective value (RMS) of the quantity;
- instruments that measure the effective value (TRMS) of the quantity;

The instruments that measure the effective value of the quantities assess the average value of the rectified wave multiplied by the form factor 1.11 (typical of the sinusoidal wave), thus taking an approximate measurement of the effective value of the wave.
The value read on the instrument is thus:
read value = average value x SinFF
where SinFF = Sinusoidal Form Factor, i.e. 1.11
Example: 22.4 A x 1.11 = 24.8 A
The average value in the half cycle can also be seen as the height of the rectangle with a base that is the same as the half cycle and has the same area as the half wave.

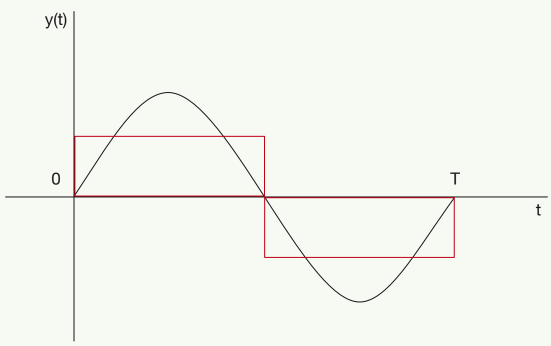


Fig. 3: Effective value of a sinusoidal signal

continues **6**.1.3

The instruments that measure the true effective value (TRMS) of the quantity perform the following operations:
- sampling of the wave over the entire period;
- squaring the samples;
- adding up the squares and making the average;
- then calculating the square root.

$$Y_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} [Y_i]^2}{n}}$$

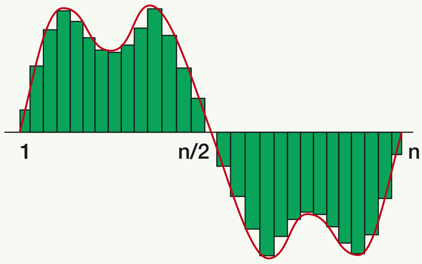


Fig. 4: True effective value of a sinusoidal signal

The instruments that measure only the effective value (RMS) of the quantities provide the value corresponding to the true effective value (TRMS) only when they measure quantities with a perfectly sinusoidal wave form.
In order to have accurate measurements in the presence of distorted waves, and enable the power to be determined correctly, instruments that are able to measure the true effective value (TRMS) of the quantities must always be used.

6.2

Harmonic distorsion and THD

Harmonics are sinusoidal waves with frequencies that are the same as entire multiples (harmonic order) of the basic wave.
At network frequency (50 Hz), the dominant harmonics generated by the non linear loads are the uneven harmonics:
- the third harmonic (150 Hz);
- the fifth harmonic (250 Hz);
- the seventh harmonic (350 Hz) etc.

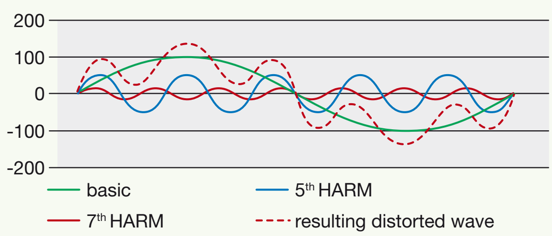
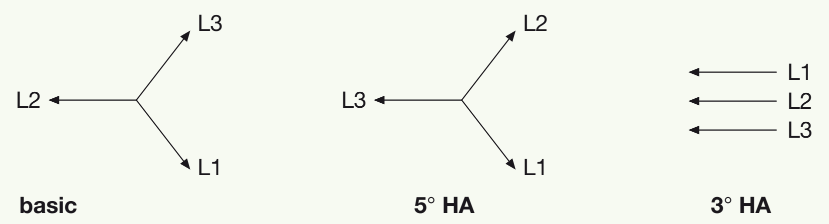


Fig. 5: Wave form with harmonic components

Non linear loads, including those listed before, are sources of current harmonics. When the concentration of these devices increases in an electric plant, their influence on the internal electric distribution system also increases.
When the current harmonics reach a sufficient amplitude, there is the phenomenon of interaction with the internal distribution system and with other devices installed in the same plant.
The current harmonics interact with the impedance of the distribution system, creating voltage distorsions and energy loss.
When the harmonic distorsion reaches excessive levels, the devices may face different problems, in particular:
- untimely tripping of the differential relays;
- current increase in the phase conductors;
- significant current increase in the neutral conductor with consequent overheating;
- overheating of the transformers and increase in noise;

- increase in the speed of the disc in the induction energy counters;
- premature aging of the electrical components;
- faults in the power-factor correction capacitors;
- faults in the filter capacitors and little stand-by power in the UPS;
- reduction of power factor and imposition of penalties by electric power provider

When the loads are balanced also the harmonic currents, like the phase currents at the basic frequency (50Hz), tend to cancel each other out.
This principle applies to all the harmonics with the exception of uneven harmonics that are multiples of three, which, unlike the others, are added up together and return exclusively through the neutral conductor.
In electric plants supplied by three-phase systems, star-connected non-linear loads that generate harmonics that are multiples of three may cause possible overloads and thus overheating of the neutral conductors.
The vector diagram below shows the quantities trend for the basic frequency, for the fifth harmonic and for the third harmonic.
The following table, which is taken from an actual measurement, shows how the total neutral current is substantially equivalent to the sum of the three phase currents in relation to the third harmonic.



TRMS current measurements		Measurements with analyser			
Line	TRMS	Line	I fundamental	I Third harmonic	I Firfth harmonic
L1	143.5 A	L1	138.2 A	35.5 A	12.1 A
L2	145.5 A	L2	140.7 A	34.7 A	11.6 A
L3	147.8 A	L3	141.7 A	39.6 A	13.2 A
Neutral	109.9 A	Neutral	10.6 A	109.4 A	3.1 A

Table 1 Influence of the third harmonic on the neutral current

THD is the total harmonic distortion of the basic wave, which considers the contribution of all harmonic components present. The THD is expressed as percentage of the basic wave and is a good indicator of the presence or absence of harmonics. THD (Total Harmonics Distortion) corresponds to the total harmonic distortion of the basic wave, which considers the contribution of all harmonic components present.
In other words, THD is the harmonic distortion that is present in the measured quantity compared with the basic wave. The THD value is expressed as a percentage and is a good indicator of the presence of harmonics.
The IEC EN 50160 standard describes the 'voltage characteristics of electricity supplied by public electricity networks'. Article 4.11 'Harmonic voltage' prescribes that the total harmonic distortion of the supply voltage (including all harmonics up to the fortieth order) must be less than or the same as 8 %.
The THD indication of current harmonics, even in percentages of a few units, becomes an important indicator of the need for a thorough harmonic analysis in order to identify the presence of harmonics, such as the third, which may be possible causes of malfunctions in the electric plant.

6.3

Cosfì ($cos\varphi$) and power factor (PF)

The cosfi, or more exactly $\cos\varphi$, is the cosine of the phase angle ϕ between current and voltage in an alternating current electrical system.
In a purely resistive (also known as ohmic) system, the phase angle is nil, so $cos\varphi = 1$. In a real inductive system, i.e. with a non-nil resistive component (e.g. an electric motor, a supply unit for a fluorescent lamp), the phase angle is between 0 and $\varpi/2$ (delayed phase displacement). In a system with a capacitive component the phase displacement is between 0 and $-\varpi/2$ (anticipated phase displacement). In both cases the value of $cos\varphi$ is lowered by one until it theoretically reaches the value zero.
$Cos\varphi$ is also defined as the power factor because it is the equivalent of the ratio between active power and apparent power. A $cos\varphi$ with a unitary value means that the apparent power corresponds to the active power and that reactive power is nil.
In the presence of electric lines with a harmonic content we have to talk of a power factor (PF) as the effect of the harmonics is calculated in the active power/apparent power ratio. Reactive power is always undesirable; a $cos\varphi$ value becomes more undesirable the further it deviates from one.
As the inductive and capacitive phases occur in opposite directions, combining the two components in a circuit appropriately, by, for example, adding capacitors to inductive loads can be done in such a manner that they cancel one another, returning the $cos\varphi$ near to one. $Cos\varphi$ is a parameter that is required to calculate power-factor correction power.

6.4

Practical tips for installing a good measuring system

Start from the need: what do I want to measure? A single electric parameter or all the electric parameters

There are different product families on the market: instruments that measure a single electric parameter (voltage, current, frequency, phase angle $\cos\varphi$), generally used in single phase systems, as instrumentation on the machine, and instruments that enable all the electric parameters to be measured and displayed, both for the single phase and in the three-phase system. This type of multifunction instrument is ideal in panels in which space is limited, in panels of substations and in main industrial panels.
If not only electric parameters need to be monitored but also energy consumption needs to be checked, measuring instruments that also include an active and reactive energy count have to be selected.

Selecting the measuring system: single parameter, multifunction, analogue, digital instrument

The instrument should be selected according to the type of distribution system.
In a single-phase system, analogue and digital instruments are selected for measuring voltage, current, frequency and the power factor.
In a three-phase system instruments can be installed that measure the single electric parameter, one per phase, or a voltmeter and an current can be installed together with the voltage and current switches, which enable the measurements to be displayed in sequence, phase by phase.
Choosing an analogue instrument ensure good reading stability, due to the mechanical inertia of the needle and the fact that the reader immediately knows whether the instrument is working normally or whether the reading is off-scale. The analogue instrument indicates the point on the measuring scale in which it finds itself, showing the upper and lower limits.
In digital instruments this indication is not possible as the only reference is the reading of the value on the display, for example, of the current. Some measuring instruments have bar indicators that show the current level as a percentage of the set full scale. Choosing a digital instrument guarantees better readability, also in poor lighting, specially for instruments with LED displays, and an immediate reaction to the measurement variation.

Sizing the system, choosing the CT

Sizing the measuring system starts with knowing the main parameters of the plant; in particular, starting from the characteristics of the protection switch, the type of distribution system, rated current, rated voltage and bar type can be known.

After the type of instrument has been defined that is most suitable for requirements, if the measurement is conducted through indirect insertion, the accessories of the measuring system such as current and voltage transformers must be chosen carefully.

If an 800 A current has to be measured, in most cases the instrument cannot be connected directly to the line. A current transformer that is suitable for the application must therefore be selected. The chosen parameters of a current transformer are not only rated current, secondary current and power but also the type of assembly. Flexible and stiff cables or bars for carrying power can be installed in a power panel The transformers can be of different types, depending on the assembly system: a through cable or a cable with a wound primary, transformers for assembly on horizontal or vertical bars.

Cabling and wiring diagrams

Connecting analogue instruments is very simple; it in fact suffices to connect the phase and neutral cables to the instrument's.terminal. Two cables fo the auxiliary supply must always be connected for digital instruments.

Multifunction instruments can be used in different distribution systems. In three-phase systems with distributed neutral three current transformers are required. In three-phase systems without distibuted neutral in which the loads are balanced and symmetrical, an Aron insertion can be carried out, i.e. two current transformers rather than three can be used; the instrument will calculate by difference the third phase that is not measured directly, considering it to be the same as the other two. In multifunction instruments not only the cables connected to the measurement, but also the RS485 serial port and the analogue and digital outputs and inputs have to be cabled.

Protecting the instrument and earthing

In order to ensure that the instrument is properly protected, fuses must always be fitted to the supply cables of digital instruments and to the voltmeter measuring inputs.

Earthing the secondaries of the CTs ensures an earth connection if the transformer develops a fault and does not affect the measurement. If there is a great potential difference between neutral and earth, this could affect the measurement negatively, in the case of instruments with measuring inputs that are not galvanically insulated.

Setting digital instruments

Before digital instruments start operating they must be set with the parameters of the measuring system and the communication parameters.

The main measuring parameters are the transformation ratios of the CTs and of the VTs, which are defined as the mathematical ratio between the nominal value and the value of the secondary; for example, setting the transformation ratio of an CT CT3/100 with a secondary at 5 A means setting kCT = 100: 5 = 20.

Troubleshooting during final testing

The main problems that arise during the test phase may be due to incorrect installation of the instruments and the accessories.

Always check that the wiring complies with the instruction manual.

The following errors are those that are most frequently committed when installing a measuring instrument:

- inverting the secondaries of the CTs
- inverting the phases of the current and voltage measuring inputs
- failure to eliminate the short circuit of the secondaries of the CTs
- setting an incorrect transformer ratio.

7 Digital communication

Digital communication is a data exchange (in binary form, i.e. represented by bits)[(1)] between “smart” electronic devices equipped with the relative circuits and interfaces. Communication is normally serial, i.e. the bits that constitute a message or a data package are transmitted one after the other on the same transmission channel (physical means). The devices that have to exchange data and information are connected to each other in a communication network. A network generally consists of nodes interconnected to communication lines:

- the node (a “smart” device that is able to communicate with other devices) is the data transmission and/or reception point;
- the communication line is the element that connects two nodes and represents the direct path the information takes in order to be transferred between two nodes; in practice, it is the physical means (coaxial cable, twin-core telephone cable, optic fibres, infrared rays) along which the information and data travel.

[(1)] A bit is the basic unit of information managed by a computer and corresponds to the status of a physical device, which is interpreted as 0 or 1.
A combination of bits may indicate an alphabetic character or a numeric figure, or may give a signal, make a switch or perform another function.

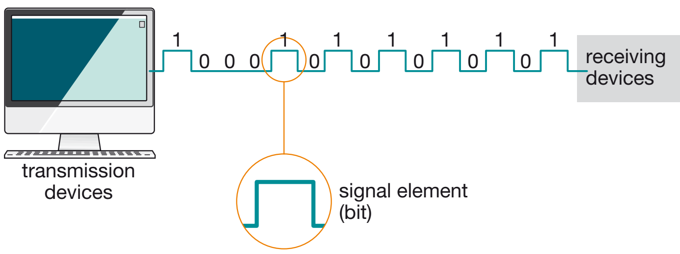


Fig. 1: Bit sequence

The main communication networks can be classified as follows:

- Loop network. Loop networks consist of a series of nodes (represented by PCs in Fig. 2), interconnected so as to form a closed loop.

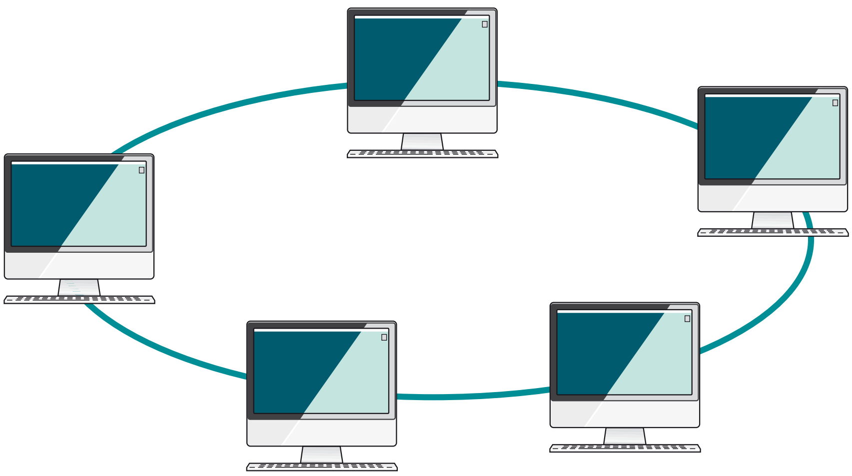


Fig. 2: Loop network

- Star network. Star networks are based on a central node to which all the other peripheral nodes are connected.

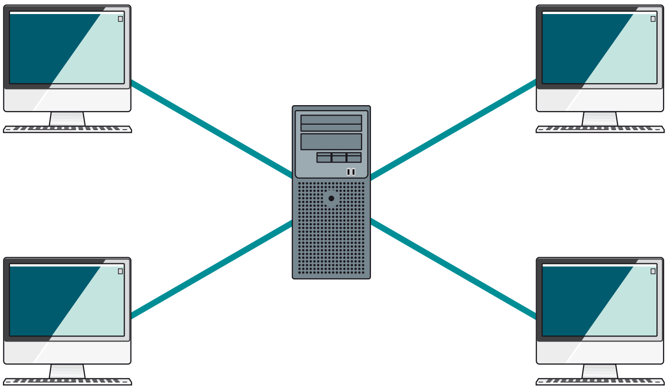


Fig. 3: Star network

- Bus network. The bus structure is based on a transmitting means (usually a twisted cable or coaxial cable) for all the nodes that are thus parallel-connected.

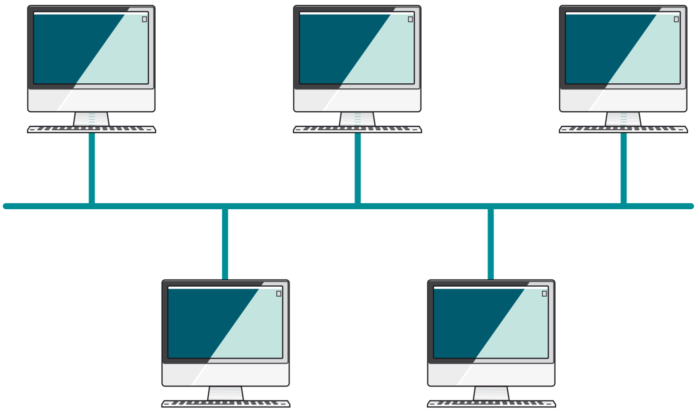


Fig. 4: Bus network

Some examples of process management in which communication is requested between the devices inserted in a communication network are:

1) data exchange between the personal computers of a firm or company that are connected together in a LAN[(2)] network.

[(2)] LAN (Local Area Network): local networks (e.g. Ethernet) that link computers and terminals that are physically near that are for example located in the same office or in the same building.

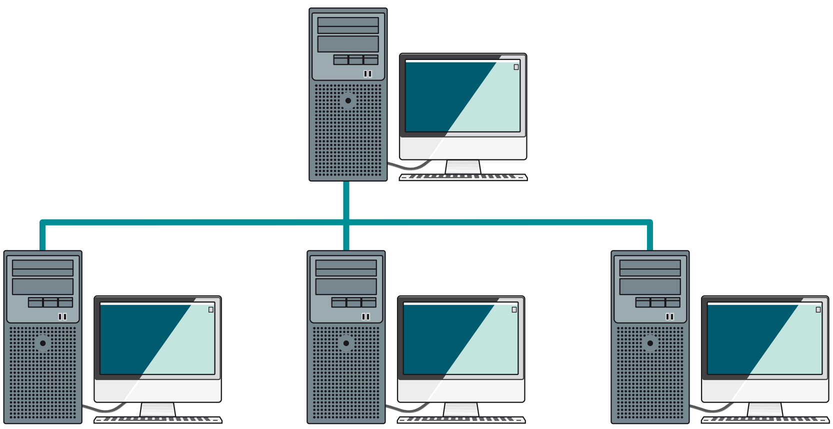


Fig. 5: Example of LAN network

2) transceiving data and commands between a supervision and control system and the field devices (sensors and actuators) of an automation system to manage an industrial process.

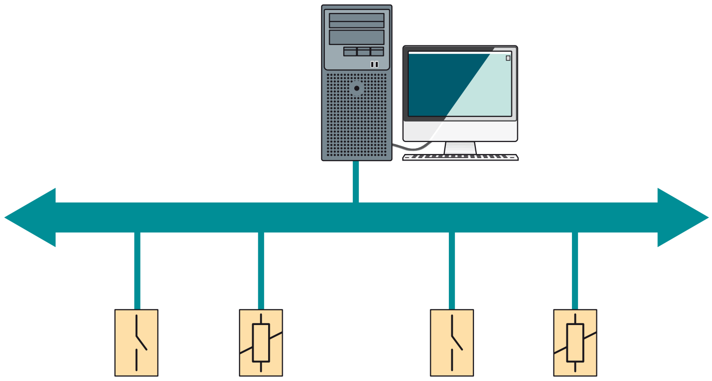


Fig. 6: Example of a supervision system for managing an industrial process

A communication protocol is required to handle data traffic in the network and allow the two communicating devices to understand each other. The communication protocol is the set of rules and behaviours that two entities have to follow to exchange information; it is a precise convention associated with the data exchanged between the communication partners. There are very many different protocols used for making different devices communicate in industrial applications. They vary according to the communication needs of each application. These needs may be:
- amount of data to be transmitted;
- number of of devices involved;
- the characteristics of the environment in which the communication occurs;
- time constraints;
- whether the data to be transmitted are critical or not;
- possibility or not of correcting transmission errors;

and still others.

There is then a further wide variety of protocols used to make IT equipment such as computers and the relative peripherals communicate. We shall not deal with these protocols but shall merely describe the protocols that are dedicated to industrial communication between field devices, i.e. the devices that interact directly with the physical process that is to be kept under control. In particular, the concepts of communication, supervision and control will be applied to managing the electric plants for distributing low voltage energy.

Communication protocols

Very complex protocols are currently used in industrial communications. In order to simplify the description, their operating layers are normally separated; each protocol has a physical layer, a data link and an application layer. Each layer describes an operating aspect of the communication and in particular:

- the physical layer specifies the link between the different devices in terms of hardware and describes the electric signals used to transmit the bits from one to the other; it describes, for example, the electrical connections and the cabling methods, the voltage and currents used to represent the bits 1 and 0 and their duration. In industrial protocols, the physical layer is generally one of the standard interfaces such as RS-232, RS-485, RS-422 etc;
- the link layer describes how the bits are grouped by character and how these are grouped by packet and how errors are detected and corrected. If necessary, it also defines the shifts or priorities that the devices have to follow to access the transmission means;
- the application layer describes what data have been transmitted and their meaning for the process being monitored. This is the layer in which the data are specified that have to be contained in the packets transmitted and received and how they are used.

Generally, the layers are independent of one another; by applying the concept of layers to communication between people we can agree whether to talk over the telephone or via a transreceiver (physical layer), whether to speak English or French (link layer) and what the topic of conversation will be (application layer). In order to establish communication between two entities sucessfully, all the layers considered must correspond to one another, i.e. for example, if we use the telephone we cannot talk to a person who is using a radio; we could not understand each other if we used different languages, etc. Without wanting to describe existing protocols in a complete manner, we will nevertheless mention some features of the communication systems through a short description of the three layers that have just been introduced.

7.1.1

The physical layer

At the physical layer we have:

- wireless systems that use as a physical means radio waves, infrared rays or luminous signals that are freely propagated in space;
- wired, or cabled systems in which the signals are transmitted by cables (or possibly optic fibres). The latter are:
- systems with point to point cabling in which each portion of cable connects two devices and is used exclusively for communication between them (a classic example is that of communication between a PC and a printer). This communication can be of the full duplex type if the two devices can transmit simultaneously, or be half duplex if they can transmit only alternately;
- systems with multipoint cabling (also known as multidrop cabling) in which many devices share in parallel the same communication cable (see Fig. 8). A very important type of multipoint system are those with a bus connection, in which a main cable without branches or with very short branches connects all the devices together in parallel.

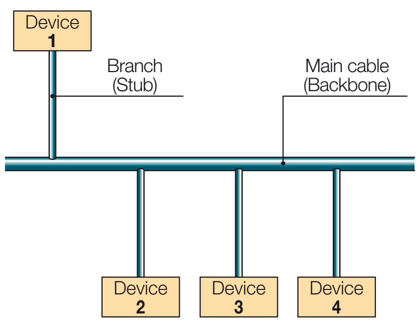


Fig. 8: Multidrop system with bus connection.

In industrial networks, the most commonly used physical-layer interfaces are RS-232 for point-to-point links and RS-485 for multipoint links.

The interfaces RS-232 and RS-485

At the physical layer we have:

The **RS-232 interface**, which is so common in personal computers that it is known as a 'serial port'. It is a point-to-point asynchronous serial communication system that can operate in full duplex.

Fig. 9: RS-232 9 pin serial connector

Fig. 10: RS-232 9 pin serial cable

We describe its characteristics simply:

- serial means that the bits are transmitted one after the other;
- asynchronous means that each device is free to transmit one character at a time that are separated by long or short intervals, as required;
- point-by-point means that only two devices can be connected together in this manner. If it is desired to use the RS-232 to connect more than two devices, each pair must have an independent channel available, with two ports dedicated to it.
- Full duplex means that the devices can transmit and receive simultaneously. Full duplex operation is possible because two electric connections exist that are separated for the two directions in which the data can travel.

The bits are transmitted in the form of voltage levels from the transmission terminal (Tx) of a device to the reception terminal (Rx) of the other device. The voltages refer to an earth signal conductor (GND) connected to the GND terminal of the two devices.

Fig. 11: Point-to-point connection between two PCs

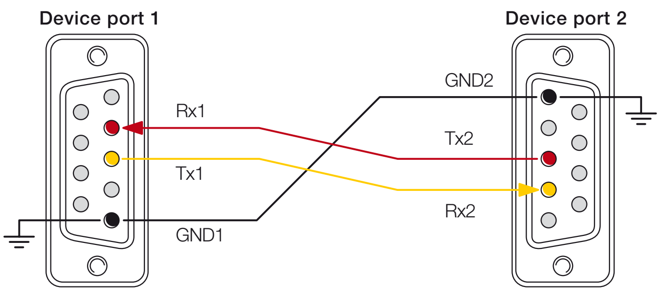


Fig. 12: Basic connections for communication between two devices with the RS-232 interface

At least three wires (Tx, Rx and GND) are required for the connection: it is possible to use extra connections to regulate the data flow (e.g. indicating when a device is ready to transmit and to receive); these operations, which constitute the hand shaking and flow control[3] processes, will not be discussed here.

[3] Flow control: method for controlling the information flow. Handshaking: Exchange of preset signals between two devices in order to obtain correct communication. With this exchange of signals the devices communicate to have data to be transmitted or to be ready to receive.

Each character that transits on the serial cable consists of:
- one or more start bits that warn the receiving device of the arrival of a new character (as the interface is asynchronous it is not possible for the receiving device to know when a character arrives, so it must be warned beforehand);
- a certain number of data bits (for example 8);
- a possible parity bit that recognises whether one of the transmitted bits is wrong (in this case the entire character is considered to be invalid and is rejected): if the parity bit is used it can be configured in even or odd mode;
- one or more stop bits that conclude the transmission.

All the listed bits have the same duration: the serial interface is configured for transmitting a certain number of bits per second (bps or baud). Transmission speeds are standardised, and traditionally multiples of 300 bits a second are used.
For example, a device could transmit at 9600, 19200 or 38400 bauds, or bits per second.
In order to communicate correctly, the two devices have to use the same settings: baud rate (transmission speed), number of data, start and stop bits, use or non use of the parity bit and, if it is used, the mode (even or uneven).
If this does not occur, no character is recognised correctly and so it is impossible to transmit data.

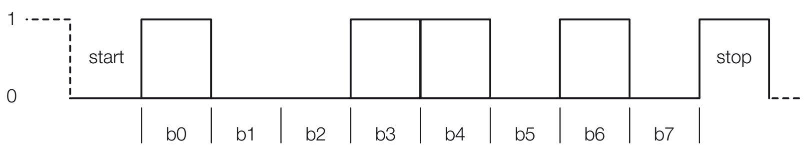


Fig. 13: Datum transmitted on 8 bits

For example, in the string of bits shown in Fig. 13 the following can be defined:
- a start bit;
- 8 bits (b0….b7) that make up the datum;
- a stop bit.

The **RS-485 interface** differs from the RS-232 through its electrical and connection characteristics. Its main advantages are: the possibility to make multidrop links[4] or links between more than two devices (see Fig. 14) and better immunity from electric disturbances.

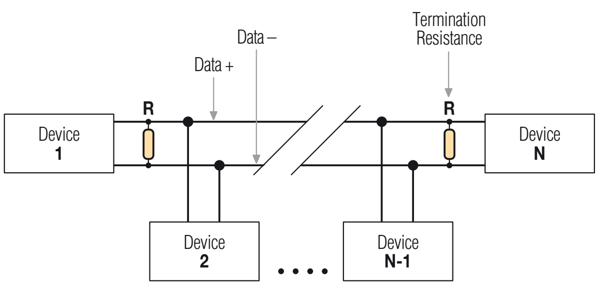


Fig. 14: Multidrop system with bus connection on RS-485

These characteristics have made the interface more used in industrial environments, from the first versions of Modbus (1960s) to the more modern Modbus RTU, Profibus-DP, DeviceNet, CANopen and As-Interface.
In the RS485, all the devices are connected in parallel on a single bus formed by two conductors known as: Date+ and Date-, or A and B or also Data1 and Data2, depending on the manufacturers of the devices.
The signals used are differential; i.e. the bits are the potential difference betweeen Data+ and Data-. The conductors are twisted and kept near to one another so that the electrical disturbances hit them with equal intensity, so that the voltage difference is altered as little as possible. When a device is not transmitting it goes into 'reception' mode, with great impedance on the communication port. The standard specification RS-485 (EIA/TIA-485)[5] imposes limits on the input impedance and prescribes the current/power that each device has to be able to transfer to the line when it transmits.

[4] In principle, in a multidrop connection the devices are connected in parallel to a main cable.
[5] EIA/TIA-485 "Differential Data Transmission System Basics" is the document that describes standard RS485, to which all the manufacturers refer.

In particular, in compliance with the prescriptions of the reference standard, correct data transmission is possible if up to 32 devices 'in reception mode' are connected on the line. Thus in accordance with the standard, RS-485 ensures that the communication can occur correctly with a maximum number of 32 devices connected to the bus; and in each communication cycle a device is placed in 'transmission mode' and the other 31 are placed in 'reception mode'.
In fact, as all the devices are connected in parallel on a single bus, only one at a time can transmit, because otherwise the signals overlap and become unrecognisable.
The RS- 485 does not have any mechanism for defining the device authorised to transmit; this task is delegated to higher layers of the protocol used. The structure of each transmitted character, its duration and the possibilities of configuring transmission are those seen previously for the RS-232 serial; for example, transmission speed set at 19200 baud, with 1 start bit, 1 stop bit and a used parity bit can be obtained. All the devices connected to the same bus can have the same settings so as to be able to communicate together.

7.1.2

The connection layer

The connecting level uses master-slave protocols when one of the devices (the master) has the task of controlling and managing the communication of all the others (slaves). Peer-to-peer systems are used when this hierarchy does not exist and the devices access the communication means equally (in this case the protocol comprises the procedures for managing the shifts and the access priority to the communication means; a prime example is Ethernet).

The most widely used communication protocols are:
- Modbus RTU, the connection protocol most widely used with electronic-industrial devices;
- ProfiBus-DP, used for field communication with sensors and smart actuators, generally for fast and cyclic data exchanges between field equipment and controllers;
- DeviceNet, also used for interfacing between field devices and controllers (PC, PLC);
- AS-i, for communication with very simple sensors, such as limit switches or control devices (e.g. pushbuttons).

7.1.3

The applicational layer

The applicational layer gives a meaning to the transmitted data; i.e. it associates a command (e.g.: open/close the switch) or a number (e.g. voltage values) with the data in binary format that the devices exchange through the communication network.
For example, of the Modbus protocol is used to read the current values remotely that are stored in a DMTME-I-485 multimeter.
The multimeter stores the values of the quantities and of the parameters in suitable registers; these registers may be read-only registers (e.g. registers measuring the currents) or reading and writing registers (e.g. registers for setting current transformers ratio).
When the master (e.g. a PC) wants to read the values of the currents, it sends the multimeter a message containing:
- the number of registers in which to read the data (the measured quantities are associated with the register number)
- the type of operation to be run (e.g.: reading the values contained in the register).

The slave (in this case the multimeter) responds by sending the requested values to the master.
These values are then shown to the operator in a comprehensible format through the user interfaces of the software and of the supervision application programmes that

continues 7.1.3

facilitate presentation of the information of the data coming from the controlled process.
Fig.15 shows a user interface of the DMTME-SW software through which an operator can display the values of the currents and all the other electric parameters that the multimeter measures.

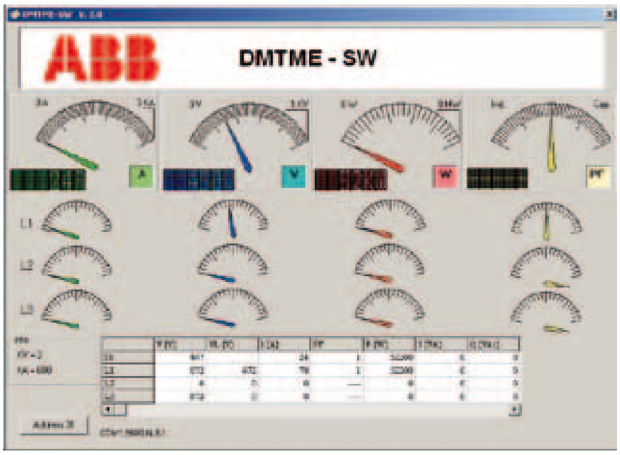


Fig. 15: screenshot of reading software for DMTME-SW data of a series of multimeters.

7.1.4

Compatibility between levels
In industrial communication, the different devices that exchange information have to use the same protocols at all the levels involved.
For example, the multimeters and the ABB network analysers use the Modbus RTU protocol on RS-485. However, there also exist industrial devices that use Modbus RTU on RS-232 or Profibus-DP on RS-485.

7.2

Supervision of electrical distribution plants
A low voltage electrical distribution plant can be considered to be an industrial process for distributing electric energy and as such it also requires a supervision and control system in order to increase its reliability and optimise its management. In order to integrate traditional plant technology and control systems in order to manage, control and monitor in a centralised and automatic manner domestic and industrial plants, the electric plant can be considered affected by two flows:
- a main flow (energy flow) consisting of the power and the energy that, through the line conductors and the command and protection devices, is supplied to the services and to the loads of a plant;
- an information flow or an informative flow (digital flow) consisting of all the information, the data and the commands used for monitoring and managing the plant.

This is the supervision system to manage this informative flow that travels on the communication network.

Depending on the extent and the complexity of the plants to be managed, supervision systems with different architectures can be devised, from very simple architecture (two-level architecture) to the most complex architectures (multilevel architectures). In the simplest two-level system there are:

1) The connection layer consisting of the SCADA (Supervisory Control and Data Acquisition) system. system. In simpler applications this level comprises a computer on which the plant's data acquisition, control or supervision software is installed. It is at this level that the data transmitted by the sensors are acquired, displayed

and processed and the commands are sent to the actuators. In this manner, an operator can, from the same position, monitor the status of the entire plant and undertake the operations required to ensure efficiency and correct operation. More in general, in applications in which the electric distribution plant and the management of the process are integrated the control level consists of the computer supervising the automation system of the entire industrial process.

2) The field layer consisting of field devices provided with a communication interface (measuring instruments, sensors, actuators and protection switches equipped with electronic cut-out means) installed in the electric plant that interact directly with the plant and connect it with the control level. The main functions of the field layer are:
1) sending the plant data (e.g. currents, voltages, energy, power, etc) to the control layer
2) actuating the commands (e.g. opening/closure of switches) received from the control layer

The two layers communicate through a bus communication network. The information (e.g. measured values) transmitted from the field layer to the control and command level that travels in an opposite direction, constitutes the informative flow that transits on the bus.

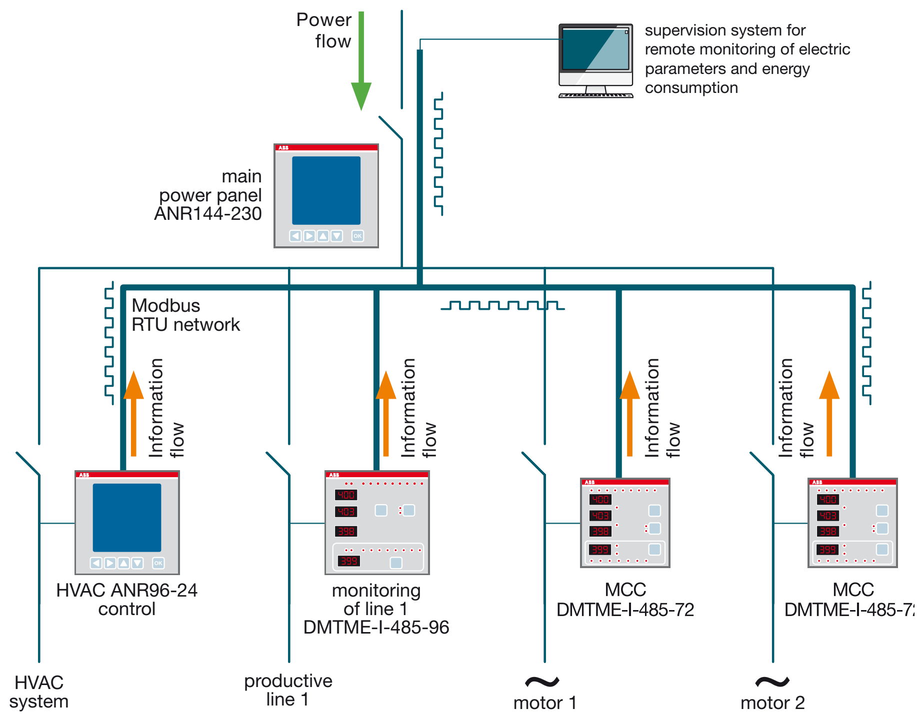


Fig. 16: diagram of a supervision system with networked multimeters an analysers.

The Modbus RS-485 network

7.3.1

Rules for correct cabling

The cabling of the industrial communication systems is different in some ways from the cabling used for power cabling and the electrician may experience some difficulties if he is not an expert in Modbus communication networks. A Modbus RS-485 connects a Master device to one or more Slave devices. Henceforth, we shall consider Slave devices to be ABB measuring instruments with serial communication, even if the cabling is similar for all Modbus devices. The main rules are set out below that must be followed for the cabling of this type of network.

1. *Connection port*

Each device has a communication port with two terminals, which are indicated for the sake of convenience as A and B. In these two terminals the communication cable is connected so that all the devices that take part in the communication are connected in parallel. All the 'A' terminals must be connected together and all the 'B' terminals must be connected together respectively; inverting the 'A' and 'B' connections of a device does not only prevent it from communicating but may also stop the entire communication system from working owing to incorrect direct (polarisation) voltage found on the terminals of the incorrectly connected device. In order to avoid errors when many devices are connected, cables of the same colour should be used for all the connections to the terminals A and cables of the same colour should be used for all the connections to the terminals B of the various devices (e.g. white for A and blue for B); this makes it easier to identify cabling errors. The communication port on the Master device, whatever it is, has two terminals that correspond to A and B.

2. *Connection between the devices*

Unlike what happens in many energy distribution systems, the manner in which the devices are connected in parallel is important. The RS-485 system used for Modbus communcation provides a main cable (Bus or backbone), to which all the devices have to be connected with branches (also known as stubs) that are as short as possible. The branches must be no longer than 1200m. Longer branches could cause signal reflections and generate disturbances and consequent errors in the reception of data.

Fig. 17 shows an example of a correct Bus connection.

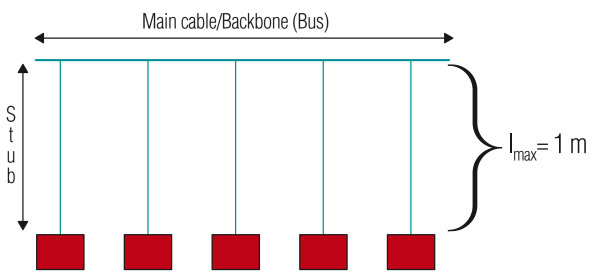


Fig. 17: Network with Bus structure

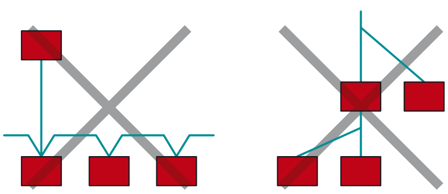


Fig. 18: Examples of incorrect Bus connections

3. ***Maximum distance and maximum number of devices.***

The main cable must be no longer than 700m. This distance does not include the branches (which must nevertheless be short). The maximum number of devices that can be connected to a main cable is 32, including the Master.

4. *Use of repeaters*
In order to increase the extent of the Modbus network, repeaters can be used; and signal amplifying and regenerating devices provided with two communication ports that transfer to each what they receive from the other. Using a repeater, the main cable is divided into different segments, each of which can be up to 700m in length and connect 32 devices (this number includes the repeaters). The maximum number of repeaters that should be serially connected is 3. A higher number introduces excessive delays in the communication system.
5. *Type of cable to use*
The cable to be used is a shielded twisted pair (telephone type). ABB specifies a Belden 3105A cable, but different types of cable with equivalent characteristics can be used. The twin consists of two conductors that are twisted together. This arrangement improves immunity to electromagnetic disturbances because the cable forms a series of successive coils, each of which faces in the opposite direction to the next one: in this manner any magnetic field in the environment traverses each pair of coils in opposite directions and its effect is thus very reduced (theoretically, the effect on each coil is exactly the opposite of the effect on the next one and thus the effect is cancelled). The shielding may be braided (be formed by a mesh of thin conducting wires) or be a foil (consisting of a sheet of metal wound around the conductors): the two types are equivalent.

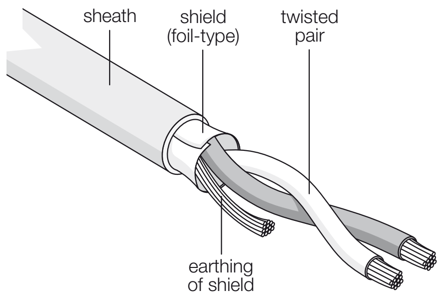


Fig. 19 : Detail of a shielded twisted pair.

6. *Connecting to the terminals*
In some countries, inserting two cables into the same screw terminal is permitted. In this case it is possible to connect the main inlet and outlet terminal directly to the terminals of an instrument without creating a branch. If on the other hand each terminal can accept only a single cable, a proper branch must be created using three auxiliary terminals for each instrument to be connected.
7. *Earth connection of the shield*
The cable shield must be earthed only in one point. Normally, this connection is made at one end of the main cable.
8. *Termination resistance*
In order to avoid signal reflections, a 120 Ohm termination resistance must be fitted on each end of the main cable. The end resistance must be used only at the ends of the main cable. If the total length of the main cable is less than 50 m termination resistances can be avoided at the ends of the main cable.

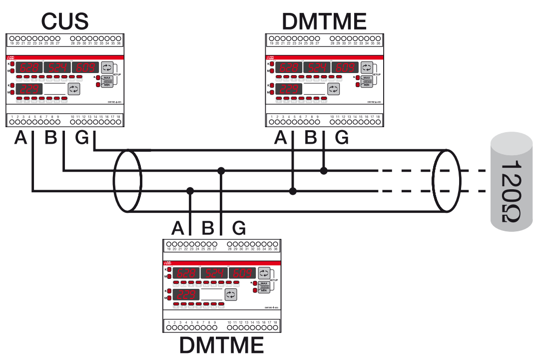


Fig. 20 : 120 Ohm resistance connection

9. *Connection to personal cmputer*
If the master used is a personal computer, in general an RS-232/RS-485 serial converter provides the connection to the bus.

7.3.2

The operation of the Modbus system
The traffic of the information on the bus is managed by a Master/Slave procedure with the PC or the PLC acting as a Master and the switches acting as Slaves. The Master directs all the traffic of the bus and only the Master can initiate the communication. It transmits data and/or commands to the Slaves and asks them to transmit the data. The Slaves transmit to the network when requested to do so by the Master. The Slaves cannot communicate directly with one another: for example, to transfer a data item from one Slave to another the Master must read the data item from the first Slave and transfer it to the second. The communication sequence between each multimeter (Slave) and the PC (Master) occurs in the following manner:
1) The PC sends a command or query to the bus.
2) the interrogated multimeter provides a response by taking the appropriate action, which may be:
- running the received command;
- providing the requested data or
- informing it that the request cannot be met.

The command or the request contains the identification of the instrument to which the communication has been sent and therefore, although the transmission has been received by all the devices connected to the network, normally only the device concerned will respond. The switches are interrogated by the PC through cyclical polling, i.e. one at a time cylically so as to completely scan the plant within a set time (polling time). The calculation of polling time considers computer processing time, tPC, to be negligible, i.e. the time that elapses between the end of the RESPONSE of an instrument and the start of a QUERY that the computer sends to the next instrument.

What is needed to implement a Modbus RTU system with ABB measuring instruments and how does the Modbus protocol actually work?

What is needed:
- master, which may be a PC or a PLC or a SCADA
- if the master is a PC with a serial input port RS232, the network of instruments must be interfaced with the master by a serial converter 232/485
- connection cable between the converter and PC that may have serial sockets or USB inputs
- shielded twisted pair (telephone type), as described in paragraph 7.3.1
- instruments with a serial port RS485, consisting of a terminal board with 3 terminals on the instrument marked A B C.

In order to be able to implement a Modbus RTU communication network between several slaves comunicating in Modbus RTU, whether they be measuring instruments, protection switches, or temperature control unit, it is fundamental to set the same communication parameters on all the objects in the network. The communication parameters are:
- data transmission speed, known as the baud rate: from 2400 bps to 19200 bps
- data bit: 8
- parity number: Even, Odd, None
- stop bit 1, 2 (if parity number = none), 1(if parity number = even, odd or none)
- address for each slave

Once the same baud rate, parity number and stop bit has been set, and after each slave has been given its own unique address, it is possible to acquire information from the master.

continues **7**.3.2

The master communicates with the slaves by sending requests for information or queries, and the slaves communicate with the master by sending answers, known as responses, to the master.
The slaves are interrogated one by one by the master, so if the network is very complex in terms of the number of instruments connected and the physical distance between them, response times increase. The Modbus network can manage up to 247 instruments. The maximum distance that can be covered is 1200m; beyond that distance a signal repeater must be used that amplifies the signal and enables distances that are greater than 1200 m to be covered.
The message that the master sends to the slave is an 8 bit message where each part of the message has a meaning.
The first part of the message is the physical address of the slave to be interrogated.
Subsequently, the function is indicated that it is desired to perform; the functions are typically reading parameters, writing set-up settings in the instrument as a transformation ratio of the CT and of the VT, and functions for acquiring the record of the networked product. The central part of the message indicates what and how much information is required. Lastly, the closure bits check that the message has arrived and has been decyphered by the correct instrument.

The information that the master requests from a measuring instrument are the values of the measured and calculated electrical parameters. The list of these values is located in the instrument on a list, each parameter has its position inside this list; the list is known as a memory map and each position is indicated as a register, which is why it is also known as the registers map. The memory map is thus the list of all the registers containing the parameters read by the instrument. The following table shows the correspondence between the address of each position, the length of the response string (2 means that the slave will respond with two values, the first of which indicates the parameter mark), the description of the electric parameter, the unit of measurement and the binary format.

Address	Word	Measurement description	Unit	Format
1000h	2	3-PHASE SYSTEM VOLTAGE	Volt	Unsigned Long
1002h	2	PHASE VOLTAGE L1-N	Volt	Unsigned Long
1004h	2	PHASE VOLTAGE L2-N	Volt	Unsigned Long
1006h	2	PHASE VOLTAGE L3-N	Volt	Unsigned Long
1008h	2	LINE VOLTAGE L1-2	Volt	Unsigned Long
100Ah	2	LINE VOLTAGE L2-3	Volt	Unsigned Long
100Ch	2	LINE VOLTAGE L3-1	Volt	Unsigned Long
100Eh	2	3-PHASE SYSTEM CURRENT	mA	Unsigned Long
1010h	2	LINE CURRENT L1	mA	Unsigned Long
1012h	2	LINE CURRENT L2	mA	Unsigned Long
1014h	2	LINE CURRENT L3	mA	Unsigned Long
1016h	2	3-PHASE SYS. POWER FACTOR	*1000	Signed Long
1018h	2	POWER FACTOR L1i	*1000	Signed Long
101Ah	2	POWER FACTOR L2i	*1000	Signed Long
101Ch	2	POWER FACTOR L3i	*1000	Signed Long
101Eh	2	3-PHASE SYSTEM COS i	*1000	Signed Long
1020h	2	PHASE COS 1i	*1000	Signed Long
1022h	2	PHASE COS 2i	*1000	Signed Long
1024h	2	PHASE COS 3i	*1000	Signed Long
1026h	2	3-PHASE S. APPARENT POWER	VA	Unsigned Long
1028h	2	APPARENT POWER L1	VA	Unsigned Long
102Ah	2	APPARENT POWER L2	VA	Unsigned Long
102Ch	2	APPARENT POWER L3	VA	Unsigned Long
102Eh	2	3-PHASE SYS. ACTIVE POWER	Watt	Unsigned Long
1030h	2	ACTIVE POWER L1	Watt	Unsigned Long
1032h	2	ACTIVE POWER L2	Watt	Unsigned Long
1034h	2	ACTIVE POWER L3	Watt	Unsigned Long
1036h	2	3-PHASE S. REACTIVE POWER	VAr	Unsigned Long
1038h	2	REACTIVE POWER L1	VAr	Unsigned Long
103Ah	2	REACTIVE POWER L2	VAr	Unsigned Long
103Ch	2	REACTIVE POWER L3	VAr	Unsigned Long
103Eh	2	3-PHASE SYS. ACTIVE ENERGY	Wh *100	Unsigned Long
1040h	2	3-PHASE S. REACTIVE ENERGY	VArh *100	Unsigned Long
1046h	2	FREQUENCY	mHz	Unsigned Long
1060h	2	MAX LINE CURRENT L1	mA	Unsigned Long
1062h	2	MAX LINE CURRENT L2	mA	Unsigned Long
1064h	2	MAX LINE CURRENT L3	mA	Unsigned Long
1066h	2	MAX 3-PHASE SYS. ACTIVE POWER	Watt	Unsigned Long
1068h	2	MAX 3-PHASE S. APPARENT POWER	VA	Unsigned Long
1070h	2	3-PHASE SYS. ACTIVE POWER 15' AVER	Watt	Unsigned Long
11A0h	2	CURRENT TRANSFORM RATIO (CT)	1 - 1250	Unsigned Long
11A2h	2	VOLTAGE TRANSFORM RATIO (VT)	1 - 500	Unsigned Long
11A4h	2	PULSE ENERGY WEIGHT	1 - 4ii	Unsigned Long

Fig. 21 : Memory map registers map of DMTME multimeters

For example, if I want to know the value of the three-phase voltage, the master will have to send a command consisting of:
- address of the instrument that I wish to interrogate (for example a multimeter located on the main control panel of the plant)
- reading function
- address of the register of the 'three-phase voltage' value
- how many other parameters i want to read, up to 5
- testing and checking that the message has reached its destination

The string sent by the master has the following format:

Address Field	=	1Fh
Function Code	=	03h
Start Address H	=	10h
Start Address L	=	00h
No. of register H	=	00h
No. Of register L	=	14h
CRC H	=	42h
CRC L	=	BBh

In the above example, the master sends a 03h reading function to the slave with the address 1Fh, starting from the parameter of the 1000h register for 14 registers.

The response sent by the slave has the following format:

Address Field	=	1Fh
Function Code	=	03h
Byte count	=	28h
Data Reg 1000 H	=	10h
Data Reg 1000 L	=	EFh

CRC H	=	Xxh
CRC L	=	Yyh

Analysing the map on the 1000h register there is the voltage of the three-phase system. Thus starting from the first register for 14 registers, the Power Factor value up to phase 2 is read.

The values of the registers in the memory map are expressed as hexadecimal values. When using freeware reading software downloaded from the Web such as Modbus Poll or Modbus Contructor that enable the data read by a multimeter to be acquired, care must be taken over whether hexadecimal or decimal values are requested from the software.

For example, the three-phase voltage value is in the hexadecimal register 1000, which become 4096 if converted into decimals.

The memory map is set by the manufacturer, who decides which register should be associated with the parameter read by the multimeter, and also decides whether all the read and setting parameters of the instruments can be transmitted via serial communication.
Who needs the registers map of a Modbus RTU instrument? It is normally the System Integrator who has to implement the communication network via PC or PLC. This is the person who implements communication between the various devices connected to the bus.
The registers map is required to indicate to the master the addresses in which electrical quantities are found.

8 Applicational examples of network analysers

An applicational example is given below, with the relative instructions for setting and use of the ANR range network analyser.
The application in the example refers to an industrial plant or to a tertiary sector (major retailing) plant with mixed linear and non-linear loads.
The ANR 144 instrument is installed in the low voltage Main Power Panel.

Fig. 1: Network analyser ANR144

Connect it in accordance with the instructions that follow

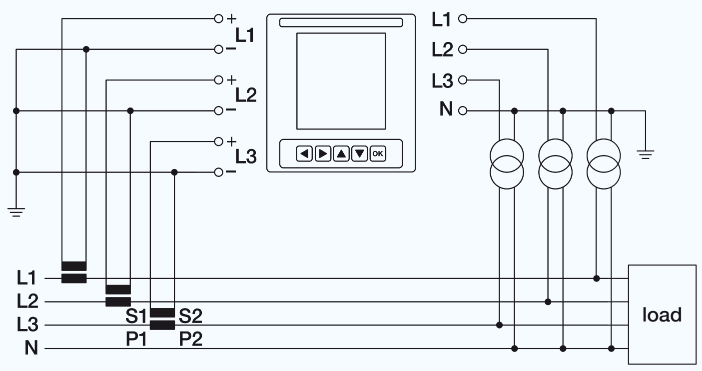


Fig. 2: Wiring diagram for inserting ANR in three-phase network with neutral.

The supply for the operation of the instrument can be taken directly from the supply line (ANR 144-230).

If the events due to the interruption of the main supply need to be stored and displayed, the instrument must be supplied with a continuity subunit (UPS) or the ANR 144-24 model must be used that enables 20 to 60 VDC and VAC to be supplied also from generators that are independent of the main supply (e.g batteries).

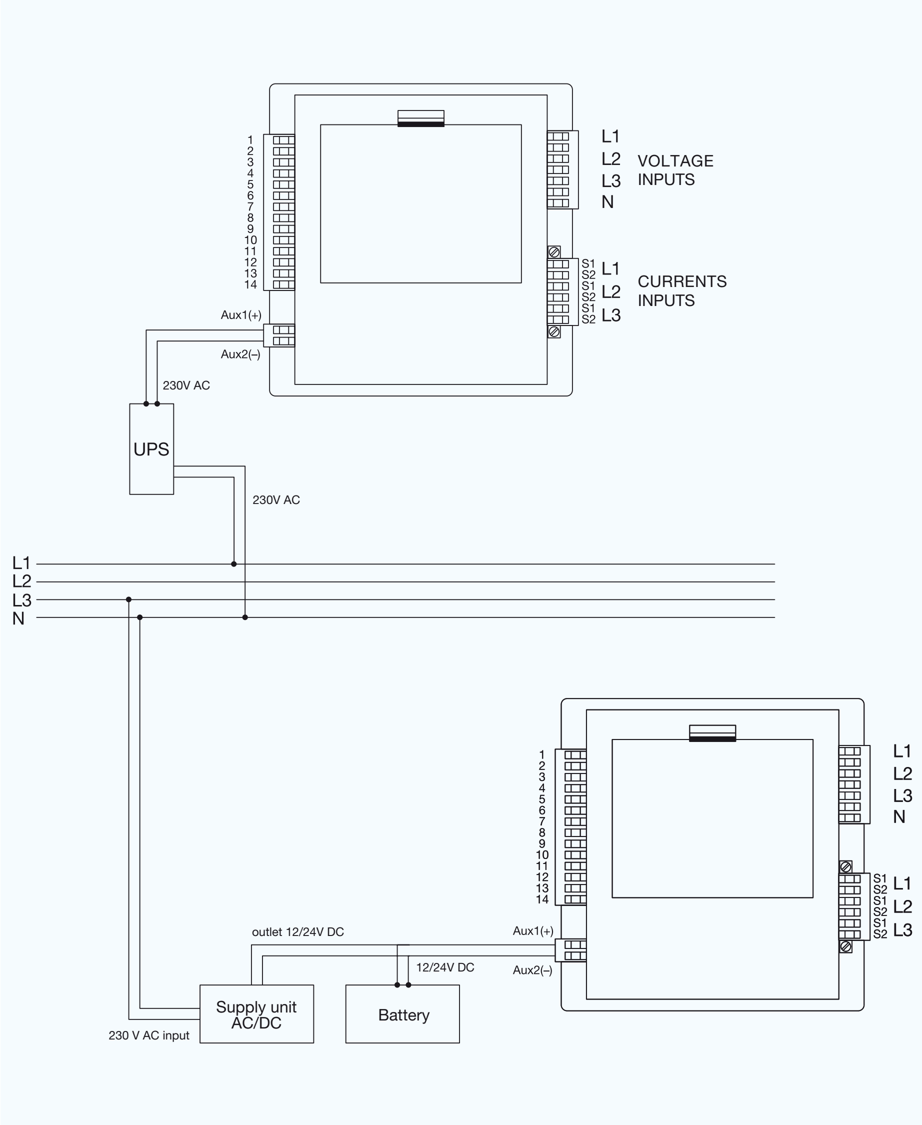


Fig. 2: Wiring diagram in three-phase network with neutral.

Once the instrument has been connected, the following parameters can be displayed and stored and the utility of the detected values can be examined:

1. Rated voltage (phase/neutral) and linked voltage (phase/phase) as a true effective TRMS value;
2. Current as true effective TRMS value on the three phases and on neutral;
3. Power factor PF ($cos\varphi$);
4. Active power
5. Harmonic distortion rate (HDR) up to 31^{st} harmonic displayed graphically and as a percentage value;
6. Harmonic distortion up to 31^{st} harmonic displayed graphically and as a percentage value;
7. Active energy consumed and generated with a subdivision of the count into total counts and according to settable times of day.

8.1

Rated voltage (phase/neutral) and linked voltage (phase/phase) as a true effective TRMS value

Measuring voltage is one of the main parameters for being able to conduct the network analysis. It is also used to assess the state of balance of the voltage on the three phases during normal operation of the plant.

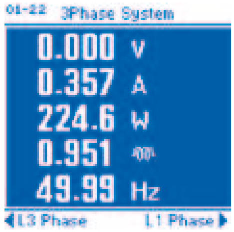


Fig. 3: Display of the parameters of the three-phase system.

8.2

Current as true effective TRMS value on the three phases and on neutral

Measuring currents is one of the main parameters for being able to conduct the network analysis. It is also important for checking that loads are correctly distributed over the three phases.

Measuring the neutral current as a true effective TRMS value is important for establishing whether non-linear loads introduce a distortion of the third harmonic as indicated in point 6.2.

- If the loads are balanced and there are no harmonic distortions, the current on the neutral conductor is virtually nil;
- in normal conditions, with loads that are not balanced but in the absence of harmonics, the neutral current is much less than the phase current;
- in the presence of harmonic distortion the third harmonic line currents are added to neutral because they are phased together and a neutral current occurs that is greater the higher the value of the third harmonic currents.

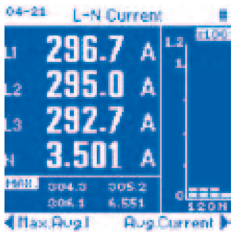


Fig. 4: Display of page dedicated to phase and neutral currents.

8.3

Power factor PF ($cos\varphi$)

The power factor, which is better known with the term $cos\varphi$, must be maintained at a value that is as close as possible to 1.

Measuring the power factor PF is important to avoid having to pay penalties to the supplier of the electric energy for PF values below 0.9.

An alarm threshold should be inserted for this measurement to warn the user if the PF gets near the 0.9 value (e.g. alarm tripped at 0.92)

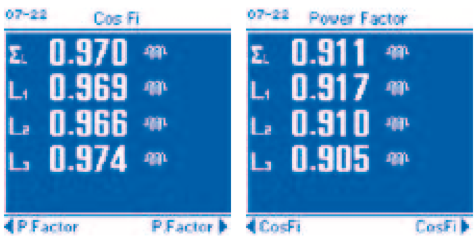


Fig. 5: Display of cosphi values and power factor.

8.4

Active power

As mentioned in chapters 1.5 and 1.6, in order to avoid penalties, it is important to control and manage absorption peaks so as to never exceed the average of available power. For correct management and optimisation of consumption, the instrument can be programmed in such a way that:

- Consumption is recorded for analysis, also for times of day, in relation to the supply contract;
- The loads that can be disconnected with the least grave consequences by the instrument should be set for disconnection in the event of the available power threshold being exceeded.

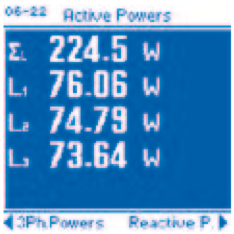


Fig. 6: Display of active power.

8.5

Total harmonic distortion rate (THD) up to 31st harmonic displayed graphically and as a percentage value

Displaying and storing the THD enables the total harmonic percentage of the loads in the plant to be assessed over time.

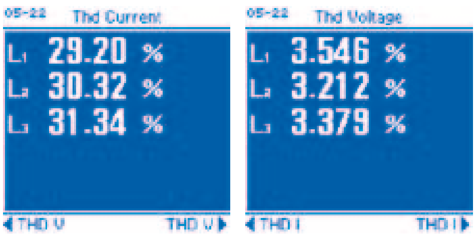


Fig. 7: Display of percentage THD values for voltages and currents.

8.6

Harmonic distortion up to 31st harmonic displayed graphically and as a percentage value

If the preceding measurement detects a harmonic content in the electric plant, an analysis of the harmonics present, up to the 31st harmonic, can be conducted, displaying the phenomena both graphically and as a percentage value. When the harmonic distortion reaches high levels, different problems may arise, as set out in point 6.2.

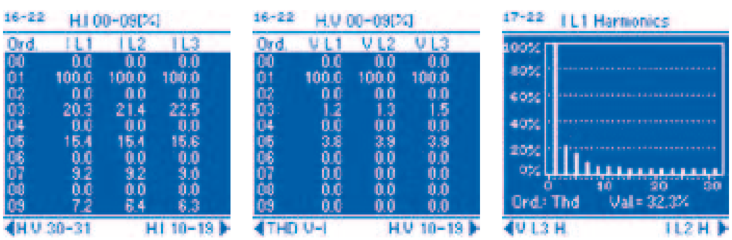


Fig. 8: Display of harmonic analysis up to 31st order, numeric and graphic representation.

8.7

Active energy consumed and generated with a subdivision of the count into total counts and according to settable times of day.

This function is particularly useful for testing and the balance between energy consumed from the network and energy produced in the case of self-generation.

9

Annex

9.1

Measurements Glossary

Accessory

Element. Group of elements or device associated with the measuring circuit of a measuring instrument to supply characteristics specified for the measuring instrument.

Amplitude of the measuring field

Algebric difference between the values of the upper limit and of the lower limit of the measuring field. It is expressed in units of the measured quantity.

Measuring range (actual range)

Field defined by two values of the measured quantity, in which the margins of error of a measuring instrument (and/or accessory) are specified.

Auxiliary circuit

Circuit, other than a measuring circuit, that is necessary for the operation of the instrument.

Measuring circuit (of an instrument)

Part of the electric circuit located inside the instrument and its accessories, together with any connection cords, supplied by voltage or a current, one or both these quantities being an essential factor for determining the measured quantity (one of these quantities can be the actual measured quantity).

Accuracy rating

Group of measuring instruments and/or accessories that meet certain measuring prescriptions that are designed to keep errors and variations within the specified limits.

Reference conditions

Appropriate set of specified values and of specified fields of values of the influence quantities for which the permissible errors for an instrument and/or for an accessory are specified. Each influence quantity can have a reference value or a reference field.

Measuring cord
Cord comprising one or more conductors, which has been specially designed for connecting measuring instruments to external circuits or to accessories.

Shunt
Resistor connected in parallel to a measuring circuit of a measuring instrument.

Division
Distance between any two consecutive segments of a scale.

Error (absolute)
For an instrument, a value that is obtained by subtracting the true value from the indicated value.
For an accessory, a value that is obtained by subtracting the true value from the (expected) marked value.
N.B.:
1 As the true value cannot be obtained through a measurement, a value is used in its place that is obtained in specified test conditions in a specified instant. This value derives from national measuring samples or from measuring samples agreed between the manufacturer and the user.
2 Attention is drawn to the fact that an accessory error can be transformed into the opposite type of error when this accessory is associated with an instrument.

Scale error
Difference between the value indicated by a measuring instrument and the proportional value of the quantity measured at different points of the scale after the instrument has been calibrated so that it does not have errors at two points.

Error (intrinsic)
Error of an instrument and/or of an accessory placed in the reference conditions.

Phasemeter
Instrument that indicates the phase angle between two electric input quantities of the same frequency and with a similar wave shape.
This instrument measures:
- the phase angle between one voltage and another voltage or between one current and another current.

or
- the phase angle between a voltage and a current.

Distortion factor (factor of total harmonic distortion of a quantity)
Ratio:
effective value of the non-sinusoidal quantity
effective value of the harmonic content

Peak factor
Ratio between the peak value and the effective value of a periodic quantity.

Graduation
Segments placed on the dial to divide the scale into appropriate intervals so as to enable the position of the index to be determined.

Index
Component (means) that is associated with the scale and indicates the position of the movable element of an instrument.

Class index
Number that indicates the accuracy rating.
Note:
some instruments and/or accessories may have more than one class index.

Length of the scale
Length of the line (cuved or straight) that passes through the middle points of all the shortest segments of the graduation, including between the first and the last segment of the scale. It is expressed in units of length.

Power factor meter
Instrument designed to measure the ratio between the active power and the apparent power of an electric circuit.

Accuracy
For a measuring instrument, it is the quality that characterises the degree of proximity between the indicated value and the true value. For an accessory, it is the quality that characterises the degree of proximity between the indicated (expected) value and the true value.
Note:
the accuracy of a measuring instrument and/or of an accessory is defined by the intrinsic error and by the limits of the variations.

Dial
Surface on which the scale and other inscriptions and symbols are located.

Resistor (impedance) an additional
Resistor (impedance) serially connected to measuring circuit of a measuring instrument.

Scale
The entire graduation and all the numbers from which, in combination with the index, the value of the measured quantity is obtained.

Overshoot
Difference (expressed as a fraction of the length of the scale) between the maximum transitory indication and the permanent indication when the measured quantity changes suddenly from one constant value to another constant value.

Analogue display instrument
Measuring instrument intended for presenting or displaying the outlet information as a continuous function of the measured quantity.
Note:
an instrument in which a variation of the indication occurs by small discrete steps but which does not have a numeric display is considered to be an analogue instrument.

Instrument with a response as an effective value

Instrument that in a specified frequency field provides an indication that has to be proportional to the effective value of the measured quantity, even when the measured quantity is not sinusoidal or has a continuous component.

Electric measuring instrument

Measuring instrument designed to measure an electric quantity or a non-electric quantity using electric means.

Electronic measuring instrument

Measuring instrument designed to measure an electric quantity or a non-electric quantity using electronic means.

Direct-action indicating instrument

Instrument in which the indicating device is connected mechanically to the movable element and is driven by the element.

Ripple rate (content) (of a quantity)

Ratio:
effective value of the continuous component
effective value of the ripple component

Response time

Time required for the indication to first enter and then remain within a range centred on the final permanent indication when the measured quantity varies suddenly from zero (corresponding to non-supplied status) to a value that is such that the final permanent indication is a specified point on the scale.

Assigned value

Value of a quantity fixed, generally by the manufacturer, for a specified operating condition.

Conventional value

Clearly specified value of a quantity to which the errors of an instrument and/or of an accessory refer, in order to define their respective degree of accuracy.

Rated value

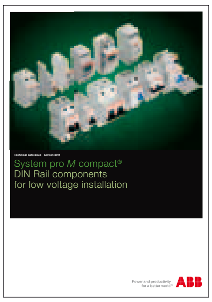
Value of a quantity that indicates the envisaged use of an instrument or an accessory.
The prescribed characteristics of the instruments and the accessories are also nominal values.

Graduation zero

Segment of the dial associated with the number zero.

If you require further details, you can order the technical literature illustrated here directly on-line from the home page of our web site http://www.abb.com/abblibrary/DownloadCenter/ in the “Order documentation and technical software” section.

System pro *M* compact®



2CSC400002D0209

Contact us

ABB SACE
Una divisione di ABB S.p.A.
Apparecchi Modulari
Viale dell'Industria, 18
20010 Vittuone (MI)
Tel.: 02 9034 1
Fax: 02 9034 7609

bol.it.abb.com
www.abb.com

2CSC445012D0201 - 03/2011 - 1.500 - CAL.

Power and productivity
for a better world™