TECNICAL GUIDE
of electrical energy efficiency

CIRCUTOR
Tecnology for energy efficiency

Jordi Serra

TECHNICAL GUIDE
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eficiencia energética eléctrica • electrical energy efficiency

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A very good thing for all of us

The electrical energy efficiency technical guide, that we are introducing you, is the result of 35 years dedicated to power quality and rational use of the electrical energy.
During these years, the changes we have seen in our sector have been very transcendent.

In the seventies, the main concern of the user was the continuity of the electricity supply and voltage variations. Fortunately, this situation improved as a consequence of the development of the infrastructures in the majority of the countries.

Nowadays, the complicated availability of the energy resources and the environment situation, unfortunately, have taken a leading role as never before.

There is no doubt about power quality and rational use of electrical energy are key factors for the enterprises competitiveness. But now, the reduction of the ecological cost of our activities is now a key and necessary factor for guaranteeing the future of our blue planet.

From our beginning, in CIRCUTOR, we have been aware of this fact. Many years ago, we begun to explain concepts as: rational use of electrical energy, energy saving, energy control, and today, electrical energy efficiency.

This philosophy, together with the great development of electronics, our accumulated experience and our innovating vocation, have allowed us to offer technology for measuring, managing and rationalizing both, power quality and energy demand.

The world has changed, and the needs are very different, but now, more than ever, our mission has been, is, and will be the same:

"To help our customers to make a rational and efficient use of the electrical energy"

To achieve it will be our success, but undoubtedly, it will be a very good thing for all of us.

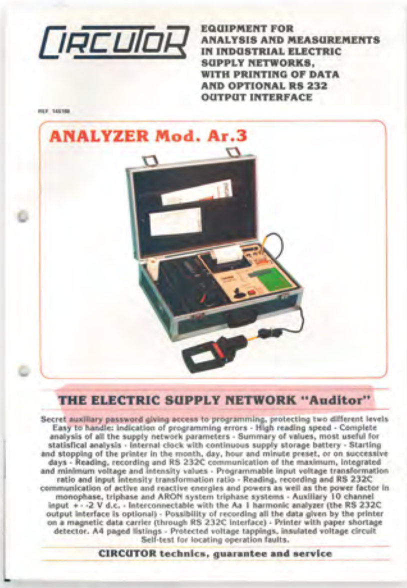
Ramón Comellas
President of **CIRCUTOR**, S.A.

Ramón Pons
President of **,** S.A.

35 years investing in

1973

1983



1984

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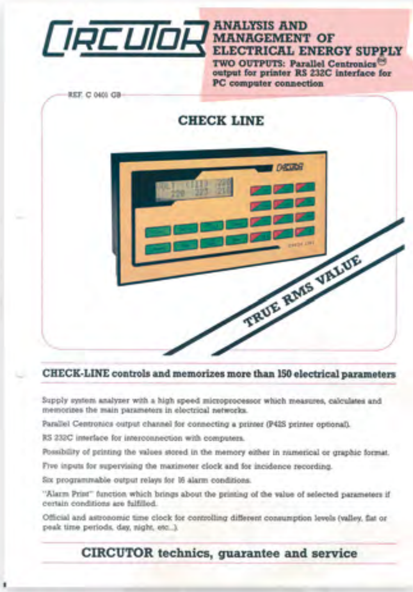

1989

1992

1993

1997

1998

energy efficiency and control

... until 2008 Medium voltage power factor correction, power quality analyzers, energy meters, smart earth-leakage protection, DIN rail network analyzers, ...

... and keeping on

THE TIME HAS AGREED THAT WE WERE RIGHT

CIRCUTOR

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eficiencia energética eléctrica • electrical energy efficiency

Introduction

The current great increase in energy demand, as well as the short term forecasts show a series of important problems worldwide:

- Serious environmental impact
- Progressive incresase of fossil energies
- Repercussions on economies
- Lack of energetic model

There are two basic reasons that lead us to this analysis.
First, there is an extremely high dependence on fossile energies as described below:

- 80 % fossil fuels
- 10 % traditional biomass
- 6 % nuclear energy
- 2 % hydraulic energy
- 2 % renewable energy

On the other hand, 15 % of the world population consume 53 % of the energy generated. This fact is specially important now, due to the growing economies. That implies a great increase in the energy consumptions of those countries.

Thus, in order to handle the current and future energy needs with the global sustainability of the environment and the economies, there are two very important strategies to work in:

- The implementation of renewable energies
- Rational use of the energy, in other words, **the need for strong policies on Energy Efficiency.**

CIRCUTOR is going to give you the necessary advices for having an efficient electrical installation.

1. Definition of Electrical Energy Efficiency (e^3)

1.1 What is e^3

Electrical energy efficiency is understood as the reduction in power and energy demands from the electrical system without affecting the normal activities carried out in buildings, industrial plants or any other transformation process.

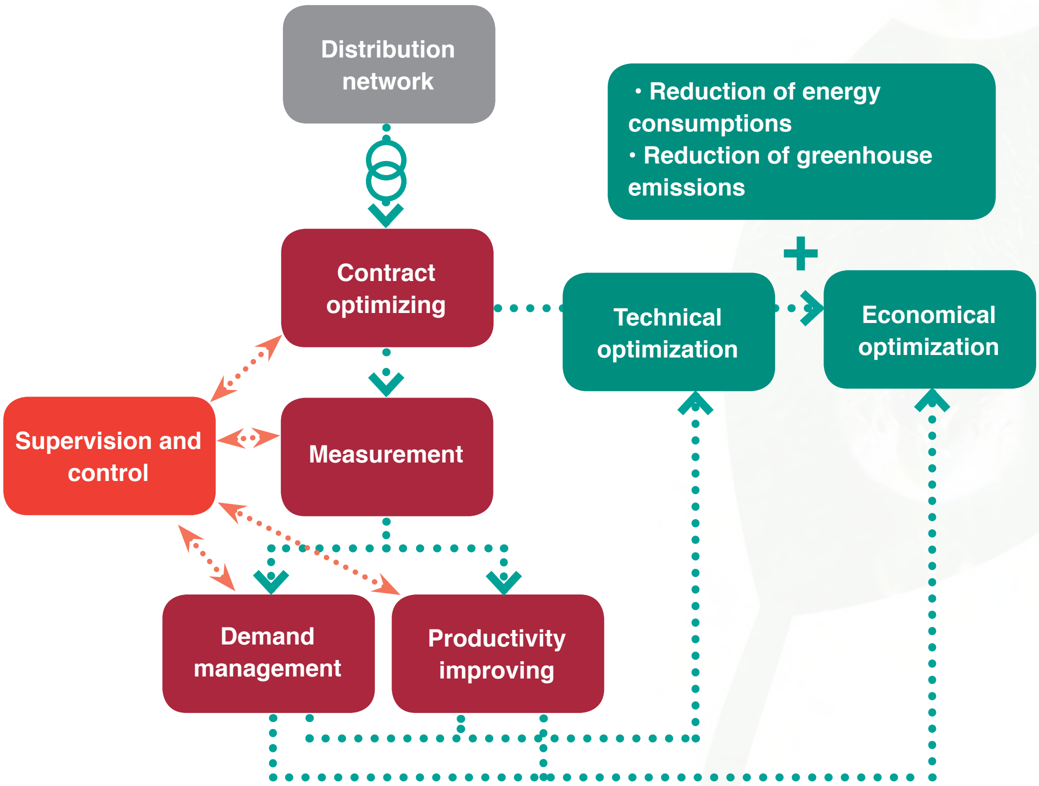
Additionally, an energy efficient electrical installation allows the economical and technical optimization. That is, the reduction of technical and economical costs of operation.

In short, a study on energy savings and efficiency will involve three basic points:

- Support the sustainability of the system and the environment by reducing greenhouse emissions as a result of reducing the energy demand.
- Improving of the technical management of the installations by increasing its efficiency and avoiding stoppages and breakdowns.
- Reduction of the economical cost of the energy as well as the operating costs of the installations.

From a technical point of view, four basic points are considered in order to have a more efficient electrical installation.

- Contract optimizing
- Measurement systems
- Demand management
- Productivity improving by controlling perturbances and costs.



1.2 Basic questions about e3

With the four basic points explained, we put forth a series of questions on each point. The questions hope to identify the objectives to work on, in order to obtain an efficient electrical installation.

Contract optimizing

- Is your electric contract the most suitable one for your needs?
- Do you know that a bad power quality can affects your activities or production processes?

Measurement systems

- Do you know how, when and where are you using the electrical energy?
- Do you really think that all your energy consumed is the most accurate one?

Demand management

- Could you reduce the consumption of electrical energy without affecting the processes or activities carried out?
- Would it be possible to improve the technical efficiency of your electrical installations?

Produtivity improving

- Is there anyway to avoid breakdowns and stoppages on your electrical equipment and installations?
- Then, could you improve the productivity of your processes?

1.3 Outline of a study of electrical energy efficiency

The first step to do in a process of electrical energy efficiency is to carry out an electrical energy diagnosis and audit. In this process, measurements of power and energy will be taken, as well as other variables necessary for making the suitable decisions.

Along those lines, two key points should be taken into consideration:

- What information do we attempt to get from the measurements?
- Which are the right points to be measured?

In all cases, there are two ways to carry out the audit depending on the installation that is being studied:

Installations that do not have measuring and supervision systems

In this case, measurements must be taken using **AR5-L** portable measuring equipment. These equipment permit storing all the variables selected in their memory (power, energy, etc.).

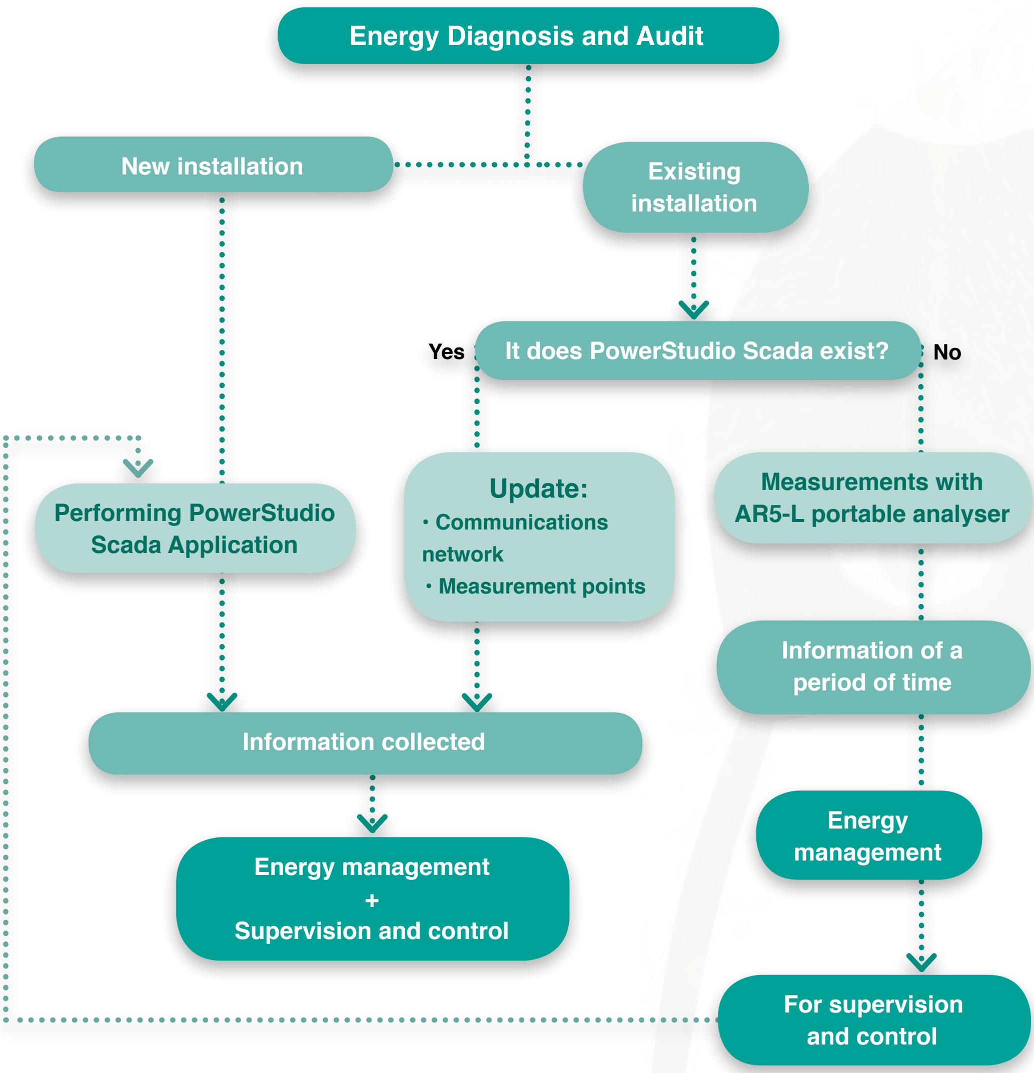
The number of measurements agree with the number of points that are considered to be critical or necessary.

Depending on the type of process, the duration of each measurement will be determined. The aim is to represent the true state of the point measured. The portable equipment permits great flexibility, but on the other hand, it does not permit the follow up of the energy consumption after the appropriate decisions have been made.

It is recommended to study the points where the measurements are taken for the subsequent installation of a fixed measurement system that communicates with the **PowerStudio Scada** management software**.** In this case, the portable measurement equipment is a support equipment used in those places where a fixed system is not available.

◢ Electrical installations that have PowerStudio management software

In these electrical installations, information can be obtained from the **PowerStudio Scada** from the data stored in its files.
Then, aside from obtaining information quickly, the critical variables can be followed up.



2. Relation among energy efficiency, power quality supply and waveform quality

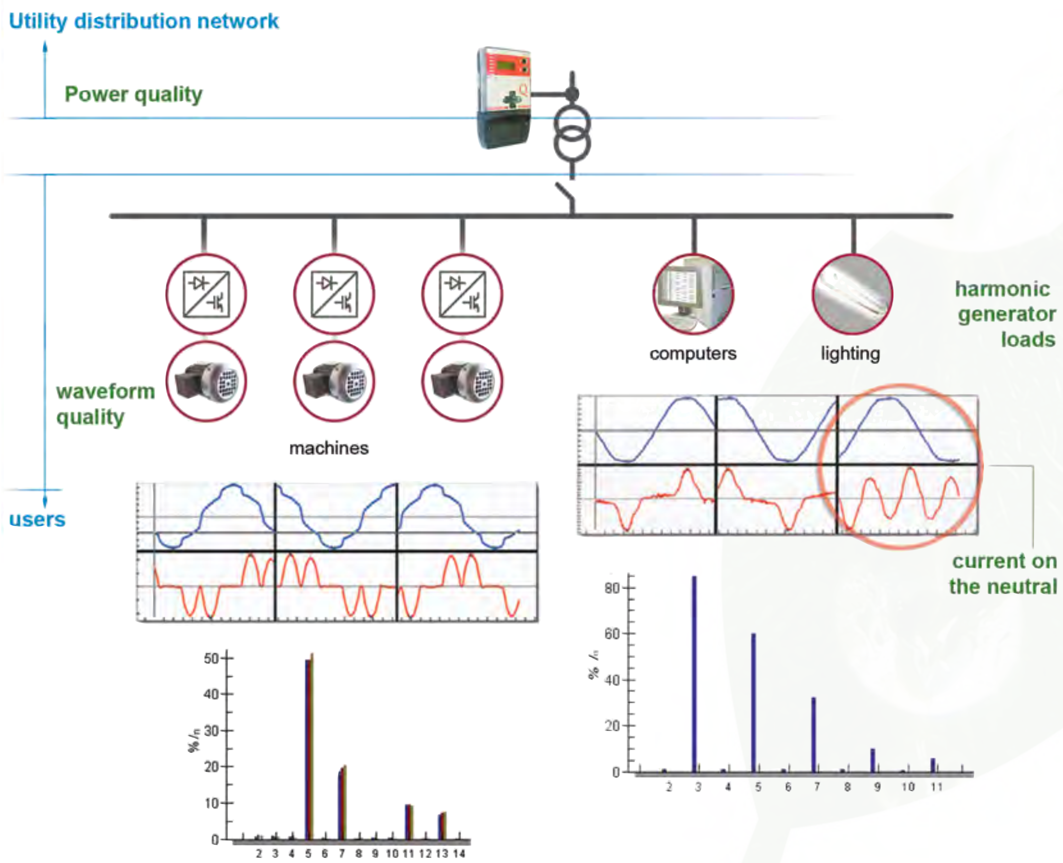
The incorporation of electronic power equipment is a reality due to the advantages such equipment offers in regards to energy savings and easiness of regulation, that is comfort.

Among these systems, it is worth emphasising all those that regulate or convert some type of electrical magnitude such as UPS, variable speed drives, soft starters, dimmers, computers, etc.

Along with the energy-related advantages of these systems, their use generates high frequency and harmonic currents, as well as current leakages to ground, thas is a bad waveform quality.

Nonetheless, it is important to distinguish between electric power quality supply and waveform quality. It allows to know the origin of the disturbances.

- The former makes reference to how the utility supply the voltage (interruptions, sags, overvoltages, etc.)
- The latter, waveform quality, makes reference to how the user uses the current, which then affects the voltage. In this case, appear the problems derived from harmonic currents and high frequencies generated by the above mentioned equipment.



3. Electrical installation costs

As previoulsy stated, besides reducing electric power consumption, an efficient electrical installation reduces its costs of operation. For a better understanding, each one of these costs is explained in detail hereafter:

3.1 Technical costs

What are they

Technical costs are understood to be the loss of capacity in transporation and distribution, as well as heating (electrical losses), disturbances and voltage drops in the electrical installations and systems.

What are they caused by

The following causes are responsible for this technical saturation in the electrical installations:

- Peaks of maximum demand
- Existence of reactive power
- Existence of harmonic currents
- Lines with unbalanced loads
- Use of non efficient receivers

How are they reduced

Technical costs are reduced as follows:

- Reactive energy compensation
- Harmonic filtering
- Phases balancing
- Damping peaks of maximum demand and relocating these consumptions in valley periods

Which are the benefits of improving technical costs

- Less energy consumption
- Improved efficiency in the electric installations by better taking advantage of the distribution lines and transformers
- Decreasing of losses and heating in lines and equipment
- Decreasing of number of breakdowns
- Continuity of electrical service
- Decreasing of the economical costs

3.2 Economical costs

◢ What are they

These are the costs of a bill that is not optimized and the amount resulting from the technical costs generated. They can be classified as follows:

- Visible costs
- Hidden costs

Visible costs

These are the costs included in the electricity bill:

- Power contracted not appropriate
- Electricity tariff not appropriate
- Hourly energy consumption
- Demand peaks
- Reactive energy consumption

◢ How are they reduced

By studying the electricity bill, the actions needed to reduce the global cost can be defined.

- Adjust the contracted power and change the tariff if necessary. This can be done at almost no cost. Nonetheless, before adjusting the contracted power or tariff, it is recommended to study the processes and the power consumption to see if the demand is adjusted to the real needs
- Eliminating extra charge or cost of reactive energy by its compensation. To do this, a capacitor bank is installed, which in most cases pays for itself within a few months after installation
- Damping the peaks of maximum demand. This consists of not exceeding the maximum allowable power permitted by the utility, and when possible, relocating loads when the energy demand is reduced

Hidden costs

◢ What are they

- All unnecessary energy consumption. So, the costs due to unnecessary power and energy consumptions or due to loads that can be dispensable certain time
- All the costs origined as a consequence of the technical costs and the use of receivers that can generate disturbances. Although they are not obvious, they can represent a significant company expense. These are divided into two types:

Electrical installation costs

- Extension of the electrical installations due to:
  - Overload of distribution lines
  - Overload of transformers

- Losses in distribution due to the Joule effect. This concept is especially important in electric distribution and in industrial plants with long distance lines
- Machine (motors, transformers, converters, etc.) and control equipment (computers, PLCs) breakdowns

Costs in productive processes

- Installation stoppages
- Non-finished product losses
- Additional costs in extra working time and manpower

How are they reduced

- By performing an efficiency study of the building or industrial plant.
- By correcting the technical costs explained in the previous point.

Which are the benefits of improving visible and hidden economical costs

- Reduced energy consumption
- Decrease of the electricity bill
- No need to invest in the extension of installations due to the lack of capacity
- Productivity improving by reducing the number of breakdowns and stoppages

3.3 Ecological costs

What are they

CO_2 emissions produced by the consumption of unnecessary energy. To give an idea of its magnitude, 1 MW·h generated by fossil fuels emits 1 ton of CO_2. If considering mixed electric energy generated by fossil fules and renewable energy sources, the ratio is approximately 0.6 tons of CO_2 per MW·h.

How are they reduced

By making a general proposal to reduce global energy consumption in an industrial plant or building. So that, an initial diagnosis is required to determine the following points:

- Energy consumption habits
- Current condition of the installation
- Installation of equipment that permits controlling and monitoring the energy consumption in the electric installations
- Energy consumption in each plant or working area
- The energy consumption that can be reduced
- The receivers that can be replaced by efficient ones

Which are the benefits of improving ecological costs

- Reduction of the emissions of greenhouse effect
- Decrease of technical and economical costs

4. Basic energy concepts

The following points define and group all the fundamental concepts related with electric energy efficiency.

4.1 Power and energy

◢ Active power (kW)

The power demanded by a receiver or a set of receivers that is converted into work or heat.

◢ Reactive power (kvar)

It is the power which uses certain receivers to create electric and magnetic fields.

This power is not converted into useful work, but it increases the total power to be transported and distributed by the utilities as well as the losses in the distribution network.

◢ Apparent power (kV·A)

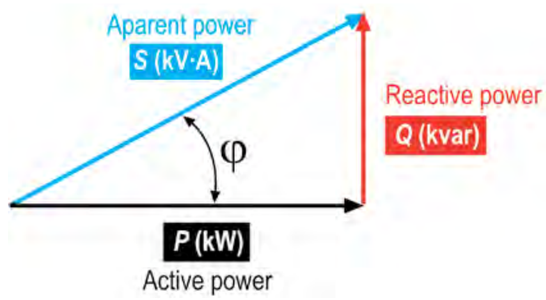
This is the real value demanded from the grid, and it is the vector sum of the active and reactive powers. It is important to point out that it is the real energy generated and transported by the transport and distribution networks.

◢ Phase angle or cos φ

This is the proportion that exists between the active and apparent power, or the cosine of the angle between active and apparent power.

The following image explains the concepts as well as how to calculate them.

Power triangle



Apparent power (kV·A)	Active power (kW)	Reactive power (kvar)	Phase angle or cos φ
$S = \sqrt{P^2 + Q^2}$	$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$	$Q = \sqrt{3} \cdot U \cdot I \cdot sen\varphi$	$\cos\varphi = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}}$

◢ Contracted power (kW)

This is the contracted active power requested from the utility.

◢ Power consumed (kW)

This is the real active power consumed. It can be more or less than the contracted power value.

Efficient power (kW)

This is the optimised power after having performed the measurements adopted in the efficiency plan.

Active energy (kW·h)

This is the active power consumed per unit of time.

Reactive energy (kvar·h)

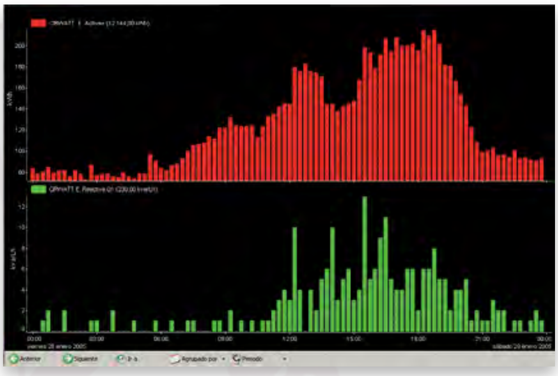
This is the reactive power consumed per unit of time.

4.2 Demand chart

This is the graphic display of the power and energy demanded from the grid. The analysis of these two charts is the start of an electric energy audit.

Energy demand chart

Thorought times, the evolution of energy demand can be observed on this chart. The periods of time can be displayed in hours, days, weeks or months.



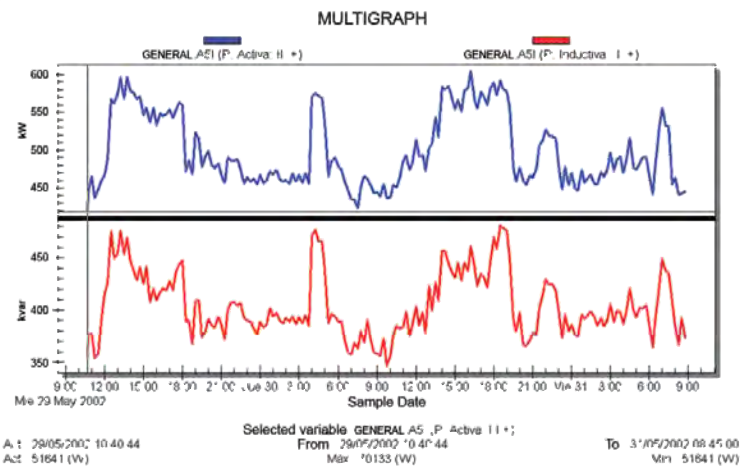
This chart permits studying the evolution of the energy consumption, and therefore deciding whether the contracted conditions are the most accurate ones. The attached figure shows the weekly demand chart obtained from a **CIRWATT** meter**.**

Power demand chart

These charts show the active and reactive power evolution, which allow to check:

- whether the contracted power is the most appropriate
- whether there are power peaks and the time when they happen
- the levels of reactive power consumed and, therefore, the informaiton necessary to compensate it correctly

The following figure is a demand chart measured by an **AR5-L** portable network analyzer.



4.3 Maximum demand

The electricity tariffs allow to use formulas that, in a moment of need, permit to demand more power than the contracted value without having a power cut due to the disconnection of the circuit breaker.

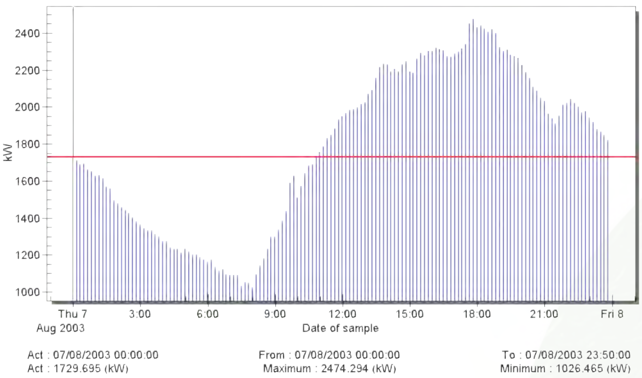
Maximum power demand is understood as the maximum demanded power by an installation, which is accumulated in an integration period that is normally 15 minutes. The **CIRWATT** maximum demand meter function records the maximum power demand measured in a given month.

Thus, one action to be carried out in an efficiency study is to damp the power demand peaks, which will permit:

- supporting the technical management of the electrical energy transport and distribution system as well as the ecological management in power generation
- reducing the demand extra charge of the electricity bill
- optimization of the installations and losses reduction

As example, we may study the spanish electricity tariff. The registered value is applied in the following formula, which is valid for a MV three periods tariff for both, regulated and free market.

$$P_{billed} = MD + 2\ (MD - 1{,}05 \cdot P_{contracted})$$



- where MD is the maximum value measured by the meter in one month.

4.4 Harmonics and distortion power

Non lineal loads such as rectifiers, variable speed drives, ovens, inverters, etc., absorb the non-sinusoidal periodic currents from the grid. These currents are the addition of a fundamental 50 or 60 Hz component plus a series of superimposed currents, with different frequencies each, that are multiples of the fundamental. We will refer them as harmonics. The result is a current and voltage deformation, which implies a series of associated secondary effects.

For understanding and analysing the measurements made in installations with harmonics, a series of parameters are defined hereafter.

Harmonic order (n)

Relation between the harmonic frequency (f_n) and the fundamental frequency (f_1).
The fundamental frequency is given as 50 or 60 Hz.

n (harmonic order)	Grid frequency	
	50 Hz	60 Hz
5	250 Hz	300 Hz
7	350 Hz	420 Hz
11	550 Hz	660 Hz

Individual distortion rate

Ratio expressed as a percentage between the RMS value of a voltage or current harmonic (U_n o I_n) and the RMS value of the corresponding fundamental component.

$$U_n(\%) = \frac{U_n}{U_1} \cdot 100 \qquad I_n(\%) = \frac{I_n}{I_1} \cdot 100$$

Example:

Grid voltage	Fundamental current	*I* of the 5th harmonic	*U* of the 5th harmonic
400 V	327 A	53 A	18 V
Individual rate for current		**Individual rate for voltage**	
$I_5(\%) = \frac{I_5}{I_1} \cdot 100 = \frac{53}{327} = 16\%$		$U_5(\%) = \frac{U_5}{U_1} \cdot 100 = \frac{18}{400} = 4{,}5\%$	

Global quantification

Total harmonic distortion rate

Ratio expressed as a percentage between the RMS value of the residual harmonic in voltage or current and the corresponding RMS value of the fundamental component. For this, the Total Harmonic Distortion Rate or THD is defined.

Total harmonic distortion rate in current THD *I*	Total harmonic distortion rate in voltage THD *U*
$THD\ I(\%) = \frac{\sqrt{I_3^2 + I_5^2 + I_7^2 + .. + I_n^2}}{I_1} \cdot 100$	$THD\ U(\%) = \frac{\sqrt{U_3^2 + U_5^2 + U_7^2 + .. + U_n^2}}{U_1} \cdot 100$

For example, the following measurement is proposed with a complete range of harmonic voltages and currents.

	Fundamental	5th	7th	11th	13th	THD (%)
I	327 A	224 A	159 A	33.17 A	9 A	84,6 %
U	400 V	20 V	17 V	6 V	2 V	6,7 %

True RMS value of voltage and current

In an electric installation where the harmonic distortion rates are high, the real current or voltage value may be significantly increased when compared with the fundamental, resulting in overloads and consequently overheating.

In order to understand this problem, the RMS value is defined taking into account the fundamental component and the existing harmonic components.

$$I = \sqrt{I_1^2 + I_3^2 + .. + I_n^2} \qquad U = \sqrt{U_1^2 + U_3^2 + .. + U_n^2}$$

Therefore, a clear consequence of the increase in the true RMS value in current is the increase in the level of losses. There are two types of losses.

- Losses due to the Joule effect.
- Magnetic losses (hysteresis or Foucault)

Harmonic residue

Difference between the total voltage or current and the corresponding fundamental value.

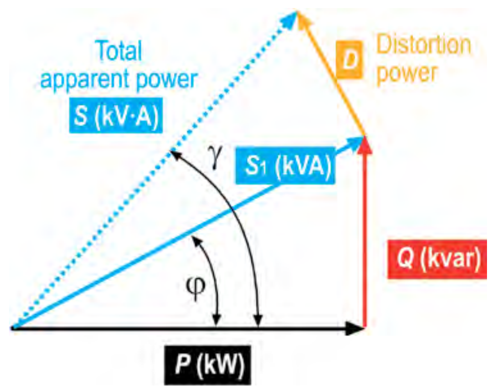
$$I_{res} = \sqrt{I^2 - I_1^2} \qquad U_{res} = \sqrt{U^2 - U_1^2}$$

Distortion power

When the electric installation has loads that produce harmonics, there is one more component to consider when calculating the apparent power. This additional power is known as the distortion power (*D*).

$$S^2 = U_1^2 . \sum_{n=1}^{\infty} I_n^2 = U_1^2 . I_1^2 + U_1^2 . \sum_{n=2}^{\infty} I_n^2 = S_1^2 + D^2$$

Power triangle



- Power $S > S_1$
- High levels of current
- Power factor cos γ less than cos φ

Power factor	
$FP = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q_1^2 + D^2}}$	$I = \frac{S}{\sqrt{3} \cdot U}$

For a cos γ constant, it is important to note that as distortion power D increases, the power factor decreases.

Overload factor

The ratio between RMS current and fundamental current or between total apparent power *S* and apparent power S_1

$$F_c = \frac{S}{S_1} = \frac{I}{I_1}$$

◢ The *K*-factor for transformers

The *K*-factor is a coefficient used to calculate the loss of useful power of a transformer as a consequence of the existence of harmonic currents.

This calculation considers the following:

- Overload due to the harmonic currents
- Reduction of the useful power to maintain the core temperature at acceptable values, given the overheating due to harmonic frequencies. It means, due to the increasing of Hysteresis and Foucault losses.

$$K = \sqrt{1 + \frac{e}{1+e}\left(\frac{I_1}{I}\right)^2 \sum_{n=2}^{40} n^q \left(\frac{I_n}{I_1}\right)^2}$$

  - e: This is the factor that represents the relation between losses in the copper and iron in the transformer. It is obtained from the transformer test data, or in its absence 0.1 is used as an approximate value
  - q: This tends to be between 1.7 and 1.8

Therefore, once the *K*-factor has been determined, the reduced useful power of the transformer is calculated.

$$S_{useful} = \frac{S_{trans}}{K}$$

4.5 Losses

This is the loss of power and energy as a result of impedances existing in the electric installation.

Types of losses

◢ Losses due to the Joule effect or in the copper

Those are the consequence of the level of current flowing throw the installation and the electrical resistance.
They are in:

- Distribution power lines
- Windings in motors and transformers

$$P_J \;\; R \cdot I^2$$

◢ Losses in iron or magnetic losses

Losses due the flowing current and mainly, due to the frequencies of the existing currents in the installation. That is, the harmonic currents.

There are two type of losses in the iron cores: Hysteresis and Foucault. The first correspons to the energy necessary to magnetise the magnetic laminating.

$$P_h = K_h \cdot \sum n \cdot I^2$$

The second correspons to those generated by the existence of induced currents.

$$P_F = K_h \cdot \sum n^2 \cdot I^2$$

Foucault losses increase in accordance with a quadratic function due to the effect of existing frequencies.

They are found in receivers that have magnetic lamiating, such as:

- Rotating electric machinery
- Transformers
- Reactors

Reduction of losses

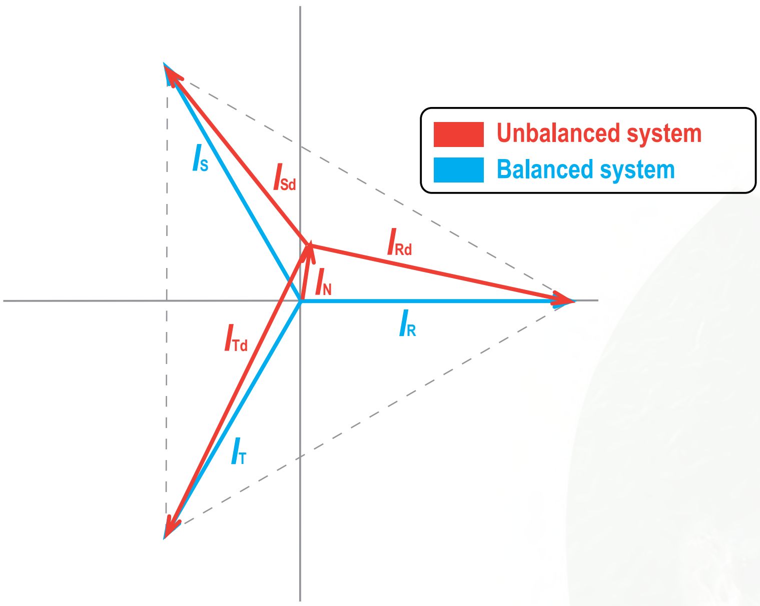
One of the important points in an efficiency study is the minimisation of losses.

To minimise losses, the flowing current values must be reduced (losses due to the Joule effect) and harmonic frequencies or multiples of the fundamental must be eliminated (magnetic losses). Reducing losses also results in:

- Reduced heating
- Less consumption in cooling systems
- Light reduction of the electricity bill

4.6 Unbalance

Unbalanced single phase and three phase loads generate unbalances in the power lines and cause current to flow throgh the neutral cable. So, it results in a bad distribution of energy in the three phases of the electrical system.



The problem of the neutral current becomes worse if there are loads that generate a third harmonic, so this increases the value of said current.

$$I_{eff} = \sqrt{I_d^2 + I_3^2}$$

These unbalances cause low levels of efficiency in the electrical system, that is, an underuse and overload of transformers and distribution networks.

This results in an increase of the levels of losses and voltage drops in the whole system. As an example, the load distribution of a 1000kV·A, 20/0.4 kV transformer is studied.

Unbalanced loads	Balanced loads
R phase: 250 kV·A - 1081 A S phase: 320 kV·A - 1384 A T phase: 430 kV·A - 1860 A Total power: 1000 kV·A	R phase: 333 kV·A - 1440 A S phase: 333 kV·A - 1440 A T phase: 333 kV·A - 1440 A Total power: 1000 kV·A
Conclusions	**Conclusions**
The transformer breaker will switch off due to the overload of phase T R and S phases will be underused T phase conductors and the neutral will be overloaded Losses due to the Joule effect will increase Voltage drop will be higher	Transformers working under rated load conditions Conductors working in rated conditions Neutral not charged Losses due to the Joule effect will decrease Voltage drop will be lower

There are different ways to reduce the existing unbalances:

- Receivers balancing: New loads distribution in the installation
- Load balancing equipment, whether for reactive power (efficient phase to phase compensation) or apparent power (multifunction active compensator)

5. Basic concepts of communication

5.1 Introduction

Communication systems are a basic tool in any energy efficiency and process control system, by remotely monitoring every parameter necessary to optimize the energy and productive resources.

Primarily, an energy management system includes the four following components:

- Field equipment
- Control equipment
- Control application clients
- Communications networks

The components of a monitoring system need a communications network in order to interact with each other. Here, the purpose of each one of these components is explained in detail.

5.2 Field equipment

This is the monitoring equipment used to measure electrical or analog and digital parameters. It is divided into the following levels:

Distribution network level

- **CIRWATT** energy meters
- **QNA** power quality analyzers

General panel level

- **CVM** network analyzers
- **RGU-10** smart earth-leakage protection
- **computer** power factor controller

Secondary panel and process level

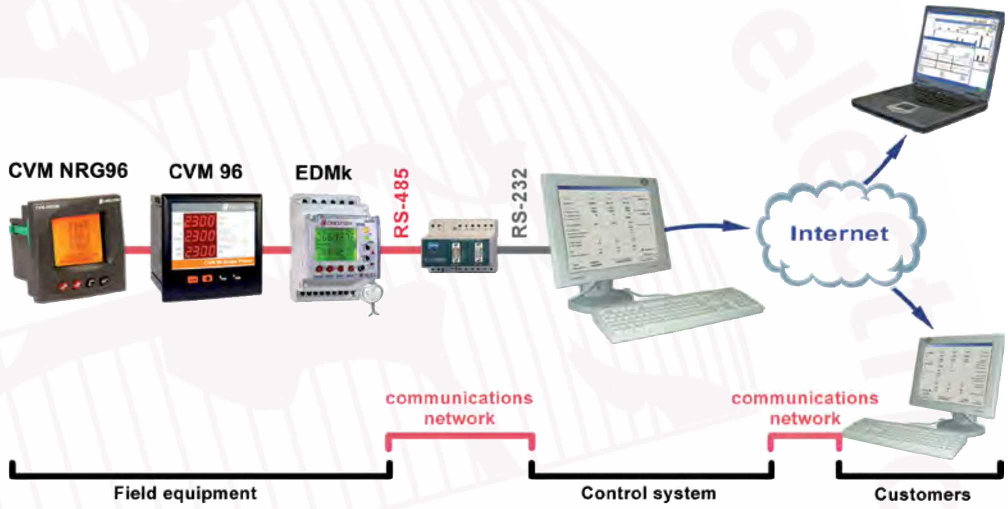
- **EDMk** submeters
- **LM** pulse centralizers
- Converters
- **DH96** digital process instruments
- **CBS** smart earth-leakage protection

5.3 Control system

This is generally a PC or PLC. It functions as the centre where all the system data is stored, and it is generally capable of making all this information available to other users (control application clients). It can also function as a communication gateway.
This control system is done with **PowerStudio Scada** software.

5.4 Control application clients

All equipment (computers, PLCs, machines, etc.) that use the information stored by the control system to act on machinery, to get statistics on energy consumption, or for other applications.



5.5 Communications network

One of the main points for having an efficient electrical installation is to obtain the necessary information and to centralise it, for being subsequently processed. This is achieved by implementing a communications network. Said network is made up of the following:

- Physical layer and method for accessing the network
- Communication protocol
- Communication network design

Physical layer and method for accessing the network

The physical layer is understood as the equipment used to physically transport the information. This physical support layer determines the communication protocol to be used. On occasion, the capacity of the physical layer limits the use of one communication protocol or another.

PHYSICAL LAYER

Cable
- RS-232
- RS-485
- Ethernet

Radio frequency
- GSM/GPRS
- Wifi
- WIMAX

Optics
- Fiber optics

Distribution lines
- PLC (transmission over power line)

Factors in determining the physical layer

- Existence of a communications network
- Network topology (internal, external, multipoint, etc.)
- Type of physical layer to be used based on the characteristics of the installation and the location (cable, radio, etc.)
- Number of units of equipment to connect to the network
- Physical distance among the equipment and the control system
- Necessary transfer speed

Cable

Comparative analysis of the different physical layers

Layer	Units of equipment to connect (Maximum)	Maximum distance	Transfer speed	Cable type
RS-232	1	10 meters	2,400 / 4,800 / 9,600 / 19,200 / 38,400 bauds	3 x 1.5 mm² twisted and shielded
RS-485	32	1,200 meters Longer distances with **CAR485** amplifier	2,400 / 4,800 / 9,600 / 19,200 / 38,400 bauds	3 x 1.5 mm² twisted and shielded
Ethernet	Depending on network design	200 meters Longer distances with amplifiers (Switch, Hubs, etc.)	▸ LAN network: 10-100 Mbauds to 1-10 Gbauds ▸ WAN network: Depends on technology (Modem, ADSL, etc.)	Minimum category 5 UTP cable
PLC	1600	According to network design and number of receivers	1200 bauds	Uses the same cable as the power electric network

RS-232

Uses

Connection between a single unit or converter and a computer

Considerations

- Short distances
- Low trasfer speed

RS-485

Uses

Internal networks for communicating among measuring equipment and a computer

Considerations

- Common system for connecting field equipment to a communications network
- Very standardised system, easily interconnected with other higher physical levels
- Low trasfer speed

Ethernet

Uses

Internal (LAN) and external (WAN) networks

Considerations

- These tend to be used in installations that have a structured communication network
- Existence of field equipment, fitted with an Ethernet port
- Easy to include existing networks with other physical levels (RS-232, RS-485, etc.), by using converters or gateways
- Simplicity of implementing, installing and expanding the network
- Direct connection between each Ethernet unit and the HUB or switch

PLC

Uses

Data transfer by using the electric power line

Considerations

- Uses the electric power network as a physical medium for communication
- Highly reliable transfer system. Filters interferences and avoids changes in impedences due to operate loads and changes of sections of cable
- Low trasfer speed

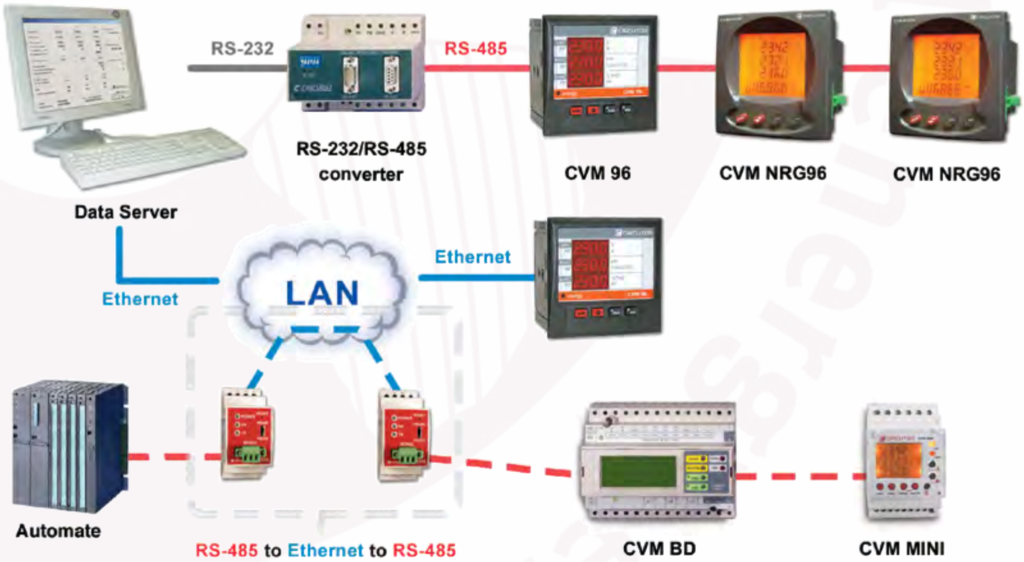
◢ Example of RS-485 and RS-232 connections

In this diagram it is observed the typical measurement equipment connections in RS-485 bus and its connection to a control system via an RS-232/485 converter.

◢ Example of RS-485 and ETHERNET protocol connections

The following diagram shows the combination of:

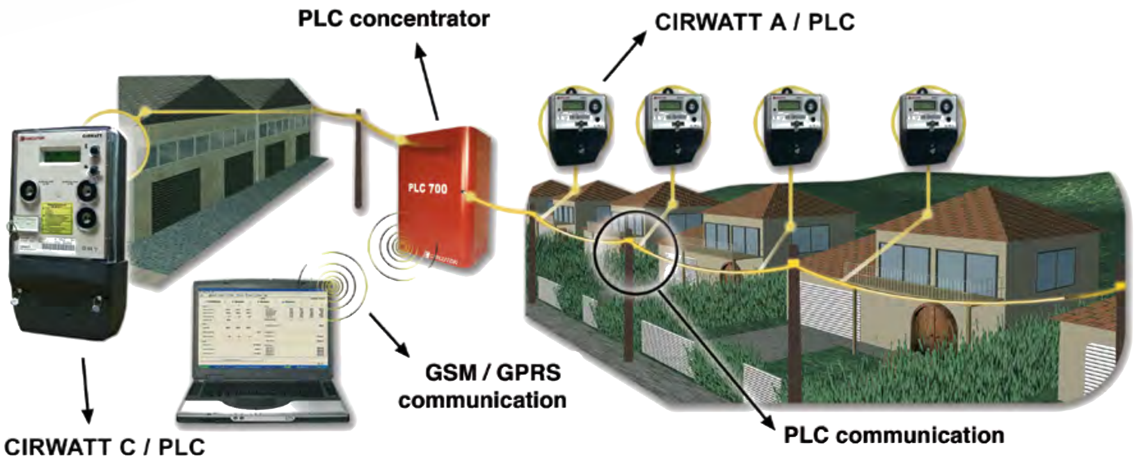
- RS-485 bus for connecting all the **CVM** measurement equipment
- Ethernet technology for monitoring the analyzers by using the existing infrastructure (local area network, LAN)



◢ Example of PLC system

As seen in the figure, the PLC system consists of the following:

- **CIRWATT PLC** meters
- Concentrator: Reads and sends all information from the downstream meters to the control centre (usually via GSM/GPRS). Normally a concentrator is installed at the output of each distribution transformer



Air

Layer	Units of equipment to connect (maximum)	Maximum distance	Transfer speed
GSM / GPRS	According to the network	According to the coverage of the telecommunications operator	▸ GSM Slow speed around 12 kbps ▸ GPRS around 56 kbps
WIFI	According to the network topology	100 m. Depending on the architecture of the office building or industrial plant (walls, obstacles, etc.) and the network topology.	20 Mbps
WIMAX	According to the network topology	From 30 to 40 km. Depending on the architecture of the office building or industrial plant (walls, obstacles, etc.) and the network topology.	100 - 300 Mbps

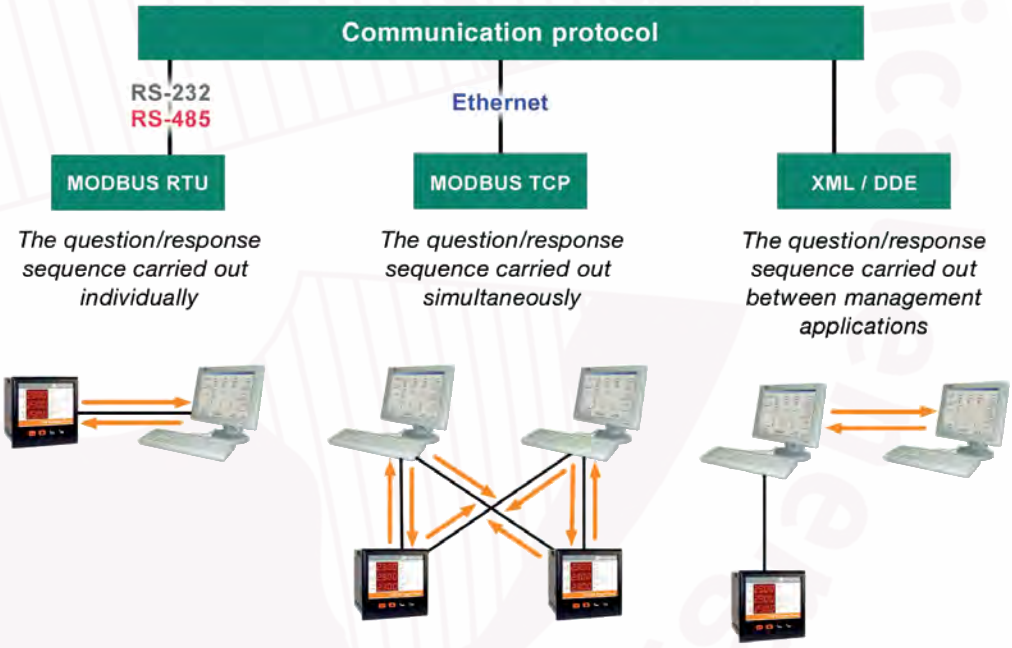
Layer	Uses	Considerations
GSM / GPRS	External networks (WAN)	▸ Commonly used in locations that are difficult to access or in locations where it is not profitable to install a cable network ▸ Allows to take advantage of the mobile telephone operators' infrastructure, offering coverage in practically any location
WIFI	Internal networks (LAN)	▸ Allows to take advantage of the existing information network (typically Ethernet), whether for internal (LAN) or external (WAN) communications ▸ Roaming in an internal environment (office building, industrial plant, etc.)
WIMAX	External networks (WAN)	▸ Permits using wireless topology for long distances ▸ External coverage with high transfer speeds ▸ High reliability

Communication protocol

As stated, the next most important parameter in a communication network is the protocol used for communicating.

Protocol is a group of conventions used for tranferring information among devices. The simplest protocol only define the *hardware* configuration. More complex protocol include synchronisation, data formatting, error detection and troubleshooting techniques. On some occasions, the physical layer limits a network to one protocol or another.

Hereafter, there is a description of the most common protocols and physical layers available in industrial networks



The protocols can be devided into:

- Low level protocol: These are used for communication between field equipment and control systems (PC, PLC, etc.) in basic applications: RTU Modbus, TCP Modbus, Profibus, etc.
- High level protocol: These not only transfer the information, but they also provide reliability and security in communication. Ethernet - TCP/IP (network and transport level), XML and DDE (application level), etc.

Communication network topology

The communication network topology defines as much the network level (internal or external) as the way that the equipment are connected. The most common industrial configurations in energy management systems are described below.

Internal networks or LAN (Local Area Network)

An internal network is understood to be one that permits monitoring and managing equipment that is installed in the building or industrial plant, which means it does not communicate outside of that environment.

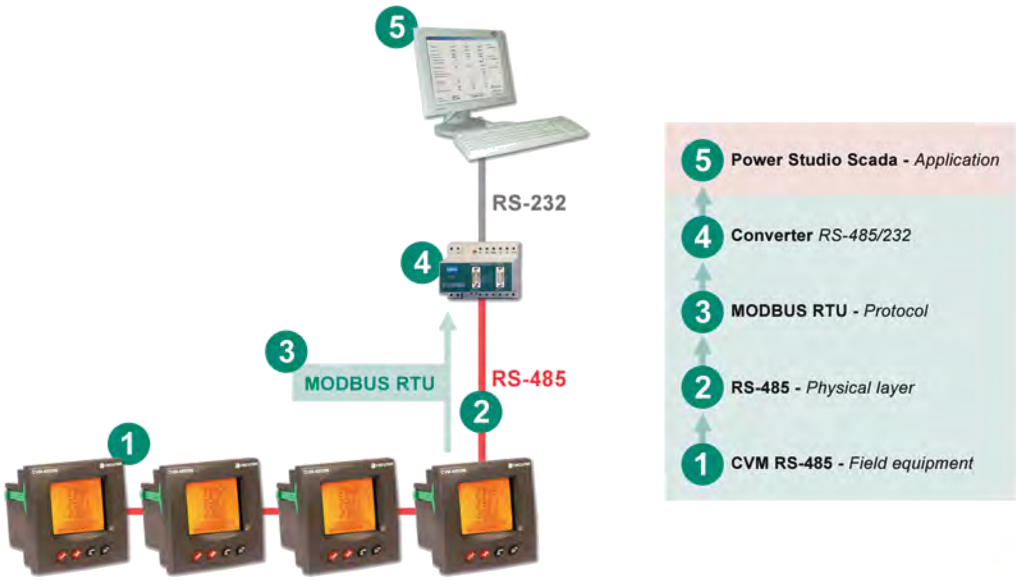
To provide a schematic reference, two basic diagrams have been inserted to show two types of internal networks, a basic and an advanced ones.

The difference between the two networks is found in the physical layer used in each one, so that, the type of communication protocol that can be used accordingly. In a basic internal network, industrial protocols (Modbus, Profibus, etc.) are used. In an advanced network the information is encapsulated in Ethernet frames and/or XML commands.

In fact, the networks are normally combined, depending on how the installations are designed in the building or the indutrial plant studied.

◢ Basic internal network

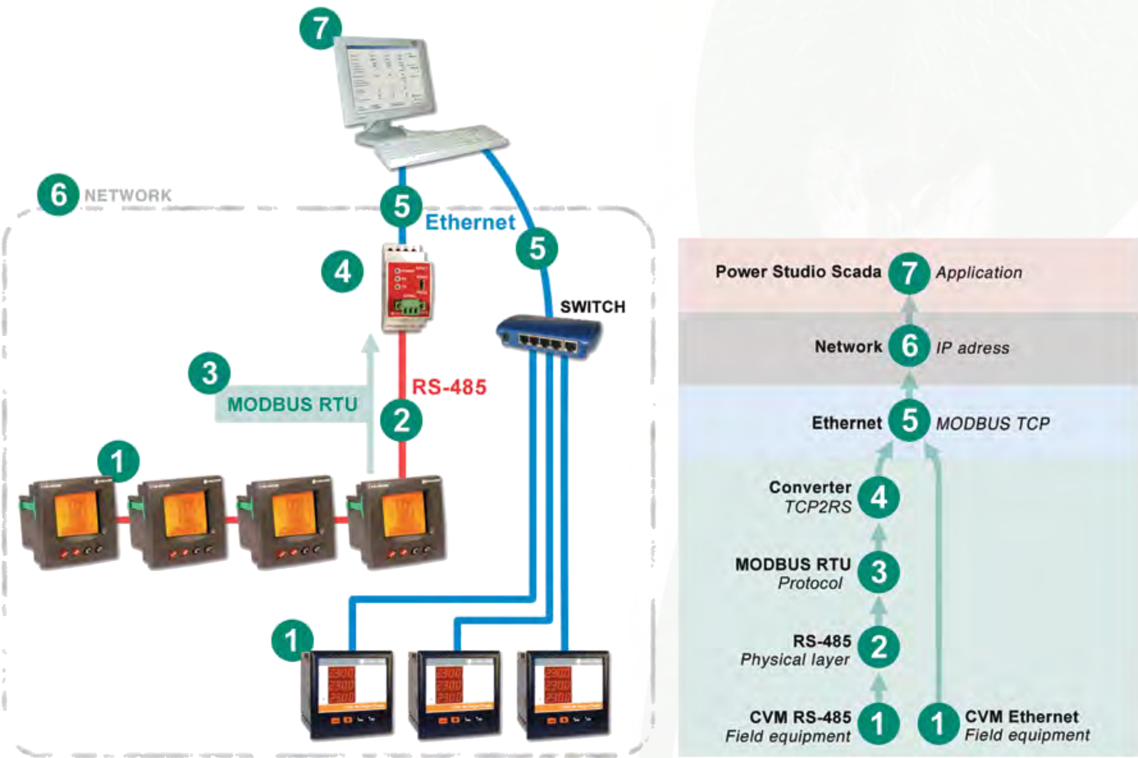
Classic network design for data transfer among **CIRCUTOR** measuring equipment and application *software* via RS-485 and RS-232.



◢ Advanced internal network

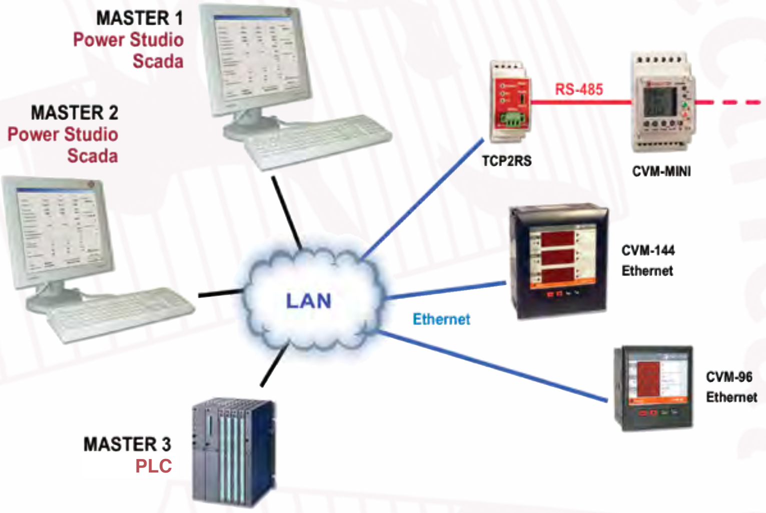
Using an RS-485 to Ethernet communications converter, the basic industrial communications network is included in a structured cable network (Ethernet) already existing in the building or industrial plant. This implies the use of higher level protocol such as TCP/IP.

This configuration facilitates connecting to other bus more easily by using a switch or a hub (if working with an internal network) or by using a router (if external communications are required).



External network or WAN (Wide Area Network)

These networks allow to connect different networks or different remote measuring points. This application is typical when it is necessary to control one or more installations remotely from a single control point or when it is necessary to monitor an installation through Internet.

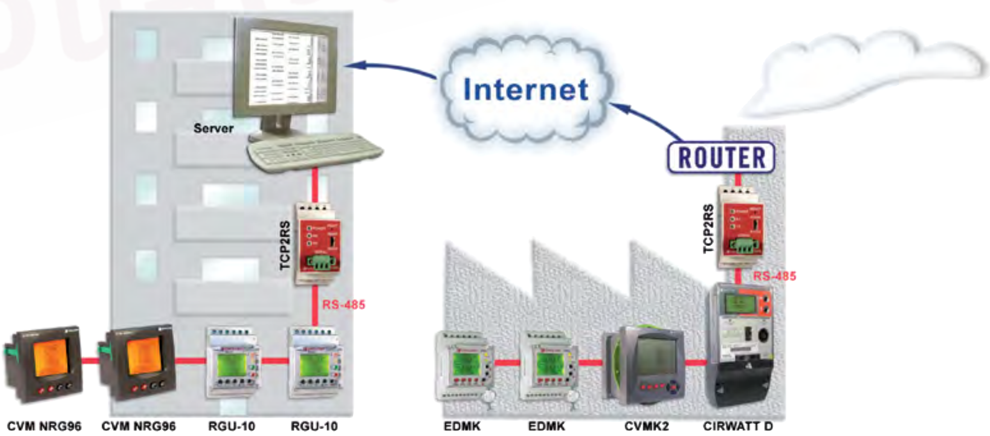


This type of applications are also known as multipoint systems. Client-server applications are also found in this field. In fact, one or more measuring or control systems makes all the information or measuring parameters available to the "clients". When this information is served to various users simultaneously, it is known as a client-server application.

◢ External network or WAN diagram

The most common applications are:

- Different internal networks connection. This application is common in an industrial centre that has several office buildings or plants to be monitored from one or more points
- Industrial network connections in areas that are difficult to access, where the infrastructure of an existing telecommunications operator is used
- Remotely obtaining information from measuring equipment. Commonly the case for **CIRWATT** energy meters and **QNA** power quality analyzers



6. General electrical energy efficiency diagram

PowerStudio SCADA (.circutor.com)

- information centralization
- Energy supervision
- Correct cost assignment
- Assists in preventive maintenance planning

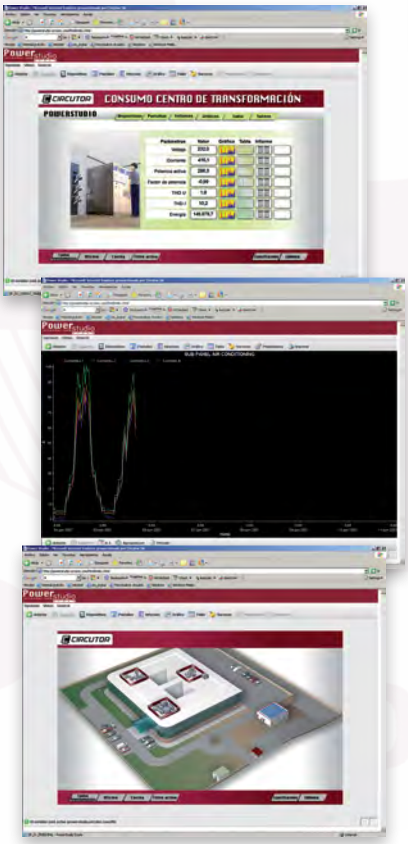
CONTRACT OPTIMIZING

- Obtaining the demand chart
- Analysing contracting conditions
- Power quality diagnosis

+

MEASUREMENT

- Where, how and when is energy consumed
- Electrical parameter measurement
- Leak current measurement



Measurement at the utility coupling point

- **CIRWATT** meters (Q)
- SmartMetering **CIRWATT with added value** (Q)
- **QNA** power quality analyzers (Q)

Process and/or work area measurement

- Electric parameters: **CVM** power analyzers (M)
- Energy: **EDMk** submeters (M)
- Process parameters: Digital Instrumentation (M)
- Leak currents: **RGU** earth-leakage relays (P)
- Leak currents: **CBS** earth-leakage station (P)

Support ofthe measurement system

- **AR5-L** portable network analyzer (M)

✓ CIRCUTOR efficient formula

M + P + Q + R = eficiencia energética eléctrica • electrical energy efficiency

+ DEMAND MANAGEMENT

- Free up available kV·A
- Dump demand peaks
- Losses reduction
- Installation optimization

Power factor correction

- **STD/PLUS** capacitor bank (R)

Harmonic filtering

- **NETACIVE** active filters (R)
- **NETPASIVE** passive filters (R)

Power demand control

- **CPP** power control (M)

+ PRODUCTIVITY IMPROVING

- Continuity of service in installations
- Reducing downtimes
- Reducing number of breakdowns

Control of disturbances

- Harmonic filtering: **NETACTIVE** active filters (R)
- Harmonic filtering: **NETPASIVE** passive filters (R)
- High frequency filtering: **EMC** filters (R)
- Earth-leakage protection: **RGU** earth-leakage relays (P)
- Earth-leakage protection: **CBS** earth-leakage station (P)

Cost charge

- Energy: **EDMk** Submeters (M)

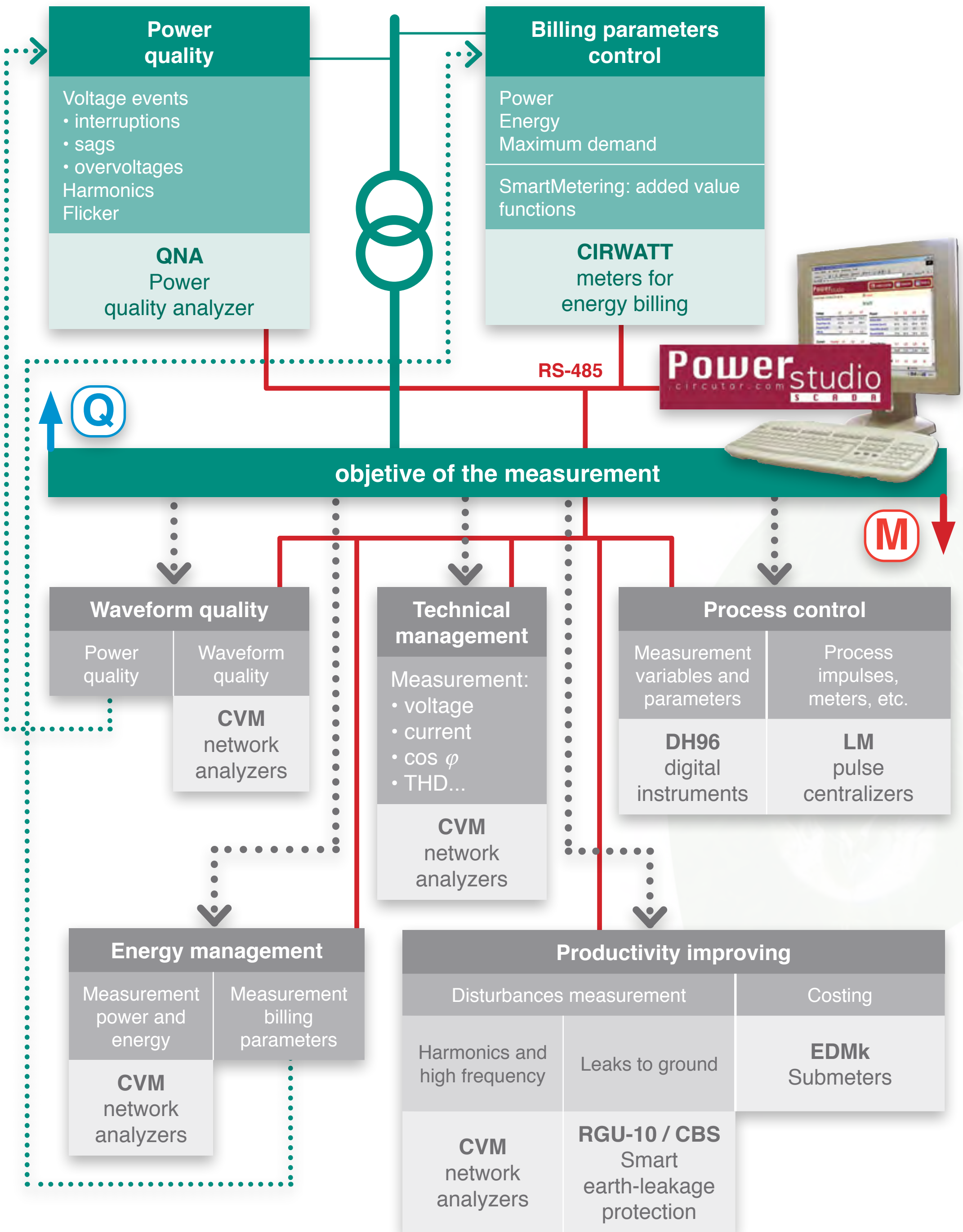
7. Contract optimizing

As described in the general **e³** diagram, contract optimizing involves the following:

- To control the billing parameters with **CIRWATT** meters in order to:
  - Obtain power and energy demand charts
  - To analyze the current contract of energy

- To control power quality by using **QNA** analyzers

This is the initial information necessary to analyze when and how much energy is consumed in the company. In other words, it is the beginning of an energy efficiency study.



7.1 CIRWATT meters

What is a CIRWATT energy meter

These are high precision multifunction measurement equipment that integrate every element necessary for billing electric energy into one single device.

Characteristics of **CIRWATT** meters:

- These meters have been designed to operate in direct and indirect measurement systems with measurement transformers
- The range of **CIRWATT** meters covers the needs for every type of client, whether for the free market or the regulated market, in consumption or in generation
- The **CIRWATT** meters incorporate several communications systems such as RS-232, RS-485, modem or Ethernet as well as some more advanced and innovative systems like PLC (Power Line Carrier) communication

Which are the benefits of CIRWATT meters

Reduced assembling space

- In one single meter, it integrates all the classic measurement equipment such as the active and reactive energy meters, the hourly clock, the maximum demand meter, etc.

Registering and data storing

- Registering of all the measured parameters
- Thus, it obtains the installation demand charts (power and energy) at the coupling point. This is the start up for an energy efficiency study

Communications

- Remote communications from the meter to a centralized control station. To do this, different types of communication methods are used according the existing infrastructure available in the installation (RS-485, Ehternet, GPRS, etc.)
- Design of multipoint measurement systems

Energy management

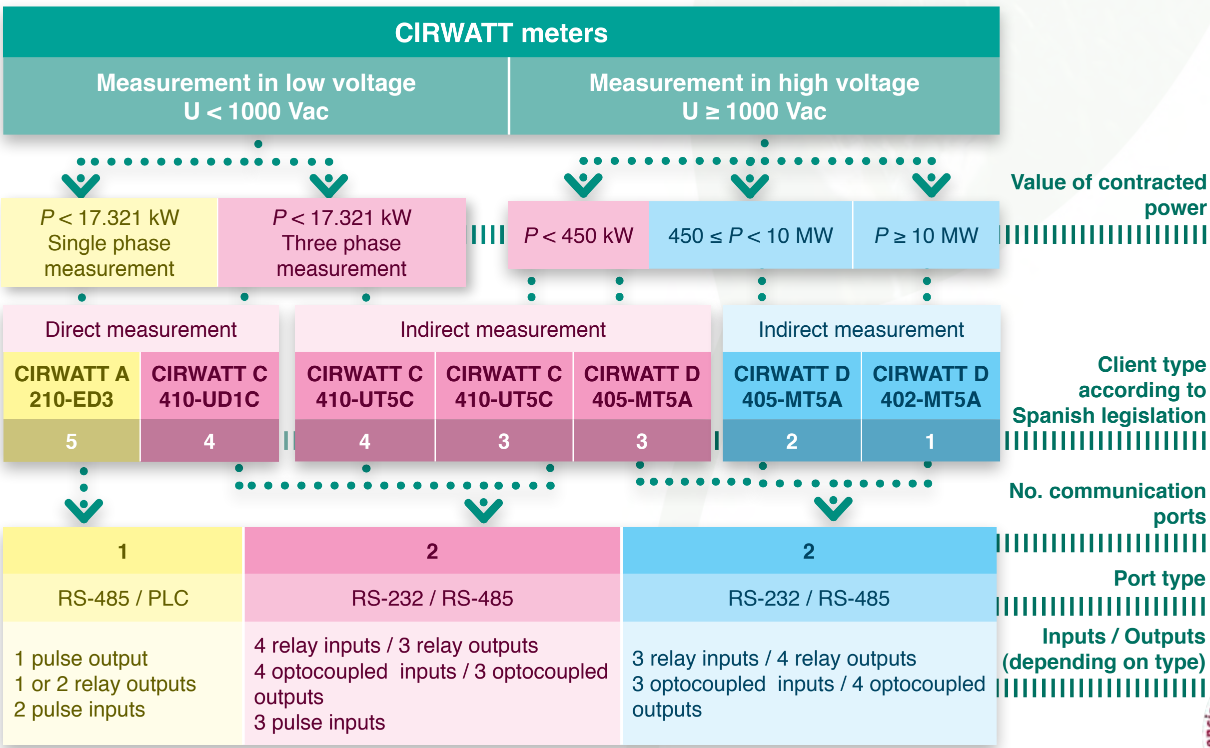
- Processing information from one meter, or a group of meters, with the **PowerWatt** remote control and management software
- **PowerStudio Scada** integration

How to select a CIRWATT meter

Steps to selecting a CIRWATT meter

1	Voltage level	▸ High voltage ▸ Low voltage	Forecast of measurement transformers
2	Choosing of the accuracy class	▸ 0.2 S active / 0.5 reactive ▸ 0.5 S active / 1.0 reactive ▸ 1.0 S active / 2.0 reactive	
3	Type of current measurement	Indirect: ▸ External transformers .../5 A, 5(10) A measurement ▸ External transformers .../1 A, 1(2) A measurement Direct: ▸ 10 A base current ▸ 100 A maximum current	
4	Network voltage measured	Indirect: ▸ Secondary voltage, transformer 3 x 63.5/110 Vac Direct: ▸ Voltage measured 3 x 230/400 or 3 x 133/230 Vac	
Specific characteristics depending on the type of CIRWATT			
5	Measured variables	▸ Voltage, current and frequency ▸ Active, reactive and apparent power ▸ Active and reactive energy ▸ Measurement in 2 or 4 quadrants	
6	Functions of energy management	▸ Load charts configurable for power and energy ▸ Close billing ▸ Register and control of set up modifications	
7	Communications	Port type ▸ RS232, RS485	
Considerations			
7	Auxiliary equipment	▸ **PowerWatt** management software ▸ **TRMC** current transformers for Low Voltage networks RS-232/RS-485 TC2PRS converters, ...	

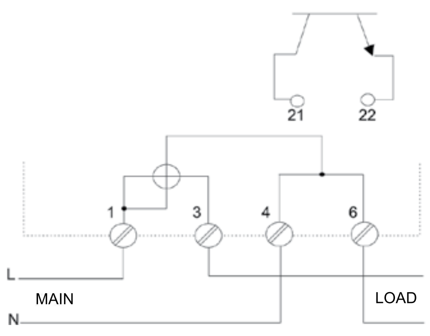
Diagram for choosing a CIRWATT meter



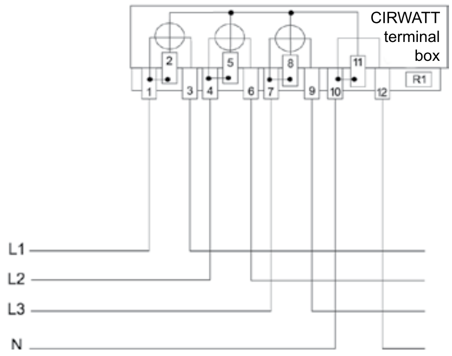
CIRWATT meter electrical diagram

- It is very important to maintain the polarity of the connections when setting up the selected current transformer (P1 - network side and P2 - load to be measured) as well as to maintain the sequence between the voltage and the current lines.
- In three-phase meters, it is not necessary to maintain the sequence of the phases.
- It is not necessary to consider the current direction in the single-phase meter, due to the meter accumulates energy in only one meter (with the exception of the equipment that reads in 4 quadrants).

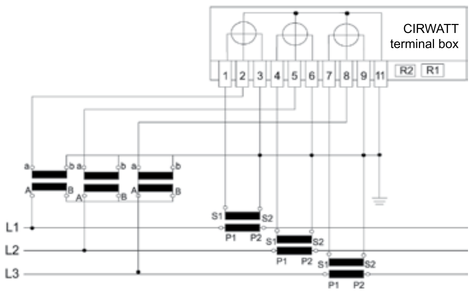
Single phase CIRWATT



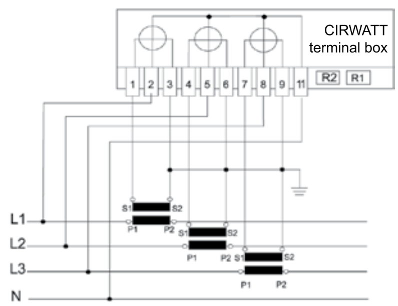
Direct three phase CIRWATT



Three phase CIRWATT, MV connection



Three phase CIRWATT, LV connection



Considerations

When selecting a meter, the type chosen is as important as other parameters such as the contracted tariff, the transforming ratio and the utility description, etc.

Smart Metering or meters with added value

Traditionally, the electric meters have been used to measure the energy. Nowadays, meters are equipped with devices that make them one of the primary tools in energy control.

These devices are the reason for calling them “meters with added value” or smart metering.

Meters with Demand Management systems

- The three phase **CIRWATT C** meter with capacity to control maximum demand (optional), analyzes the real demand, and is capable to disconnect and reconnect non-priority loads in order to avoid the excess of power demand. It has 3 outpus, two of which are used for controlling two loads. The third one, operates as an alarm, which is activated when the other two outputs have been deactivated and there is still a tendency to exceed the contracted power

- The three-phase **CIRWATT C** meter has an astronomical clock function (optional) with three programmable ouputs. For each of these, three types of operations can be programmed (sunrise, sunset and fixed hours). Depending on the geographical location and date, the sunrise and sunset will vary, thus the meter can be programmed to automatically activate and deactivate the relays for the resulting reduction in energy consumption. This is ideal for public lighting, stores with shop windows lights, etc.

Meters with network and supply management systems

- **CIRWATT** meter with switch off element incorporated: By simulating a magnetic chart as an circuit breaker, it allows limiting consumption by remote control
- **CIRWATT PLC** meter. Using the PLC system, the information read and logged by the meter is sent to a concentrator, via the electric power line, normally located in the transformer centre. From this point, all the information is sent to the control centre via GSM/GPRS or some other system

Meters with multi-supply systems

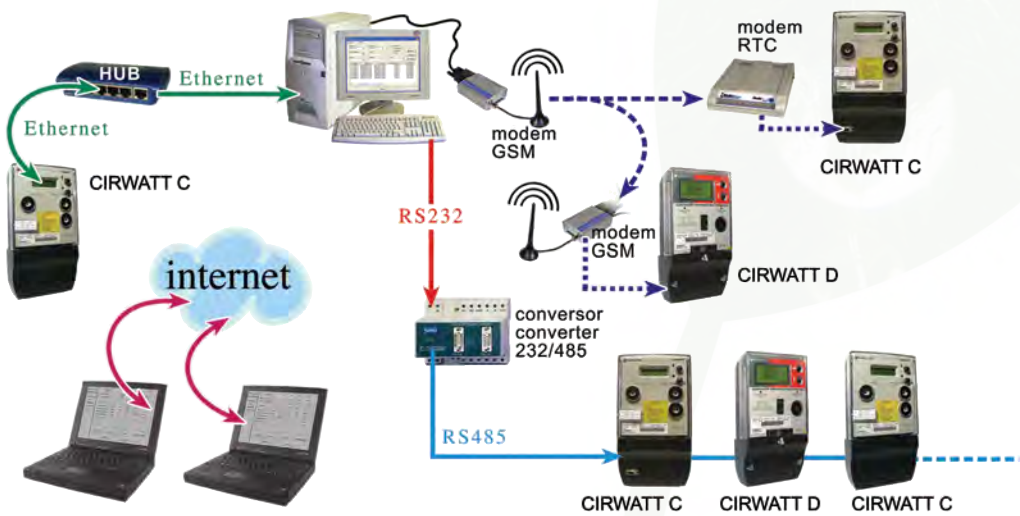
- **CIRWATT A** and **CIRWATT C** have impulse inputs that optionally permit the simultaneous reading of different consumptions (electricity, water and gas) on the same meter via impulses
- Data is downloaded from the different meters by means of a portable terminal, PLC system, modem or serial communication

Meters with communication systems

Selecting the type of communications is a key point. In fact, the application to be developed is determined accordingly. One example are multipoint systems.

- Specially applicable in companies with branches that are spread out geographically such as supermarkets, banks, offices, hotel chains, etc.
- There are different solutions, but normallly are communications via modem, GSM/GPRS or Ethernet
- The most common solution is one that combines the different communication systems

7.2 QNA power quality analyzer



+i Q.1

What is a power quality analyzer

A **QNA** is a high level power quality analizer which measures and registers all kind of voltage events produced in an electrical network.

◢ Considerations for QNA analyzers

- **QNA** range has been designed for measuring Low Voltage, Medium Voltage and High Voltage networks with a very high accuracy. They are installed in the same panel, than meters, in the coupling point
- Depending on the voltage level, the **QNA** analyzers need voltage and current transformers (High Voltage, Medium Voltage) or only current transformers (Low Voltage)
- **QNA** are designed and certified in accordance with the IEC 61000-4-30 international standard, which specifies the measuring methods that should be used for this type of equipment. This standard defines class A equipment as prototype equipment because of its accuracy, and thus it can be used in litigation. **QNA** analyzers are class A equipment according to said standard
- **QNA** analyzers offer different functionality depending on the type:
  - Measurement of the power quality
  - Measurement of the power quality and energy management

What are the benefits of power quality analyzers

- Register and follow up of every event that occurs in an electric installation
- Determining the source of events to subsequently prevent and correct them
- Remotely sending information to a centralised control station. To do this, different types of communication systems are used, based on the existing infrastructure in the installations (RS-485, Ehternet, GPRS, etc.)
- Design of multipoint systems

How to select a power quality analyzer

Steps to selecting a QNA analyzer

1	Voltage level	▸ High voltage ▸ Medium Voltage ▸ Low voltage	Forecast of measurement transformers
2	Anyalysis needed	▸ Power quality ▸ Power quality and energy management	
3	Number of simultaneous measurements	▸ 1 three phase system ▸ 2 three phase systems	
Specific characteristics depending on the type of QNA			
4	Power quality variables	▸ Voltage, current and frequency ▸ Neutral current ▸ Neutral-ground voltage ▸ Harmonic distortion rate in voltage THD *U* ▸ Harmonic distortion rate in current THD *I* ▸ Flicker ▸ Voltage unbalance and asymmetry ▸ Events: Sags, interruptions and overvoltages ▸ Events according to EN 50160	
5	Functions of energy management	Energy measurement ▸ active and reactive ▸ precision 0.2 S ▸ 4 quadrants Power measurement ▸ active, reactive and apparent ▸ accuracy 0.2% ▸ Power factor	
6	Communications	Port type ▸ RS232, RS485 ▸ Ethernet ▸ GPRS/GSM incorporated Communication protocol ▸ MODBUS, RTU ▸ CIRBUS ▸ ZMODEM	
Considerations			
7	Auxiliary equipment	▸ **TRMC** current transformers (Low Voltage applicaitons) ▸ R232/485, **TC2PRS** converters, etc.	

Diagram for choosing a QNA analyzer

QNA, class A, power quality analyzers

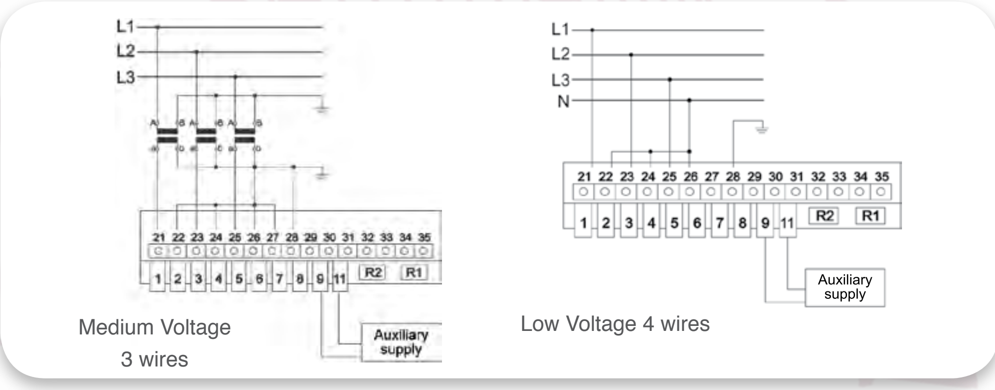
Power quality		Power quality + Energy management
1 three phase system measurement	2 three phase system measurement	
QNA -413	**QNA -423**	**QNA -412**
RS-232 - RS-485 GPRS - RS-232	RS-232 - RS-485 GPRS - RS-232	RS-232 - RS-485 GPRS - RS-232 Ethernet

Communication options

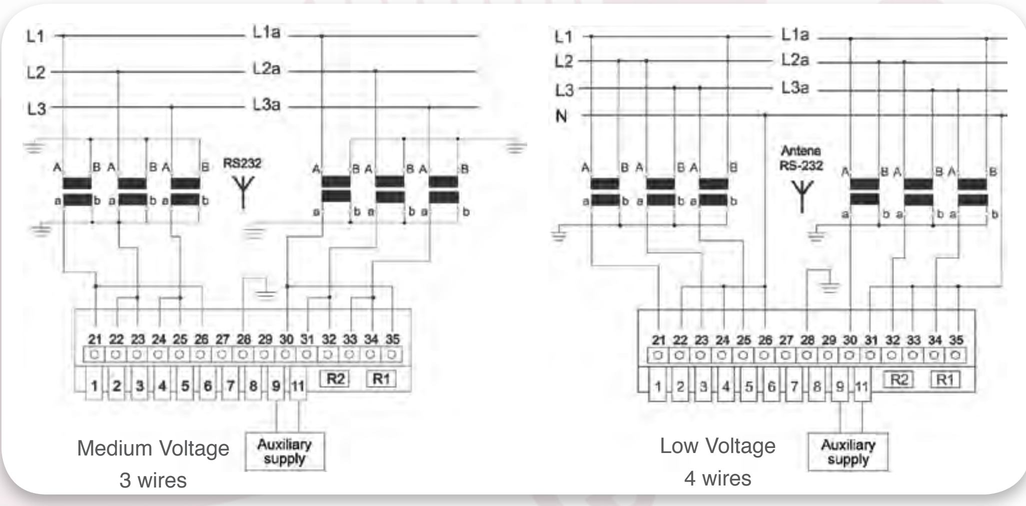
QNA connection diagram

- **QNA** are always connected indirectly through current transformers.
- It is very important to maintain the polarity of the connections when setting up the selected current transformer (P1 - network side and P2 - load side). See section 8.6 on current transformers

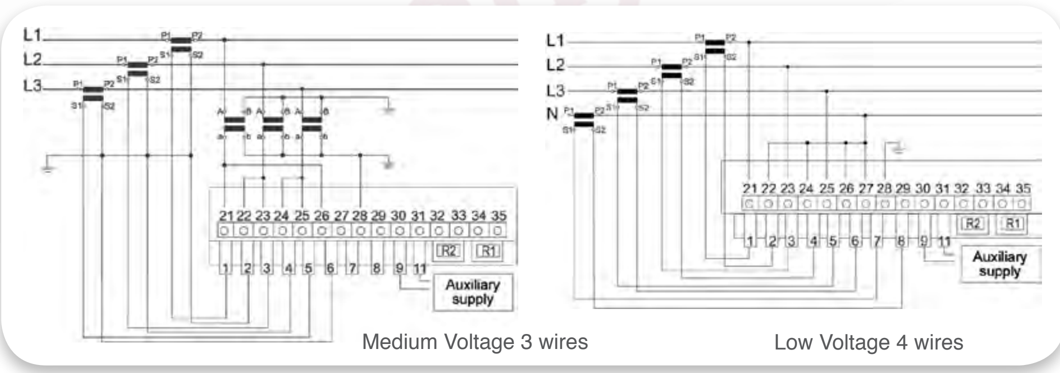
QNA 413



QNA 423



QNA 412

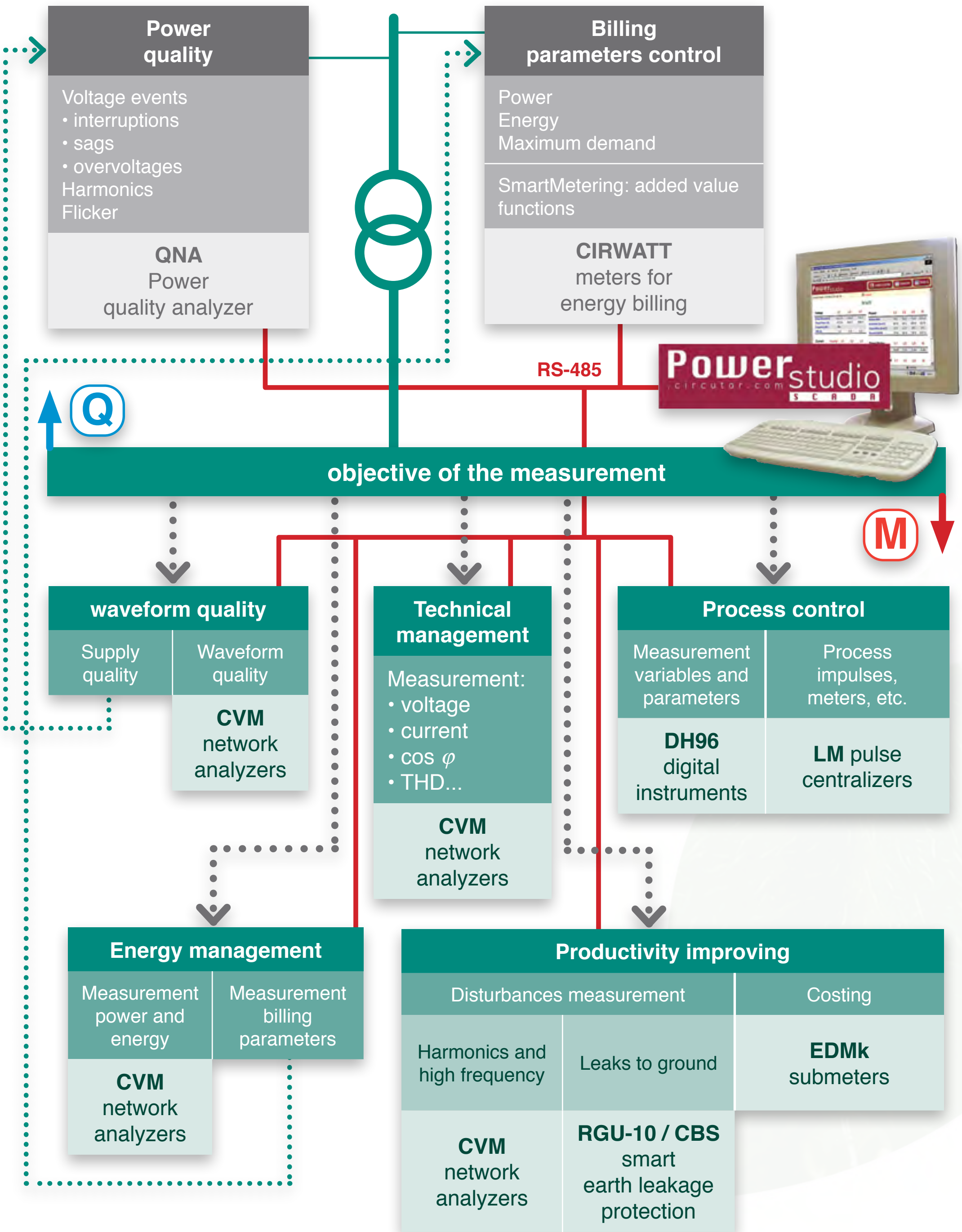


Considerations

- The measurement in 4 quadrants makes possible to install **QNA** in power plants.

8. Energy management systems

An energy management system is understood as the group comprised by measurement equipment, communication network and application software, that allows managing and processing information. This is the base for carrying out an energy efficiency study.



8.1 PowerStudio Scada energy management software

What is PowerStudio Scada

PowerStudio Scada is a software or a control application which allows a centralized system of data collection. The processing of this infrormation allows to make repports which help in the decission making about preventive or corrective actions.

What are the benefits of PowerStudio Scada

PowerStudio Scada offer the following features.

◢ **Make the installation more user-friendly**

- Remote setting up of equipment
- Customized screen design depending on the process

◢ **Centralization and treatment of the information**

- Visualization of parameters in real time
- File registers
- Displaying of the files through datasheets and charts

◢ **Client-server relation**

- WEB server function
- Capacity to be asked by another Scada system by using XML and DDE servers integrated

◢ **Help to installation management**

- Carrying out alarm modules
- Carrying out reports and energy bill simulation
- Telecontrol of equipment

Actions to make with the registered information in PowerStudio Scada

Energy management

- Follow up of the basic billing parameters, power, energy, demand peaks and hourly consumption
- To obtaining power and energy charts
- Carrying out energy consumption reports and billing simulation
- To adjust the electricity contract to the real needs

Technical management

Monitoring of the evolution of the loads for control purposes:

- Available capacities of transformers and lines, using basic parameter control such as THD *I*, cos φ, current, etc.
- In the case of large installations, the monitoring of the voltage values in panels and at the end of the lines
- All types of electrical, mechanical or thermal variables which have been integrated and require follow up and control

Productivity improving

Help to correct costing

- Cost of the energy consumption in processes or working areas by using submeters
- Help to the correct calculation of product marginal costs
- Machine working time control for bonus allocations,etc.
- Reports on energy consumed per manufacturing line and produced units

Help to preventive maintenance

With the supervision of variables and the establishment of alarms, the number of stoppages and breakdowns is reduced, given that, the correct planning and programming of the maintenance actions can be carried out. Examples:

- Monitoring of the smart earth-leakage protection
- Control of the variations of the different electric parameters such as voltage levels and high currents
- Control of the state of electrical protections
- Establishment of signalling and alarms

Process control

Integration of process variables in **PowerStudio Scada**. In this way a common follow up can be carried out for controlling the critical process parameters and the electrical energy consumptions.

Steps to selecting an energy management system

1	Definition of objectives	▸ Obtaining power and energy charts ▸ Cost control ▸ Electrical parameter control ▸ Process parameter control ▸ Others
2	Measurement points	Definition of the measurement points
3	Choosing of equipment for energy billing	Definition of equipment of the coupling point. ▸ **CIRWATT** meters for billing ▸ **QNA** power quality analizers
4	Selecting equipment for principal protection and measurement	Definition of equipment for the LV general panel ▸ **CVMk2** and **CVM NRG96** network analyzers ▸ **RGU-10** smart earth-leakage protection ▸ **computer** reactive energy relays

5	Choosing equipment for working areas and process control	Definition of equipment for secondary control panels
		▸ **Measurement and protection:**
		    ▸ **CVM MINI** network analysers
		    ▸ **EDMK** submeters
		    ▸ **CBS** smart earth-leakage protection
		▸ **Process**:
		    ▸ **LM** pulse centralizer
		    ▸ **DH96** process digital instruments

6	Transformers	Definition of the ratios and sizes of: ▸ Current transformers for measurement ▸ Toroidal current transformers for earth-leakage protection
7	Communications Network	▸ Design of the communications network (see section 5) ▸ Selection of converters or gateways if required

8	Software **adaptation**	▸ Creation of screens with single line drawings, backgrounds, etc.
		▸ Identification, parameterization and communication of devices
		▸ Implementation of the desired functions
		    ▸ Report generation
		    ▸ Alarm panels, etc

Considerations

The systems comprises different items to take into account, such as:

- Measurement, protection and process equipment
- Computer and software
- Adaptation of software if required
- Installation of the measurement equipment
- Communications network. The type of communications network depends on the existing infrastructure and the points we want to communicate (See point 5)
- Communication of the equipment

+i M.3 / M.5 / M.6 / M.7 / M.9

8.2 CVM network analyzers

What are CVM network analyzers

The **CVM** network analyzer series are high precision measurement centres, whose main aim is to control and supervise the main electrical parameters on three or four wire three-phase networks (for both LV and MV, 50 or 60 Hz).

Which are the benefits of CVM network analyzers

The **CVM** range makes easy the measurement, given that, on the same equipment, the function of many analogue indicators can be carried out, minimizing the assembly space in the electrical panel. The integration of the parameters measured in the **PowerStudio Scada** allows to manage the information later on.

CVM network analyzers measure magnitudes related with:

- Energy management powers, energies, maximum demands, etc.
- Electrical parameters: Voltage, current, cos φ, etc.
- Waveform quality: THD, harmonics
- Process parameters, through the use of analogue inputs

How to select a CVM network analyzer

Basic concepts

The nomenclature listed hereafter is used for the definition of the types of **CVM**.

- Equipment with denomination **ITF**. Galvanic insulation of the current circuit by means of transformers mounted on each phase inside the equipment. Its use is recommended on networks where the transformers are referenced to earth or when an important level of events or disturbances is forecasted (E.g.. **CVM NRG96-ITF**)
- Equipment with denomination **HAR**. This equipment measures the harmonic currents, expressing the value in A (E.g..: **CVM NRG96-ITF-HAR**)
- Equipment with protocol indication. They indicate the communication port and/or protocol which exists on the equipment (E.g.. **CVM NRG96-ITF-HAR-RS485**)

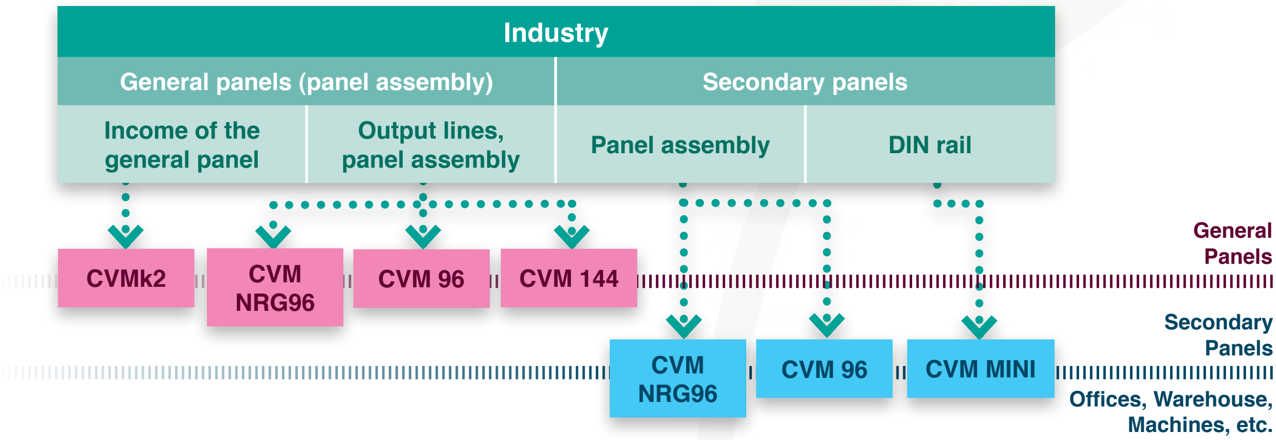
- Number of outputs of relays **C**. This indicates the number of digital outputs (there are types with relay output). If there is a figure afterwards, this indicates the number of outputs other than the unit (E.g..: **CVM NRG96-ITF-HAR-RS485 C**)
- Number of **A** analogue outputs existing in the equipment (E.g..: **CVM 144-ITF-RS485-A4**)
- "Current" equipment or I_N. The **CVM** measures the neutral current (E.g..: **CVM 96-ITF-RS485-C2-HAR-IN**)

Steps to selecting a CVM analyzer

1	Where to put the **CVM** in the installation	▸ Income of the general panel ▸ Output lines of the general panel ▸ Secondary panels ▸ Machines
2	Constructive characteristics	▸ Size of the equipment ▸ Type of assembly ▸ Type of current input
3	Basic parameters of the network	▸ Measurement voltage ▸ Auxiliary voltage
Specific characteristics depending on the type of CVM		
4	Communications	▸ Port type ▸ Communication protocol
5	Functions of energy management	▸ Measuring energy ▸ Maximum demand ▸ 2 or 4 measurement quadrants ▸ Electric parameters
6	Wave quality functions	▸ Graphic representation of the wave ▸ Harmonic measurement ▸ Measurement of THD *U* and THD *I*
7	Inputs and Outputs	▸ Using expansion cards in modular equipment ▸ Compact equipment incorporated in the same
Considerations		
8	Auxiliary equipment	▸ Current transformers **TC, TP**, etc. ▸ R233/485 converters, **TCP2RS** converters, etc. ▸ Impulse centralisers type **LM**

Diagram for choosing a CVM in accordance with the assembly place

The definition in accordance with this concept depends basically on the type of panel and dimensions to be mounted in each one of the areas to be measured. Therefore, in the following panel the type of **CVM** recommended depends on the sector where it will be situated.



Building
Hospitals, Shopping centres, Hotels, Schools, etc.

	General panel				Secondary panels
	Income		Outputs		
Type of assembly	Large panels Panel	Modular panel DIN rail	Large panels Panel	Modular panel DIN rail	Modular panel DIN rail
General Panel	CVMk2	CVM MINI	CVM NRG96	CVM MINI	
Secondary Panel					CVM MINI

Diagram for choosing a CVM depending on its characteristics

CVM Network analyzers

Type of assembly	Panel			DIN rail	
Size	144 x 144 mm	Round hole 4“	96 x 96 mm	3 modules	8 modules

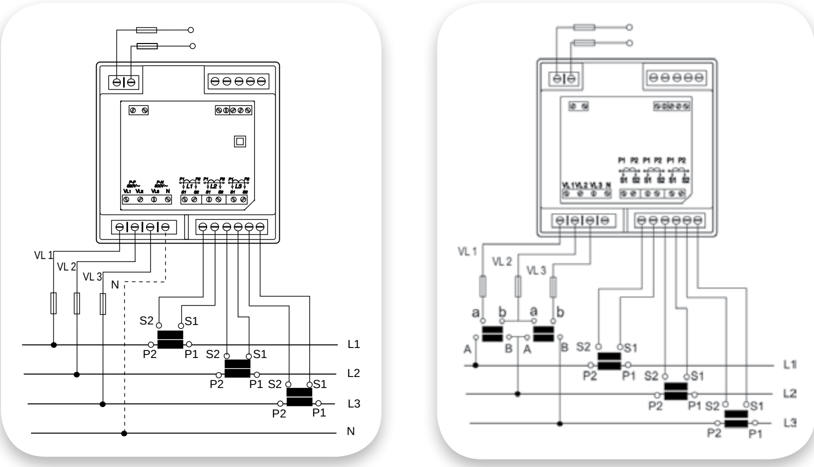
	Modular equipment Expansion cards		Compact equipment			
	CVM 144	CVMk2	CVM 96	CVM NRG96	CVM MINI	CVM BDM (with memory)
Measurement	Electric and energy parameters					
		• Graphic display • ITF inputs • 2 com ports • 0.5 precision • Harmonics				
Optional	• ITF inputs • Relay outputs • Analogue inputs • Harmonics • Com port	• 0.2 precision • Relay outputs • Analogue inputs	• ITF inputs • Harmonics • Com port	• ITF inputs • Harmonics • Com port	• ITF inputs • Harmonics • Com port • Panel installation	• ITF inputs • Relay outputs • Outputs 4...20 mA • Harmonics • Com port
Communications Ports	• RS-485 • Ethernet	• RS-485 • Ethernet	• RS-485	• RS-485	• RS-485	• RS-232 • RS-485
Protocols	• Modbus/RTU • Modbus/TCP • Johnson Controls • Profibus DP	• Modbus/RTU • Modbus/TCP • Profibus/DP	• Modbus/RTU • Modbus/TCP • Johnson Controls	• Modbus/RTU	• Modbus/RTU	• Modbus/RTU

CVM modular expansion cards

CVM 144 Expandable	CVMk2
• Relay outputs • Modbus/RTU • Digital inputs • Current leakage • Neutral current • Analogue	• Analogue input/output 0-20/4-20 mA • Digital input/output • Modbus/TCP + SD memory slot • Expansion of SD memory • Profibus/DP

CVM connection diagram

- The connection of the **CVM** is always done indirectly through current transformers
- For having a correct operation, it is obliged to keep the correct polarity (P1 - network side and P2 - load side) (see section 6.4 on current transformers)



Direction of the load
to be measured

Considerations

- The final precision of a measuring unit (transformer plus measuring equipment) is the addition of the precisions of both
- Depending on the topology of the communication network, the type of **CVM** chosen must have a suitable type of communications port or a suitable converter must be provided

+i M.5/M.7

8.3 Energy meters for partial consumptions or submeters

What are submeters

Submeters are equipment destined for the internal reading of the different electrical consumptions (kW·h or kvar·h), with the aim of:

- Charge the energy costs per department, section or machine
- Follow up of internal consumptions
- Obtaining the demand charts of the different areas

Which are the benefits of submeters

As has already been defined, the clear objective is the charge of costs in work and process areas, or in certain installations where the division of the cost of the electrical energy is vital.

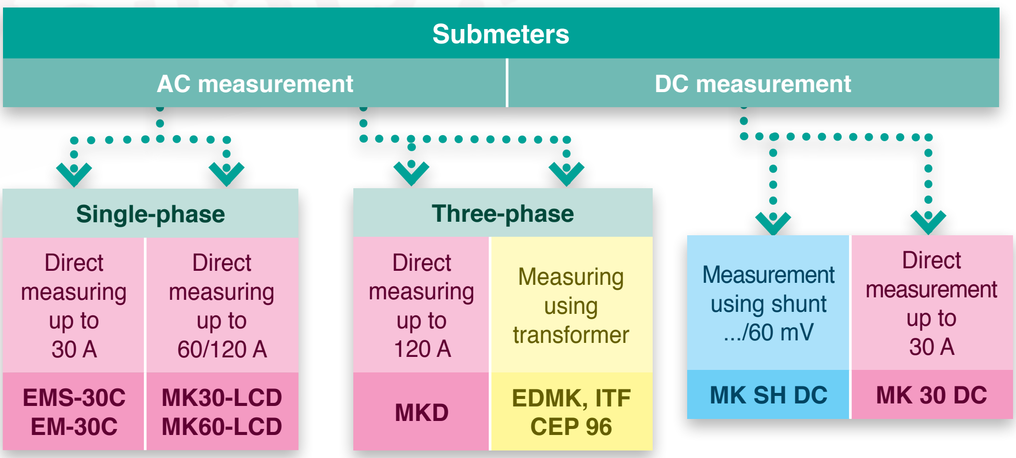
- Mooring lines at seaports
- Commercial outlets in large supermarkets or shopping centres, airports, etc.
- Residences and apartments
- Campings
- Fairs, etc.

How to select a submeter

Steps to selecting a submeter

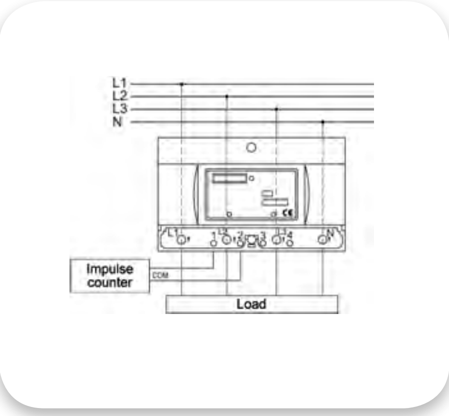
1	Type of network	▸ AC Three-phase system ▸ AC Single-phase system ▸ DC system
2	Type of measurement	▸ Direct ▸ Indirect
3	Basic parameters of the network	▸ Measurement voltage ▸ Auxiliary voltage 400 or 230 Vc.a.
4	Communications	▸ With communications port ▸ Without communications port
Specific characteristics of the type of submeters		
5	Energy management functions	▸ Active or reactive energy metering ▸ 2 or 4 Measurement quadrants ▸ Unbalance: cos φ
6	Outputs	Optocoupled digital outputs incorporated in the equipment ▸ 100 pulses 1 kW·h ▸ 1 pulse 1 kW·h
Considerations		
7	Auxiliary equipment	▸ Current transformers **TRMC**, **TA**, **TC** ▸ **Shunts** for DC measurement ▸ **LM** pulse centralizers

Diagram for choosing a submeter

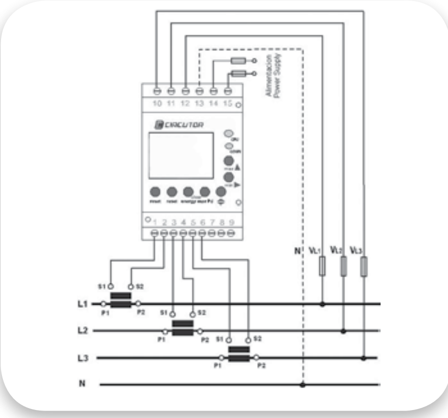


Submeter connection diagram

◢ **AC direct measurement**



◢ **AC indirect measurement**



Considerations

- DC submeters are especially designed for application in solar farms
- In case of indirect measurement, the final precision of the measuring is the addition of the precisions of both (transformer plus submeter)

For this reason the most suitable selection of the ratio to the transformer and the type of precision are very important.

+i M.3

8.4 LM pulse centralizers

What are pulse centralizers?

Equipment capable of grouping and reading impulse signals and digital states (0/1), so that this information is then available on a communication port.
Through this, the centralizer can be integrated in **PowerStudio Scada**.

Which are the benefits of a LM pulse centralizer

Impulse centralisers enable us to integrate into the management system different types of measuring parameters, either of the energy or process type.

◢ **Centralisation of alarms using digital inputs:**

- Control of the state of the electrical protections
- Status of fire alarms, presence detectors, opening of doors etc.
- Process equipment, proximity sensors, inductive or capacitive detectors, end stops
- etc.

◢ **Centralisation of pulse signals**

▶ Pulse output for electrical submeters. Reading and accumulation of pulses, so that accumulated energies can be read later from another system, via communications

◢ **Centralisation of pulse signals from other meters that may not be electrical.**

▶ Gas meter reading: The gas meter must provide a digital output proportional to the reading
▶ Water meter reading: Water meters must provide the corresponding pulse output so that they can be read

◢ **Process equipment**

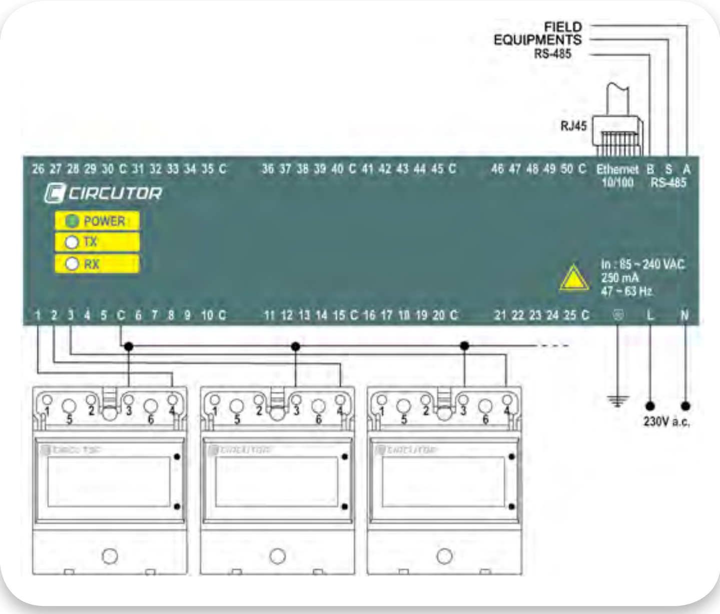
▶ Reading of any sensor or device with pulse output:
- Flow meters with pulse outputs
- Counter for manufactured items
- Operation machine meter, etc.

▶ Signal reading from timers:
- Machinery working times. Application for preventive maintenance
- Personnel working time. Application for charge of bonuses and performances

Steps to selecting an impulse centralizer

1	Number of inputs	Free voltage optocoupled inputs: ▸ 24 inputs. **LM24-M** ▸ 50 inputs. **LM50-TCP**
2	Communications	▸ Modbus/RTU **LM24-M** ▸ Modbus/TCP **LM50-TCP**
Specifics characteristics of the type of LM		
3	Basic parameters	▸ Auxiliary Voltage **LM-24:** 230 Vc.a. ▸ Auxiliary Voltage **LM-50:** 85 - 265 Vc.a. / 95 - 300 Vc.c.
4	Outputs	▸ Serial port RS-485 ▸ Ethernet Port
5	Type of connector	▸ DB-9: **LM24-M** ▸ RJ45: **LM50-TCP**
Considerations		
6	Auxiliary equipment	▸ RS-232/RS-485 Converters ▸ **TCP2RS.** RS-232/485 to ETHERNET Converters. Modbus/TCP Protocol

LM connection diagram



Considerations

- Module inputs are voltage free
- If there is no auxiliary voltage, the equipment saves the accumulated values of the meters in the memory

+i M.3

8.5 Digital process instruments DH96

What are digital instruments

These are programmable digital instruments to read electrical (voltage, current and frequency) and process variables (pulses, weights, temperature, pressure, etc.).

Furthermore, using optional modules they carry out additional functions such as contacts for alarms and switching, communication and analogue signals.

Which are the benefits of DH96

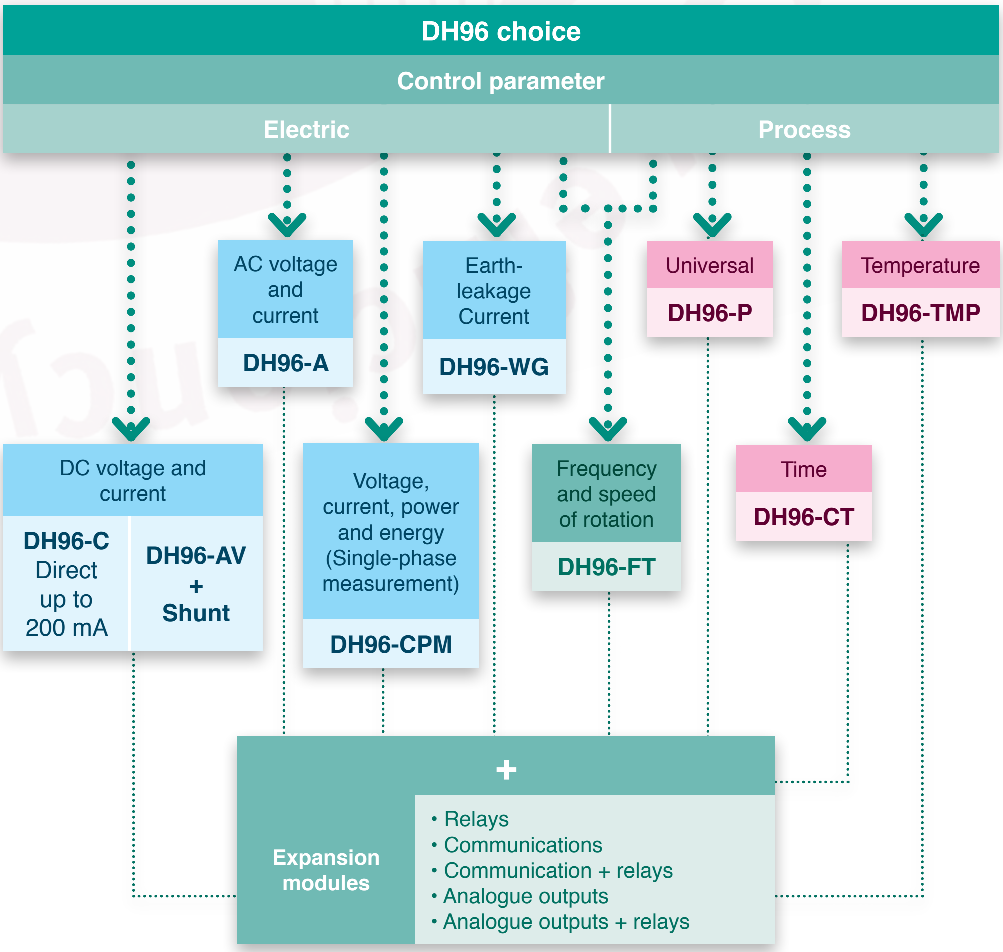
- Integration of physical and process variables in **PowerStudio Scada**
- Establishment of ratios between consumed energy and controlled parameters (kW/m³, kW/unit produced, etc.)
- Information of the productive process

Measurement

Steps to selecting a DH96

1	What are we aiming to control?	▸ AC electrical magnitudes (voltage, current, frequencies) ▸ DC electrical magnitudes (voltage and current) ▸ Time. Chronometer function ▸ Speed of rotation ▸ Temperature ▸ Analogue process signals ▸ Earth-leakage current
2	Basic parameters of the equipment	▸ Auxiliary voltage ▸ Direct or indirect measurement, in accordance with the current value
3	Modules of options	▸ Output relays ▸ Communications ▸ Communications and output relays ▸ Analogue outputs ▸ Analogue outputs and output relays
Specifics characteristics of the type of DH96		
4	Measurement characteristics	▸ Precision 0.1, 0.2, 0.5 ± 1 digit ▸ Measurement of CC or AC ▸ Voltage measurement scales 50,100,150, 200, 300, 600 V ▸ Voltage process scales 120, 500, 1, 10 V ▸ Current measurement scales 10, 5, 300, 600 V ▸ Current process scales 1...20 mA
Considerations		
5	Auxiliary equipment	▸ Current transformers **TC**,**TCB**,**TCM**... ▸ Toroidal transformers **WG** ▸ External sensors (encoders, temperature sounding **TP100**, thermopars, tachometers, detectors **NPN** or **PNP**, etc.)

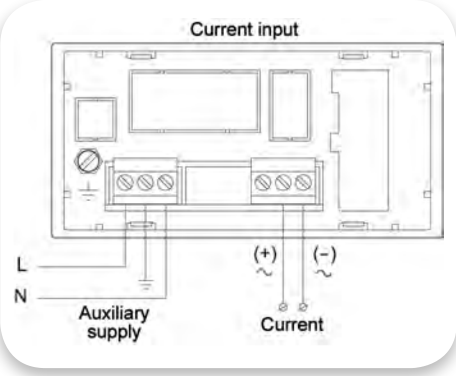
Diagram for choosing a DH96



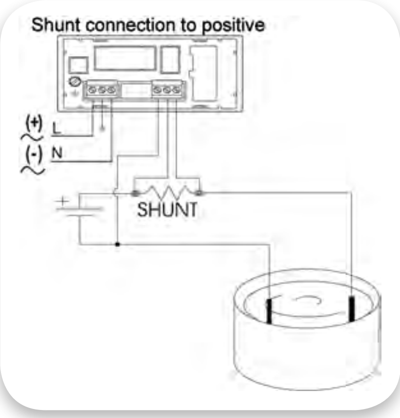
Technical Guide to Electrical Energy Efficiency

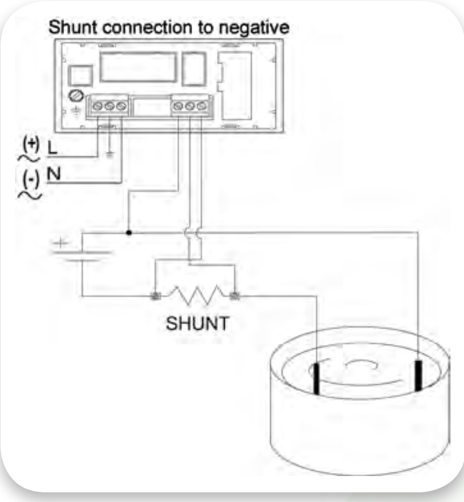
DH96 connection diagram

◢ **DH96 A - C - P**



◢ **DH96 AV / CPM / BG**





Considerations

- For integration into **PowerStudio Scada** a communications module is always required
- All measurement sensors of process parameters are external to the **DH96** indicator

+i M.2/M.5/M.7

8.6 Measurement current transformers

What are measurement current transformers

Current transformers are instruments which transform a high current into another proportional current but lower, which is easier to work with and reduces the size of the measurement equipment.

Which are the benefits of measurement current transformers

Measurement transformers are necessary for different reasons:

- They enable equipment to take reliable and accurate measurement
- They galvanically insulate electrical network measurement equipment
- They avoid disturbances generated by the transport of high currents

How to select a current transformer

Main characteristics

Transformation ratio

This is the relation between the rated primary and secondary current, for example: 100/5 A. A primary transformer value in accordance with the rated current of the circuit breaker should be chosen. With reference to the secondary, the most common is .../5 A. The use of .../1 A is recommended for long cable distances, in order to reduce the burden.

Burden (rated power)

Value of the apparent power for the type of rated accuracy specified. The value is given by the addition of the receiver power plus that consumed by the secondary circuit wiring of the transformer.

Type of accuracy

Name given to a current transformer whose errors remain within the limits specified for the rated conditions.

Size of the window

Working space for passing power wires or the bus bar.

Calculation of the burden

The total power to be measured is the addition of the power of the measurement device plus the power consumed in the wiring of the secondary circuit.

$$P_{total} = P_{device} + P_{wire}$$

Equipment measurement power

The following table shows the most common power values for measurement equipment.

Devices	Typical Consumptions
Moving metal instruments	0.3 ... 15 V·A
Moving coil instruments	0.5 V·A
Analogue Watt meters	0.2 ... 2.5 V·A
Maximum demand Indicators	2.5 ... 5.0 V·A
Digital instruments	0.5 ... 1.0 V·A
Energy meters	1.0 ... 1.5 V·A
Registering Instruments	2.0 ... 5.0 V·A

Power consumed by the wiring depending on the surface and the distance

Example of the calculation

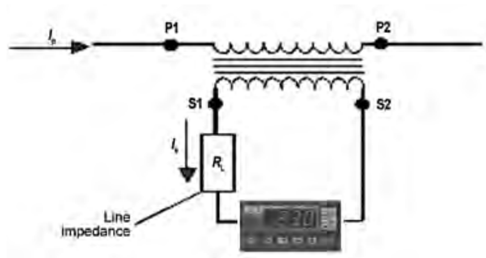
- Cable resistance of the secondary circuit

$$R_L = \rho \cdot \frac{L}{S}$$

- Copper resistivity:

$$\rho = 0{,}0172 \cdot \frac{\Omega \cdot mm^2}{m}$$

L: Length of the circuit
(Bear in mind the return)
S: Surface of the cable in mm^2



- Power of the wiring

$$P_{Linea} = R_L \cdot I^2$$

R_L: Resistance of the secondary circuit
I: Secondary current

Example

- Ratio 2000 / 5 A
- Length between transformer and load L = 10 m.
- Cable of 2.5 mm^2
- Relay power 1 V·A

$$R_L = \rho \cdot \frac{L}{S} = 0{,}0172 \cdot \frac{2 \cdot 10}{2{,}5} = 0{,}14\,\Omega$$

$$P_{Linea} = R_L \cdot I^2 = 0{,}14 \cdot 5^2 = 3{,}4 \text{ V·A}$$

If the transformer were 2000/1 A

$$P_{Linea} = R \cdot I^2 = 0{,}14 \cdot 1^2 = 0{,}14 \text{ V·A}$$

Conclusion

- The power of the transformer should be 5 V·A (cable + relay)
- In the case of long distances the use of the ratio .../1A is reccommended to decrease the burden

Value tables

Power consumed by the wiring for a secondary TC of 5 A (V·A)

Length (m)	5	10	15	20	25	30	35	40	45	50
mm2										
1,5	2,9	5,7	8,8	11,5	14,3	17,2	20,1	22,9	25,8	28,7
2,5	1,7	3,4	5,2	6,9	8,6	10,3	12,0	13,8	15,5	17,2
4	1,1	2,2	3,2	4,3	5,4	6,5	7,5	8,6	9,7	10,8
6	0,7	1,4	2,2	2,9	3,6	4,3	5,0	5,7	6,5	7,2
10	0,4	0,9	1,3	1,7	2,2	2,6	3,0	3,4	3,9	4,3

Power consumed by the wiring for a secondary TC of 1 A (V·A)

Length (m)	10	20	30	40	50	60	70	80	90	100
mm2										
1,5	0,2	0,5	0,7	0,9	1,1	1,4	1,6	1,8	2,1	2,3
2,5	0,1	0,3	0,4	0,6	0,7	0,8	1,0	1,1	1,2	1,4
4	0,1	0,2	0,3	0,3	0,4	0,5	0,6	0,7	0,8	0,9
6	0,1	0,1	0,2	0,2	0,3	0,3	0,4	0,5	0,5	0,6
10	0,0	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,3	0,3

Construction characteristics

Bus bar	
‣ The load conductor (cable or bus bar) passes through the core of the transformer ‣ Wide range of current measurement, from 40 A to 5,000 A	
Primary Winding	
‣ The load conductor (primary) is winded in the core of the transformer ‣ These are very accurate at low currents ‣ Recommended for measuring currents less than 100 A ‣ Supply a high level of power at low current	
Split core	
‣ They are bus bar transformers which, as a special feature, the core is split into two parts. They can be mounted whitout dismounting the bus bar ‣ Very easy to mount ‣ Wide range of measurement	

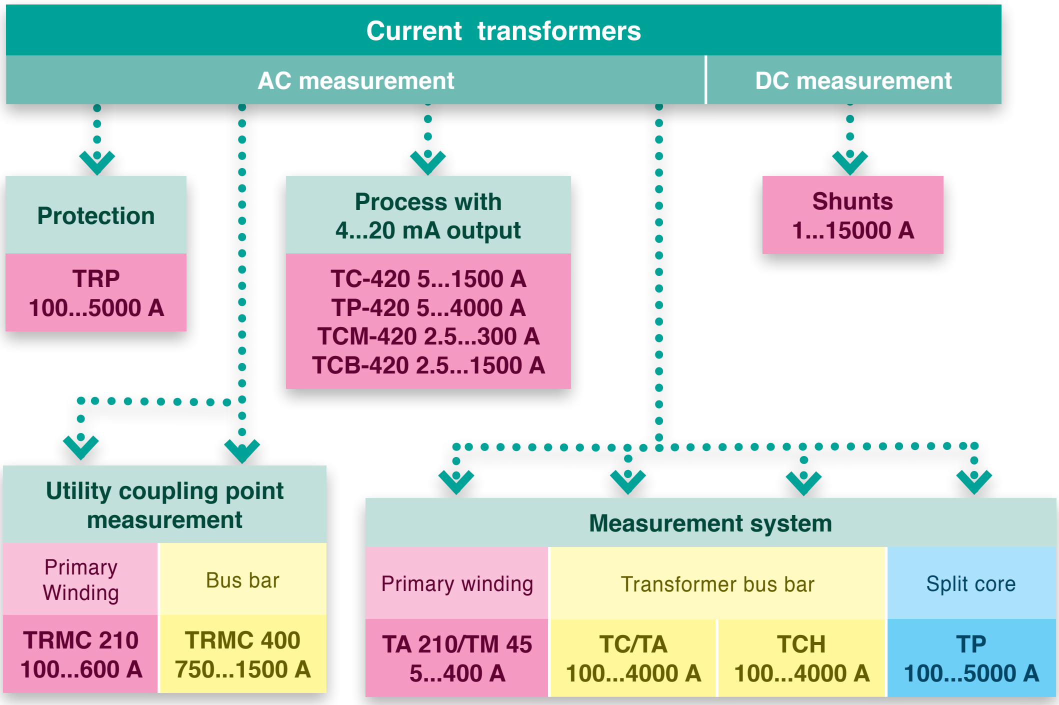
Shunt

A shunt is a resistance which causes a voltage drop when the current flows. Normally, this voltage is 60 mV at rated current. It is used for indirect DC current measurement.

Steps for selecting a current transformer

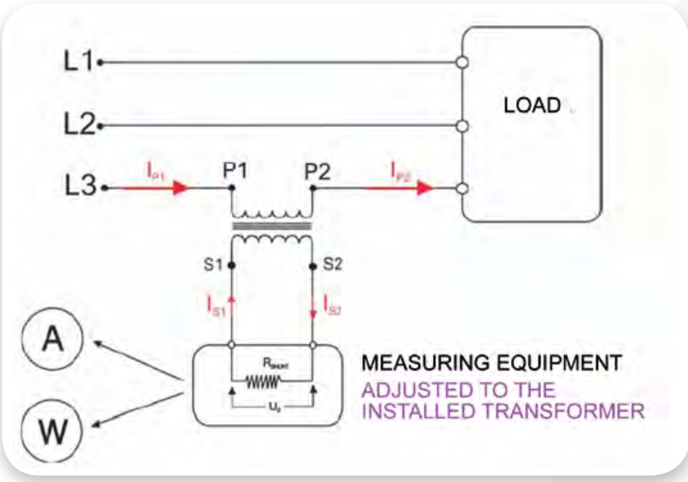
1	Type of application	‣ Utility measurement point ‣ Measurement system ‣ Process system ‣ Protection
2	Transformation ratio	‣ Primary from 5 ... 5000 A depending on type ‣ Secondary .../5 A or .../1 A
3	Burden and accuracy	‣ Accuracy: 0.5 S (only TRMC and TCH), 0.5, 1 and 3 ‣ Burden: Depends on the type of transformer and the accuracy required
4	Size of the window	‣ Working space for passing power wires or flatbar
Specific characteristics of the type of transformer		
5	Construction characteristics	‣ Primary winding ‣ Bus bar ‣ Split core
6	Electrical characteristics	‣ **Safety factor, SF**: This is the ratio between the maximum secondary intensity and the rated current ‣ **Withstand**: RMS current value of the primary which the transformer is able to support certain time, without having damages ‣ **Dynamic Current** : Pick value of the maximum primary current that the transformer must support, without being damaged either mechanically or electrically by the resulting of electromagnetic strengthes ‣ **Thermal Class** : Maximum working temperature of the transformer ‣ **Extended range:** It is the maximum overload supperted by the transformer maintaining the accuracy and the thermal class ‣ **Service voltage:** The maximum voltage of the installation at which the transformer can work

Diagram for choosing a current transformer



Current transformer connection diagram

- 1 transformer in each line
- 3 transformers in total, in a three-phase system with neutral. In case of the installation of a CVMk2, a current transformer in neutral could be installed



Considerations

- The final precision of a measurement is the addition of the accuracies of its components
- For this reason, it is very important to choose the most suitable ratio and accuracy

8.7 AR5-L/CIR-e³ portable network analyzers

What are portable network analyzers AR5-L/CIR-e³

Portable network analyzers **AR5-L/CIR-e³** are instruments which measure the different electric and energy parameters and have four basic applications:

- Carrying out energy diagnosis in installations which are not equipped with **PowerStudio Scada** software
- Measurement of electrical paramenters and disturbances
- Support for a Scada application already installed, by making measurements at certain loads or areas of the installation
- Energy audits

Which are the benefits of AR5-L/CIR-e³

Energy efficiency studies and energy audits

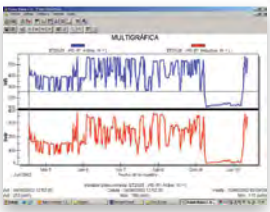
Obtaining the necessary information for developping electrical energy consumption studies. To do so, the following electrical variables are measured:

- Power (active, reactive and apparent)
- Energies (active and reactive)
- Demand charts
- etc.

Thanks to the **CIR-e³ web** environment, the data can be analysed independently from where the measurements have been taken.

It is recommended, once the study has been done, to install a **Po**... a for following

up the commented paramenters, as well as other that could contribute more information to the technical manager.



Help to the technical management of the Installation

By using the correct software all the following electrical variables are studied:

- Harmonics
- Power quality: (disturbances, voltage events and Flicker)
- Machine connections and switchgear transient analysis
- Leakage current measurement

So, it is obtained all the needed information for the forecast of maintenance or engineering service action.

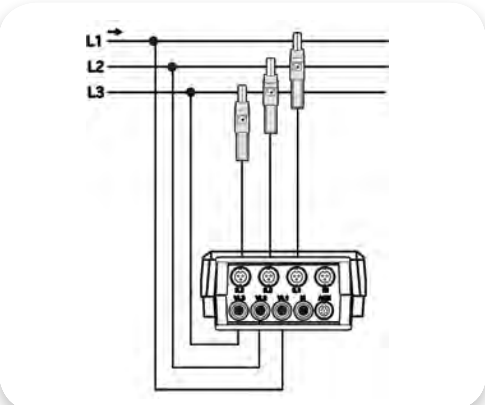
How to use an AR5-L/ CIR-e³ portable analyzer

1	Use of individual protection equipment	‣ Helmet with face screen ‣ Insulation gloves ‣ Insulation protection for footwear
2	Objectives of the measurement	‣ Energy management (power and energy) ‣ Electrical parameters (voltage, current, cos φ, etc.) ‣ Disturbances (only **AR5-L**) ‣ Flicker (only **AR5-L**) ‣ Transients (only **AR5-L**) ‣ Leakage to ground (only **AR5-L**)
3	Choice of the measurement points	‣ Coupling point ‣ Income to the general panel ‣ Line output ‣ Secondary panels ‣ Machines ‣ etc.
4	How to deal with the measurement	‣ Use of individual protection equipment ‣ Choice of the place to connect the equipment ‣ Choice of the suitable measurement software. ‣ Suitable measuring clamps for the rated current of the line ‣ Setting of the measurement time depending on the process subject to study
5	Downloading the information	‣ Closing of the equipment in accordance with what is indicated in the instructions manual ‣ Uploading the information to the PC via the port enabled for the purpose and study and interpretation of the measurements using **PowerVision** software ‣ Uploading of the information to the CIR-e3 server for later handling with the web application.
Considerations		
6	Auxiliary equipment	‣ Use of individual protection equipment ‣ Measuring clamps **CP-5, CP-100**, **C-Flex**, etc. ‣ Supplier and interface ‣ **PowerVison** software / **CIR-e³ web**

Portable network analyzers connection diagram

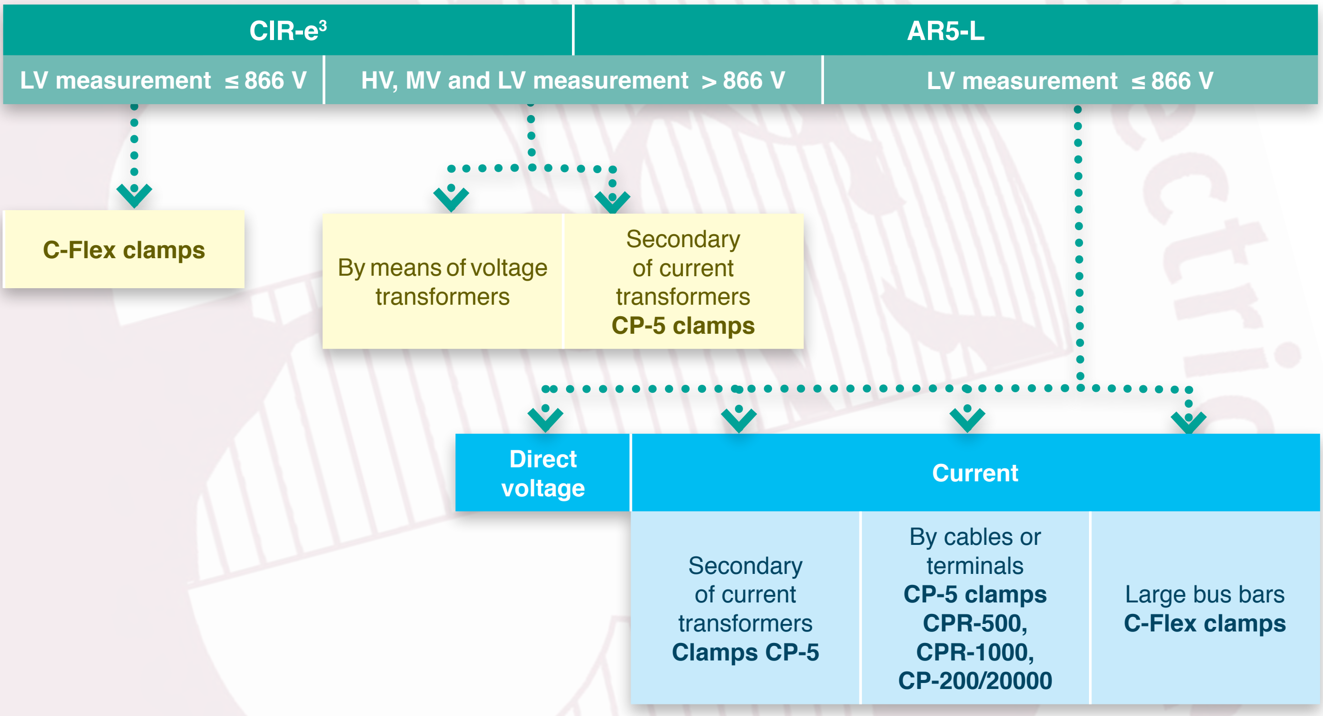
Diagram for choosing measurement clamps and register softwares

◢ **Three-phase 3 wires (AR5-L)**



◢ **Three-phase 4 wires (CIR-e³)**

Considerations

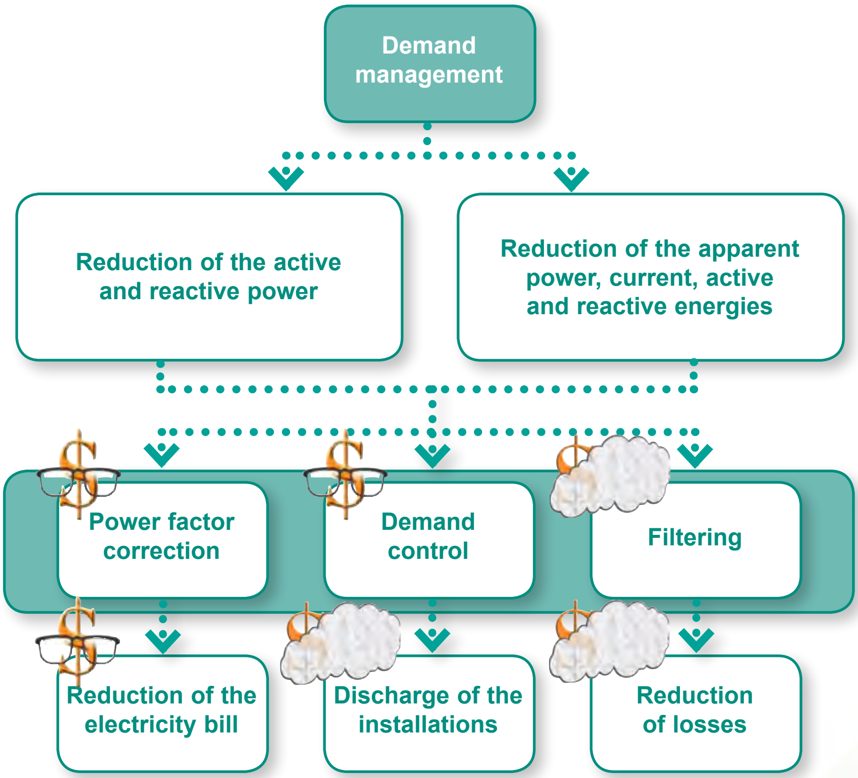


	Register softwares						
	Harmonics	Power quality	Flicker	Fast-Check	Check-Meter	Leak	FileVision
Functions	Harmonics Energy parameters Electrical parameters:	Voltage events	Flicker	Start-ups and transients	Verification of meters	Leakage to ground	Monitoring of the registered data in place

- Measurements on HV and MV installations are always made by means of measurement transformers
- For measuring with portable analyzers it is compulsory the use of individual protections as well as the own safety procedures of the enterprise
- The following are recommended as protection equipment:
  - Helmet with face screen
  - Insulation gloves
  - Insulation protection for footwear
- The safety recommendations laid down in the instructions manual for the equipment must also be adhered to

9. Demand management

Demand management is the different actions to be taken to decrease the power and the energy demanded to the network.



As is shown in the drawing, the concepts mentioned will lead to an economic advantage, due to the energy cost reduction and the additional capacity achieved by the installations.

9.1 Objectives of demand management

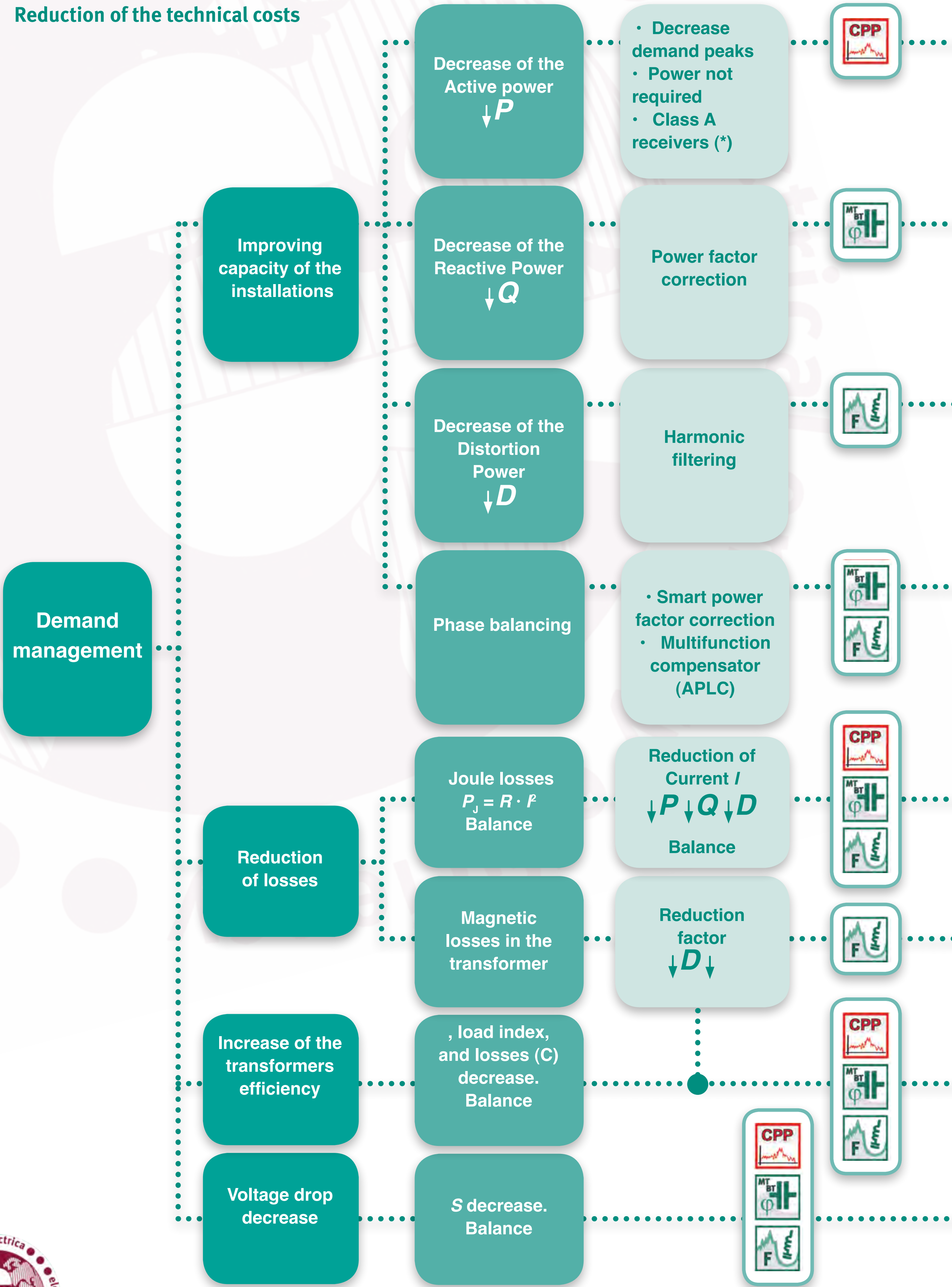
Reduction of the economic costs

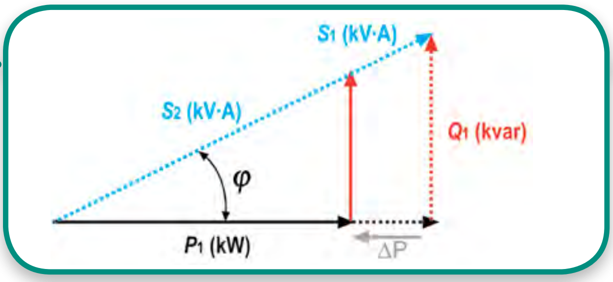
One of the first results from an energy efficiency study is the reduction of visible costs of the electrical energy. These are:

- Extra charge due to reactive energy
- Penalty for consumption at peak times
- Penalty for billing by maximetre (maximum demand)

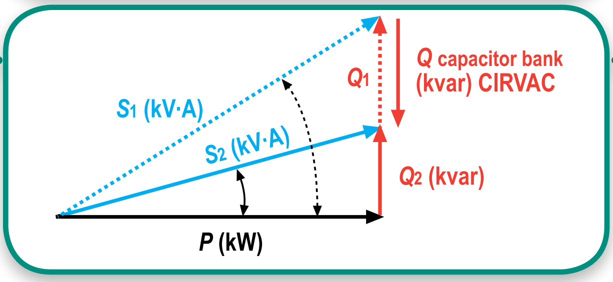
Furthermore, the reduction of the technical cost makes not necessary the extension of the installations. So that, the hidden costs are reduced.

Reduction of the technical costs



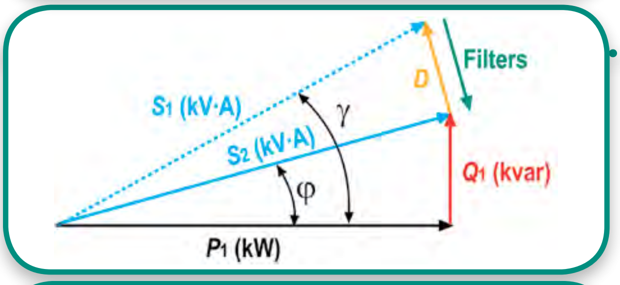


$P_{\text{efficient}} = P_{\text{current}} - P_{\text{peak}} - \Delta P_{\text{type A}}$ - Losses



Q Decrease

$$S_2 = S_1 \cdot \frac{\cos \varphi_2}{\cos \varphi_1}$$

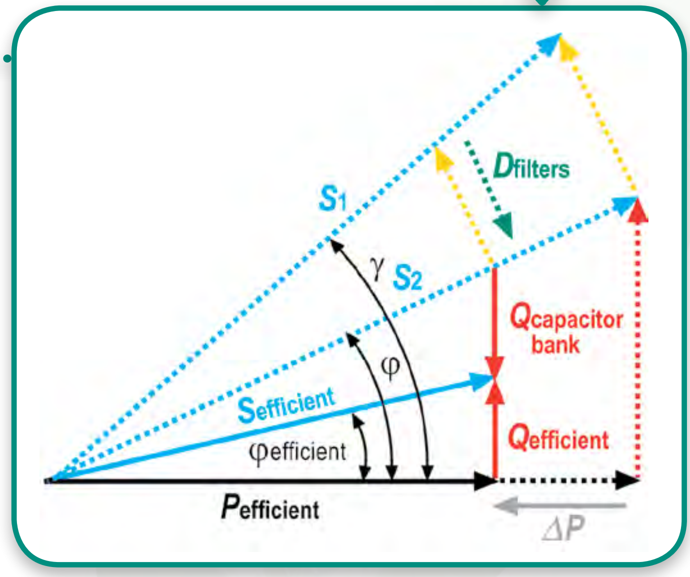


Overload factor decrease

$$F_C = \frac{S_1}{S_2} = \frac{I_1}{I_2}$$

Reduction and balance of apparent power *S*

Reduction of the coefficient of unbalance (Kd) and assymmetry (Kc)



$$P = R \cdot I_{\text{efficient}}^{2}$$

$$\downarrow$$

$$I_{\text{efficient}} <<< I$$

Increase S_{useful} transformer → $S_{\text{useful}} = \frac{S_{\text{trafo}}}{K}$

$$\eta(\%) = \frac{C \cdot S \cdot \cos \varphi}{C \cdot S \cdot \cos \varphi + P_F \cdot K + C^2 \cdot P_J}$$

$$\Delta U = Z \cdot I_{\text{efficient}}$$

$$\downarrow$$

$$I_{\text{efficient}} <<< I$$

(*) **CIRCUTOR** manufactures and commercialises equipment for electrical networks demand management, excluding therefore, efficient receivers

CPP	Power control **CPP**
MT BT φ	Capacitor banks **STD/PLUS, CIRKAP**
F	Harmonic filters **NETACTIVE, NETPASSIVE**

9.2 Demand management systems

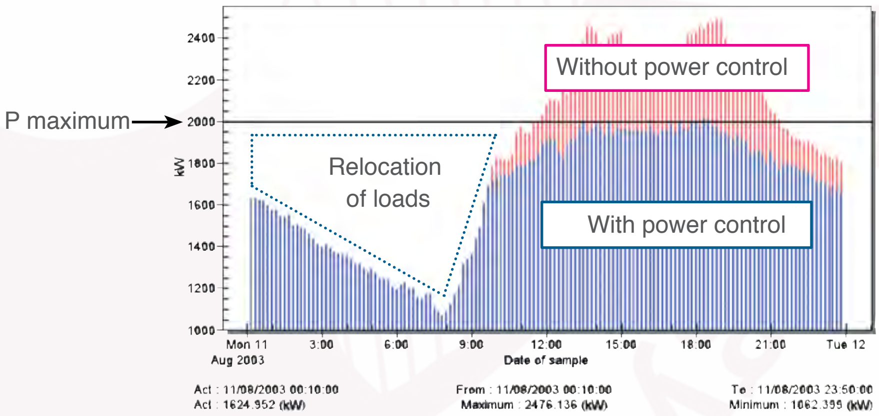
What is a maximum demand control

The maximum demand control is an equipment or a group of equipment which supervise the power demanded by the installation. So, when tere is a peak of active power it desconnects some loads previously selected.

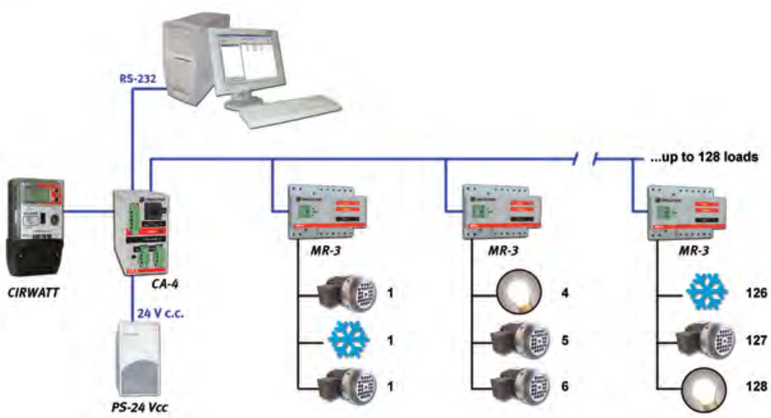
In this way the installation power is maintained at a previously defined level which corresponds to the maximum permitted by the electrical tariff without any extra charge.

Prior to the equipment installation, a study must be carried out to determine the loads which may not be necessary at critical times, or if possible, how they can be distributed in periods of less consumption during flat or valley periods when the energy cost is lower.

Which are the benefits of maximum demand control



- Installation loads control:
  - Disconnection of previously selected loads
  - Control and sequencing of load start-ups
  - To avoid connecting unnecessary loads at critical times
- A decrease in the electricity bill thanks to the reduction or elimination of additional costs incurred by the maximeter
- A decrease in the power demand, thus a lower load level which will help to reduce the technical costs



Steps to selecting a CPP maximum demand control

1	Obtaining the demand chart of the installation	▸ **CIRWATT** meter with energy and synchrony pulse outputs ▸ **CIRWATT CPP** meter with integrated maximum demand control ▸ If **CIRWATT** is not in available, use the **CVM** network analyser with energy pulse output option
2	Study of the installation	▸ Determination of consumption habits ▸ Possible loads to be disconnected at peak demand hours ▸ Possible loads that cannot be disconnected at peak demand hours ▸ Sequencing of equipment and machine start-ups
3	Loads to be controlled	▸ Determination of the number of machines ▸ Location in the installation ▸ Existing communications network
4	Communications Network	▸ If not available must be carried out
5	Load controller	▸ Definition of the type of load controller

6	Implementation of **PowerC** software (**CPP-LT** equipment)	▸ Type of calculation of maximum demand
		    ▸ Fixed Window
		    ▸ Rolling demand
		▸ Definition of the load and load groups list
		▸ Choice of priorities
		▸ Design of work schedule
		▸ Assignment of the tariff period

7	Programming of the equipment in situ **DH96 CPP** **CVM R8-C**	▸ Monitoring on equipment screen ▸ Software **Easycom** for **DH96-CPP** data visualization

Diagram for choosing a CPP maximum demand control

The following drawing shows the equipment that may be used depending on the size of the installation and the number of loads.

	CPP maximum demand control			
Applications	Shops, light industry, warehouses		Industry and building (hospitals, sports centres, offices...)	
No. of loads	2 loads + alarms	Up to 4 loads	Up to 17 loads	Up to 128 loads
	CIRWATT CPP	DH96 CPP	CVM-R8 CPP CVM R10-C	CA-4/ MR-3
No. of power Terms	3	1	3	8
Demand control system	Fixed window	Any	Fixed window	Any
Software	Technical Softwatt	Easy Com	--	Power C
Communications	RS-485,Ethernet, PLC, ...	RS-232 or RS-485	RS-485	RS-485

Choice of the suitable maximum demand calculation system

In order to carry out a maximum demand control the power value consumed during a certain period of time must be integrated.

This information comes from the income measurement equipment of the installation. The most correct method is using a **CIRWATT** energy meter. This obtains:

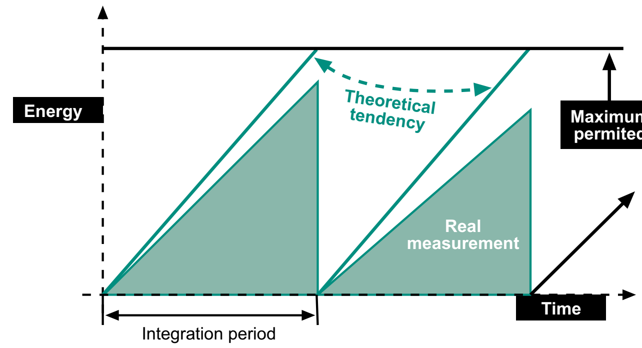
- Demand charts. For communicating with the load controller, we use the output pulse from **CIRWATT**
- Utility synchrony pulse. In this way, the periods of integration are closed at the same time as the utility

If no **CIRWATT** meter is available, the **CVMk2** analyzer with pulse output should be used. However it is not possible to synchronize the closing of the measurement period at the same time that the utility does. This fact can be put in order by means of the calculation of the maximum demand by using de rolling demand system. According this, it is possible to define the most suitable maximum demand control, fixed window or rolling demand.

Fixed window demand control

In this case, a synchrony pulse meter is available, which will indicate the moment of closure of the integration period and the start of a new one.
In the previous figure, the pulse synchrony closure process can be observed. Thus, the calculations carried out by the system will coincide with the same billing periods as the utility.

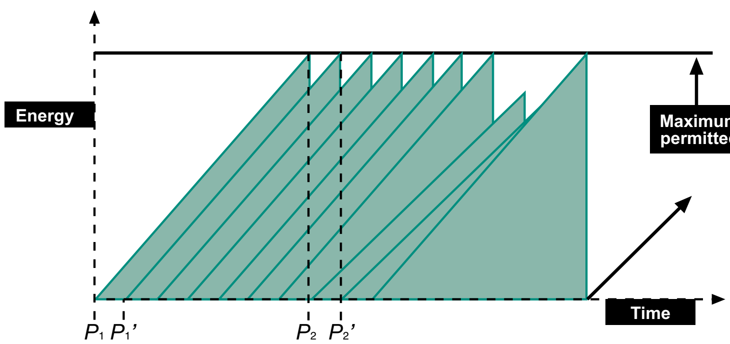
Functioning system Fixed Window



Rolling demand

This is used when the utility synchorny pulse is not available. By means of the energy measurement, the periods of energy integration and the calculation of maximum demand are opened and closed continuously. In this way, the system ensures to be working, at most, at the permitted limit.

Functioning system Sliding Window



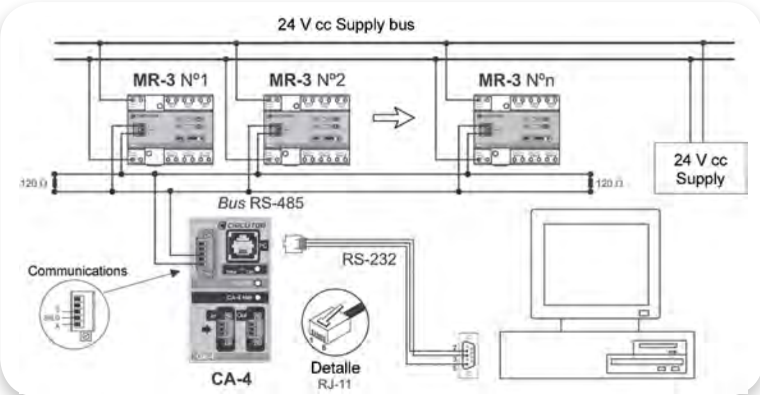
Where a CPP can be applied

As loads which tend to be managed, the following are proposed:

- Outdoor lighting lines
- Air conditioning and heating
- Fans
- Fluid recirculation pumps
- etc.

The final decision will be taken depending on the study carried out beforehand.

CPP connection diagram



Considerations of the CPP system

Remember that the design of a **CPP** system must take into account the following points:

- To obtain the demand chart by using a **CIRWATT** meter or a **CVMk2** network analyzer**.**
- The need for communication between the **CPP** equipment and the **CIRWAT** pulse output for reading the energy demand
- Diagnosis and audit of the plant subject to study, when its size justify it. The study will list the loads which are not needed during moments of demand peaks
- When using **CA-4** type, it is necessary to forecast the RS-485 bus among the load controller and the expansion modules **MR-3**.

9.3 Power factor correction

What is power factor correction (PFC)

PFC is the reduction of the reactive energy demanded to the network by means of the installation of capacitor banks.

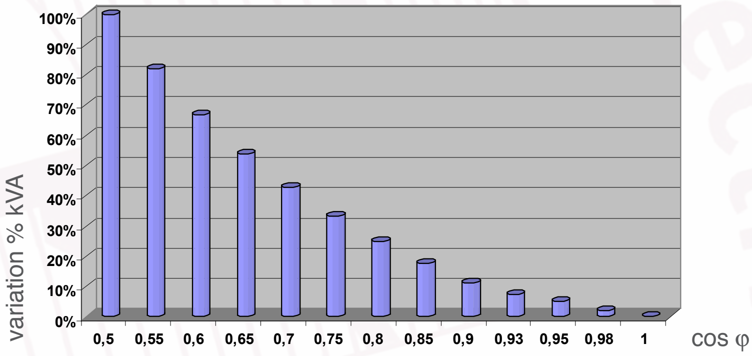
Depending on the installation subject to study, the PFC is made in LV or MV networks or by using **STD/PLUS** and **CIRKAP** capacitor banks respectively.

Which are the benefits of PFC

The reduction of the reactive power implies first a reduction of the electricity bill. Moreover it implies a series of technical advantages, as a consequence of the apparent power demand reduction.

In fact, as can be seen in the following figure, the decrease of the cos φ, implies an exceptional decrease in the apparent power demanded (V·A). And thus brings:

- Available capacity for transformers and lines
- Less losses in the lines
- Voltage drops reductions



Reduction in the electricity bill

- By means of the elimination of the reactive charge
- Hereafter are attached the ways to calculate de reactive energy in the spanish tariff and free market.

Regulated tariffs

Consumption of reactive energy is penalized depending on cos φ which is obtained from the calculation of the measured parameters, that is, by means of active and reactive energies.

$$\cos \varphi = \frac{W_a}{\sqrt{W_a^2 + W_r^2}}$$

Once the cos φ, has been calculated, the reactive energy penalty is then calculated. It is applied to the addition of the billing of active power and energy consumed.

Intervals of cos φ	Calculation of kr(%)
$0.95 < \cos \varphi \leq 1$	$\frac{37{,}026}{\cos^2 \varphi} - 41{,}026$
$0.90 \leq \cos \varphi \leq 0.95$	0
$\cos \varphi < 0.90$	$\frac{29{,}16}{\cos^2 \varphi} - 36$

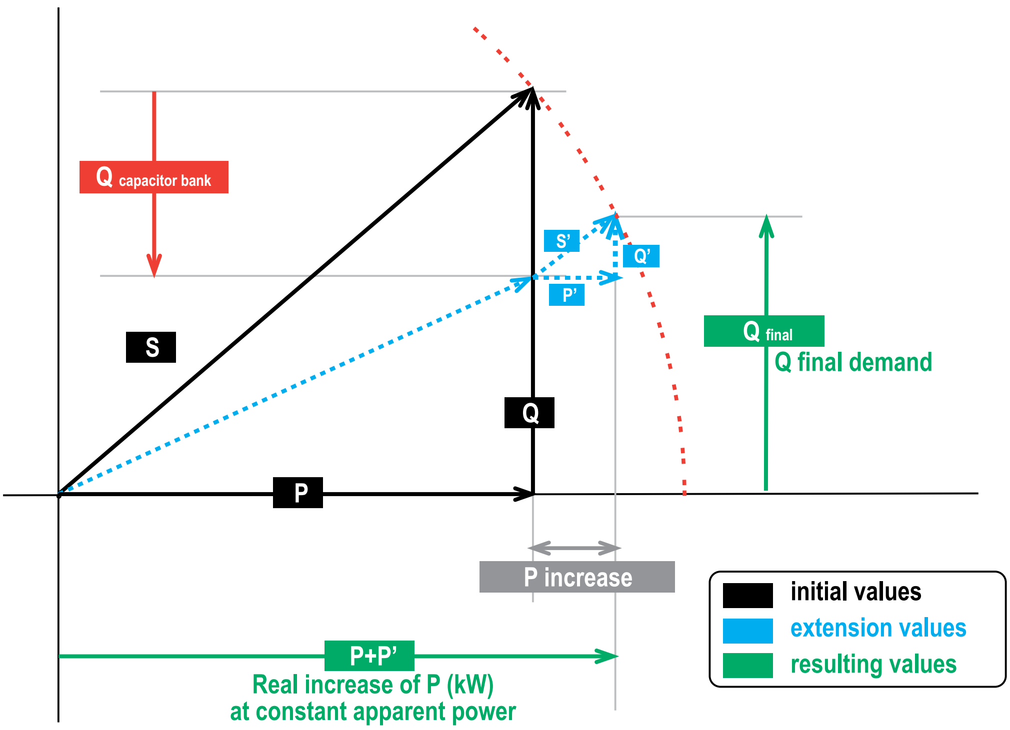
Free-market

In the free market the reactive energy is paid as consumed energy if the value of cos φ is below 0.95. The method of payment is very simple. To do so, it is calculated the difference between the measured reactive energy and the needed reactive energy for having a cos φ value of 0.95. This excess of reactive energy is multiplied by the unit cost of the kvar·h.

Decrease of the apparent power demanded

As can be observed in the following vectorial diagram, the reactive compensation will contribute:

- Reduction of the demanded kV·A to the network, therefore, optimization of the existing installations
- Increase on the active power demand without the need to increase installations as can be seen in the following drawing:



The following expression allows the calculation of the apparent power after carrying out the installation of a capacitor bank **STD/PLUS** or **CIRKAP**.

$$S_{final} = S_{inicial} \frac{\cos \varphi_{inicial}}{\cos \varphi_{final}}$$

Reduction of the kV·A requested from the grid depending on the compensation value of cos φ			
cos φ initial	cos φ final		
	0.95	0.98	1
0.5	47.4%	49.0%	50.0%
0.55	42.1%	43.9%	45.0%
0.6	36.8%	38.8%	40.0%
0.65	31.6%	33.7%	35.0%
0.7	26.3%	28,6%	30.0%
0.75	21.1%	23.5%	25.0%
0.8	15.8%	18.4%	20.0%
0.85	10.5%	13.3%	15.0%
0.9	5.3%	8.2%	10.0%
0.93	2.1%	5.1%	7.0%
0.95	0.0%	3.1%	5.0%
0.98		0.0%	2.0%
1			0.0%

CALCULATION FORMULA AND DATA TABLE

» Using the previous formula, starting from the cos $\varphi_{initial}$ and that required, the apparent power reduction coefficient is calculated

» The reducetion coefficients are attached directly in percentages

Losses reduction

The decrease of the kV·A, and therefore of the current, will mean a decrease in the losses due to the joule effect in distribution.

In effect, the following table is a reminder of how to calculate the losses due to the joule effect and, in addition, the reactive energy consumption in the distribution lines. The latter is particularly important in overhead lines.

In both cases it will depend on the level of current flowing in the installation. Therefore, the importance of the decrease.

Joule effect losses in a line	Reactive consumption in a line
$P(kW) = 3 \cdot R_L \cdot I^2 \cdot L$	$Q(kvar) = 3 \cdot X_L \cdot I^2 \cdot L$

The following shows how to calculate the losses reduction in two ways.

- Using the value of the capacitor bank to be installed
- Using the ratio between initial and final cos φ

As in the previous case, the losses reduction coefficient is calculated easily.

Reduction of losses due to connection of a capacitor banks (1)	Losses level by calculating cos φ ratio (2)
$\Delta P = 3 \cdot R_l \cdot L \cdot \frac{P^2 + (Q - Q_{bank})^2}{3 \cdot U^2}$	$pr_{final} = pr_{initial} \cdot (\frac{\cos \varphi_{initial}}{\cos \varphi_{final}})^2 = p_{initial} \cdot C_{pr}$

Reduction of the Joule losses depending on the compensation value of cos φ (Cp)

cos φ initial	cos φ final		
	0,95	0,98	1
0,5	72,3 %	74,0 %	75,0 %
0,55	66,5 %	68,5 %	69,8 %
0,6	60,1 %	62,5 %	64,0 %
0.65	53,2 %	56,0 %	57,8 %
0.7	45,7 %	49,0 %	51,0 %
0.75	37,7 %	41,4 %	43,8 %
0.8	29,1 %	33,4 %	36,0 %
0.85	19,9 %	24,8 %	27,8 %
0.9	10,2 %	15,7 %	19,0 %
0.93	4,2 %	9,9 %	13,5 %
0.95	0,0 %	6,0 %	9,7 %
0.98		0,0 %	4,0 %
1			0,0 %

CALCULATION FORMULA AND DATA TABLE

» By means of formula (1) the losses reduction is directly calculated when a bank is installed

» By means of formula (2) starting out from the initial cosine and the required one, the reduction coefficient of joule losses is calculated

» On the tables the reducer coefficients are attached directly in percentages.

Voltage level increase

The decrease of the apparent power due to the PFC will contribute to a decrease the voltage drop.

In fact, the connection of the capacitor bank implies the increase in voltage at the points where they are connected.

The IEC 60-871-1 standard for MV capacitors or the IEC 60831-1 for LV capacitors offer the expression for the calculation of the voltage increase which occurs when a capacitor bank is connected.

The power, the type of equipment and the number of steps, depend on the particular needs of each installation.

Its regulation permits the improvement of the voltage levels at different states of the load of the transformer station avoiding an excess of capacitive energy.

The following table shows two calculation expressions:

- Bus bar voltage increase connecting a capacitor bank in accordance with the stated IEC regulations
- Calculation formula of a voltage drop of a line. Here it can be observed that it will depend directly on the value of the cos φ (or tg φ) of the installation

Voltage increase when a capacitor bank is connected, according IEC standard	Voltage drop in lines
$\Delta U(\%) = \frac{Q_{bank}}{S_{cc}} \cdot 100$	$U(\%) = \frac{P \cdot L}{10 \cdot U^2} \cdot (R_L + X_L \cdot \tan \varphi)$

Units to understand the expressions:

- Q_{bank}:power of the capacitor banks (kvar)
- Q: Reactive power demanded without capacitor banks (kvar)
- S_{cc}: Short-circuit power at the coupling point (kV·A)
- P: Active power transported by the line (kW)
- L: Length of the line (km)
- *U: Network voltage (kV)*
- R_l y X_l: resistance and reactance of the cable (Ω/km)

Steps to selecting a LV capacitor bank

1	Where the compensation is carried out	▸ On the LV general panel ▸ In areas or secondary panels ▸ On the loads
2	Method of compensation	Fixed ▸ Transformers ▸ Motors Automatic ▸ Banks with electromechanical contactors ▸ Banks with static system
3	Calculation of the power	Theoretical calculation ▸ Based on reactive, active and cos φ values of the installation, as well as the type of load Electrical energy bill ▸ Estimation of the power by using the electricity bill analysis Measurements ▸ Obtaining the active and reactive demand through the use of the portable analyzer **AR5-L** **PowerStudio** supervision system ▸ Demand curves obtained directly from the **CVM** panel analyzers by using **PowerStudio** software
4	Determination of the type of equipment	Standard Banks ▸ Equipped with voltage and power capacitors in accordance with the network rated values Banks with detuned reactors ▸ Banks fitted with voltage reinforced capacitors and detuned filters, tuned at 189 Hz
Considerations		
6	Auxiliary equipment	▸ **TP** current transformers for the power factor controller measurement ▸ Switch ▸ Circuit breaker ▸ Smart earth-leakage protection **RGU-10 C**

Selection table in accordance with the place and compensation method

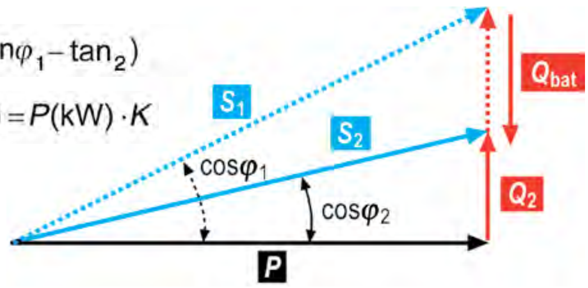
	Method of compensation	Place of assembly	Advantages	Comments
Centralized	Automatic	In the general LV panel	▸ Reduction in the electricity bill ▸ Increase of transformer capacity	▸ Secondary lines with same load
Areas	Automatic	In different areas of a large company or industry	▸ Reduction in the electricity bill ▸ Increase of transformer capacity ▸ Increase of distribution lines capacity	▸ Individual compensation can be carried out locally ▸ Possibility to regulate one of several loads by using a reactive relay
Individual	Fixed	On the loads	▸ Reduction in the electricity bill ▸ Increase of transformer capacity ▸ Increase of distribution lines capacity ▸ Reduction in voltage drops	▸ Need for a bigger number of equipment ▸ Normally installed in large receivers

Calculation of the rated power

Theoretical calculation

$$\Delta Q = Q_{bank}(kvar) = P(kW) \cdot (\tan\varphi_1 - \tan_2)$$

$$\Delta Q = Q_{bank} = P(kW) \cdot (Q_1 - Q_2) = P(kW) \cdot K$$



Calculation fixed capacitor for transformer

Some practical rules:

- A fixed capacitor about 5% of the transformer rated power should be fitted.
- It is recommended not to install a fixed capacitor with a power bigger than 10% the transformer power, to avoid a risk of possible resonances

$$Q_{nonload} = S_n \cdot I_o(\%)$$

$$Q_{load} = c^2 S_n \cdot u_{cc}(\%)$$

$$Q_{total} = Q_{nonload} + Q_{load}$$

- u_{cc}: short circuit voltage
- I_0: no load current
- c: load index

Calculation fixed capacitor for motor

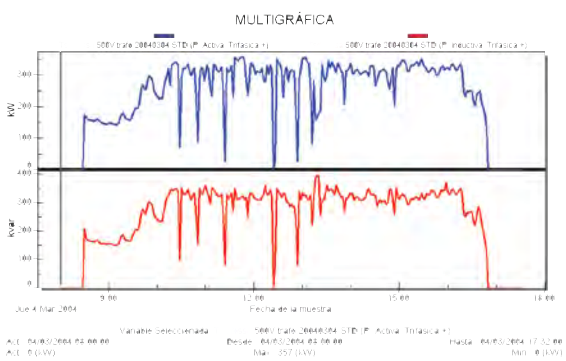
- The values of the attached table are the powers of the capacitors (kvar) for the direct connection on the motor terminals
- Using contactor, use theoretical calculation formula

Motor power		Revolutions per minute (r/min)			
kW	CV	3000	1500	1000	750
5,5	7	2,0	**2**	2,5	3
7,5	10	2,5	**3**	4	5
10	14	4,0	**5**	6	7,5
15	20	5,0	**6**	7	9
18,5	25	6,3	**7**	9	10
22	30	8,0	**9**	10	12,5
30	40	10,0	**12,5**	15	15
37	50	12,5	**15**	20	20
45	60	15,0	**20**	25	25
55	75	20,0	**20**	25	25
75	100	25,0	**25**	30	30
90	120	30,0	**30**	35	35
110	150	30,0	**35**	40	40
132	180	35,0	**40**	45	45
160	220	45,0	**55**	55	60
200	272	50,0	**60**	60	65
250	340	60,0	**65**	65	70

Compensation up to 90% of non load power of the motor

Measurement using AR5-L or PowerStudio supervision system

- Evolution of the reactive power, therefore the definition of the power of the bank and its regulation
- The speed of the load variations, which defines whether the battery installation should be with electromechanical switching or static system
- The state of the disturbance level of the network, by which it can be seen whether the type of equipment is the most suitable, that is **STD/PLUS** banks, **STD/PLUS FR** banks with detuned filters or the need to install a **NETACTIVE** and **NETPASSIVE** filters.



Election of the type of LV equipment

There are two possible types of equipment:

- Standard banks at network rated voltage **STD/PLUS** series. In non polluted network or with a low contents of harmonics
- Capacitor banks fitted with detuned filters **STD/PLUS FR**

There are two criteria to take into account in the installations:

- The existence of harmonics
- The possibility that resonance may exist between the transformer and the bank

The existance of harmonics depends on the type and quantity of devices in existence that can generate harmonics. As an example, the following is a list of harmonics generated by the most common receivers:

- 6 pulse variable speed devices: 5th and 7th Harmonic
- UPS: 5th and 7th Harmonic
- Welding machines: 3rd Harmonic
- Discharge lamps: 3rd Harmonic

By means of the files of **PowerStudio Scada,** or in its absence, by means of the **AR5-L** portable analyzer, the complete spectrum which exists on the installation can be seen, specially on the bus bar where the capacitor bank will be connected.

Once this point has been studied, the possibility of the bank resonance must be calculated. To do so the following expression is used:

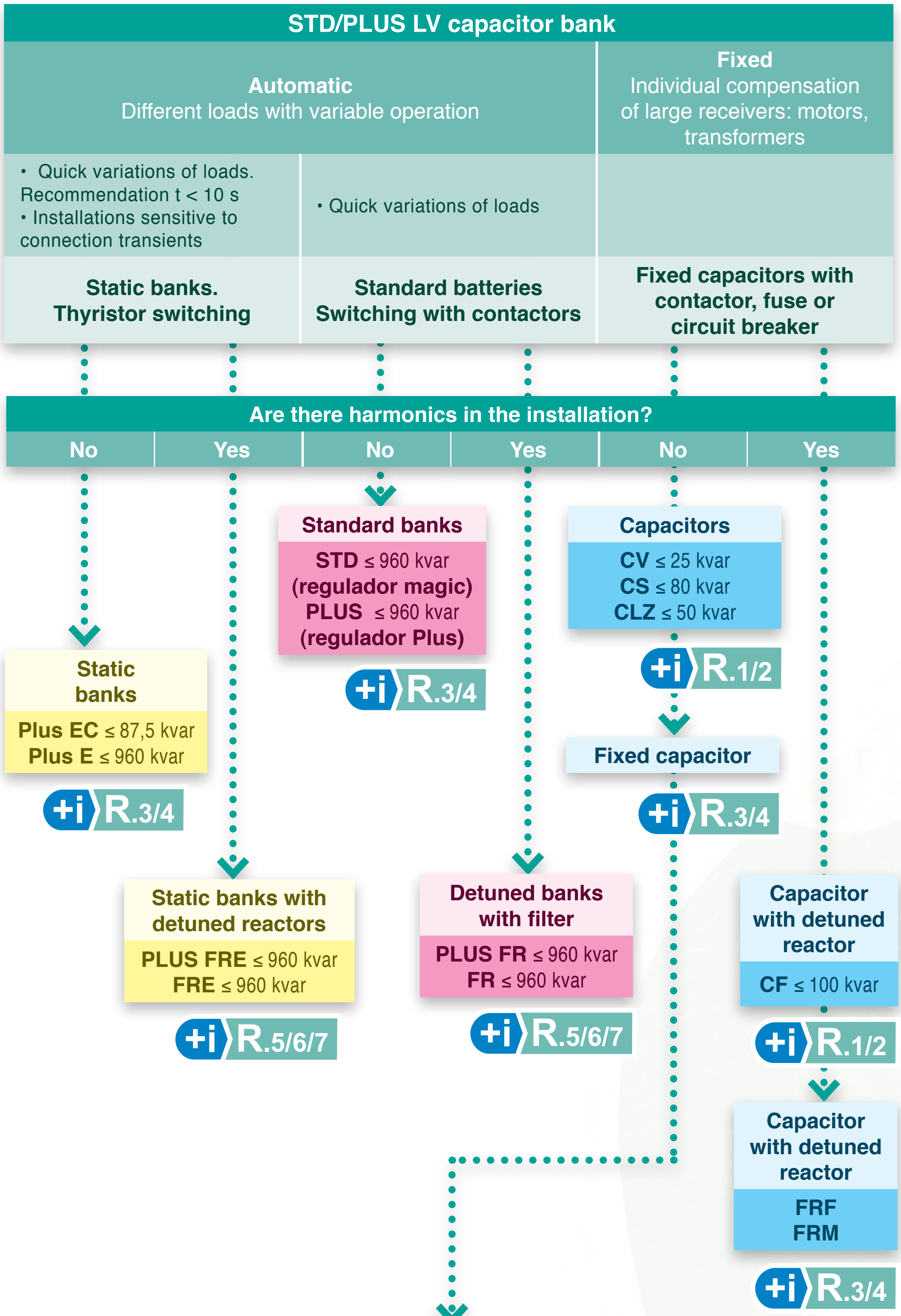
$$n = \sqrt{\frac{S_{cc}}{Q}}$$

where: $\mathbf{S_{cc}}$ is the short circuit power in capacitor bank connection point
Q the power of the capacitor bank

Depending on the measurements carried out, the following criteria for choosing the correct capacitor bank are attached:

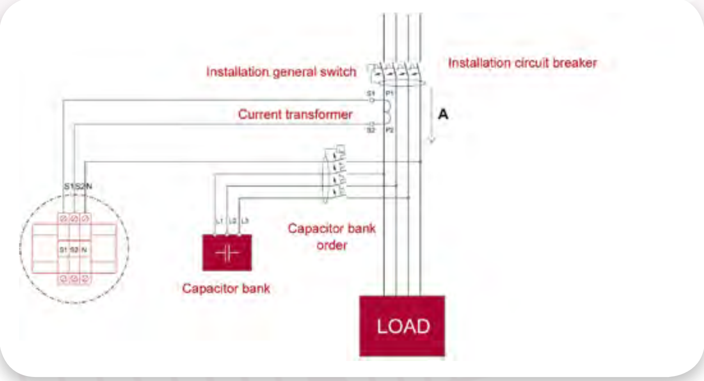
THD *U* (%)	THD *I* (%)	Solution	Comment
THD $U < 2$	THD $I < 15$	Standard bank	Check possible resonance
$2 <$ THD $U < 3$	$15 <$ THD $I < 30$	Detuned banks	Correct tune selection
THD $U > 4$	THD $I < 15$	Detuned banks	If there are capacitors, check posible resonance
THD $U > 4$	THD $I < 15$	Filters	Detailed study

Diagram for choosing LV capacitor bank



Fixed compensation			
Transformers	Motors	Small installations	Individual loads
Capacitor + fuse **CSF** Capacitor + breaker **AM: Small power** **CSM: medium power** **CSMM: high power**	Capacitor + contactor + breaker **ACM: Small power** Condensor + contactor + fuse **ACF: medium and high power**	Capacitor + contactor + fuses + reactive relay **ACD: equipment with only one step switched by a reactive power relay. Connection when the reactive power is detected** Need for current transformer	

Capacitor bank connection drawing



Considerations

◢ **The following auxiliary equipment needs to be provided**

Essential

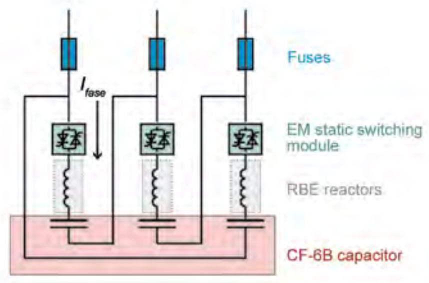
- Bus bar current transformers **TC** series or split core **TP** series. The primary current will always be defined by the value of the automatic general switch
- Circuit breaker and smart earth-leakage protection

Optional

- Switches for switching of the bank

◢ **To choose a static capacitor bank**

Static capacitor bank, **EMK**, **ECK** or **FRE**, enable real time adjustments, therefore high speed connection and disconnection.

FRE CIRCUTOR System	Advantages
	‣ Better adjustment of cos φ ‣ Very accurate reactive power chart follow up. Thus better optimization of the installation ‣ Ideal application in installations sensitive to transients, such as hospitals, data control centres, etc. ‣ Essential in generators start ups with hard inductive loads ‣ Very low maintenance

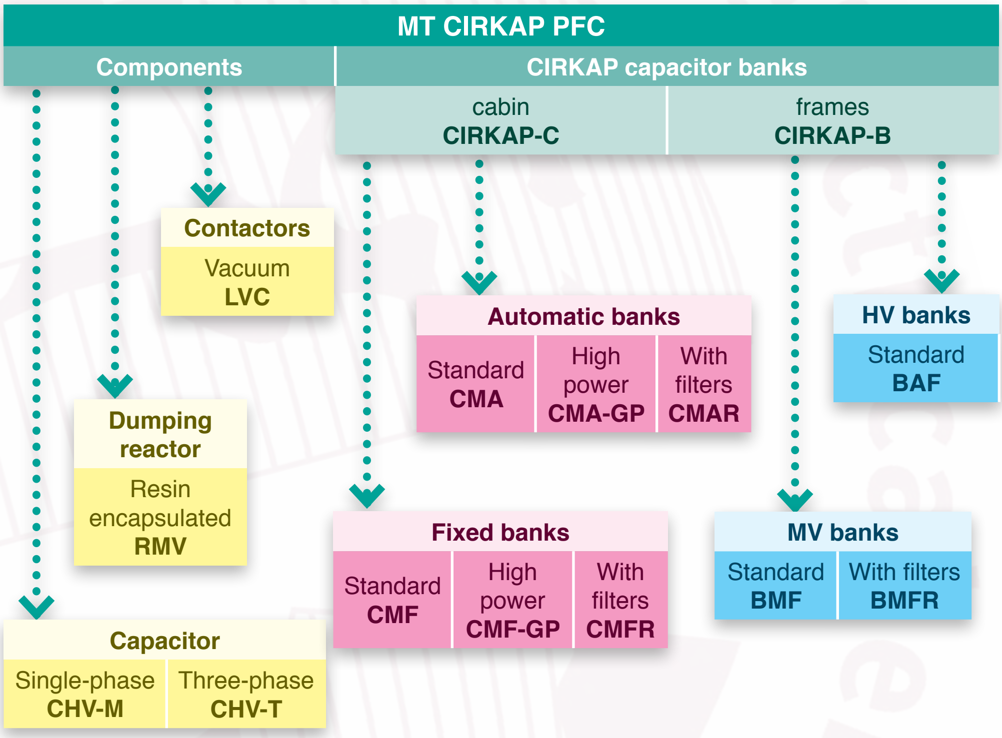
+i R.3/4 *The rational use of electrical energy*, J.Balcells

Steps for choosing MV capacitor bank

The following drawing explains the information sequence required for the definition of MV capacitor bank or the components information for designing the capacitor bank.

general basic information		
1	installation	▸ Network voltage (kV) ▸ Network frequency (Hz) ▸ Short circuit power (kV·A) ▸ Existence of more banks (yes/no) ▸ Existence of harmonics (yes/no)
2	Banks	▸ Power of the banks (kvar) ▸ Banks voltage (kV) ▸ Fixed/ automatic ▸ Standard type: or with detuned filters ▸ Need for general protection (yes/no) ▸ Location: indoor or outdoor ▸ Other special needs to be defined
Banks definition		
3	Configuration	If U > 11. kV and Q < 1,400 kvar ▸ Three-phase capacitor bank If U > 11.5 kV and Q < 1,400 kvar or if U < 11.5 kV and Q > 1,400 kvar ▸ Double star bank, single-phase capacitors
4	Design	Fixed ▸ cabin type **CMF** ▸ frame type **BMF** Automatic ▸ **CMA** type ▸ Number of steps and power of each
Definition of the components		
5	Capacitors	▸ Single-phase or three-phase configuration ▸ Rated voltage (kV) ▸ Frequency (Hz) ▸ Insulation level (kV) ▸ Power (kvar) ▸ Special creepage distance (mm/V)
6	Reactance	▸ Quantity (3 per bank or step) ▸ Inductance (µH) ▸ Current (A) ▸ Insulation level (kV) ▸ Withstand (kA/1s) ▸ Location inside or outside
7	Switchgear	For automatic banks ▸ Contactor U < 12 kV ▸ Switch U > 12 kV ▸ Capacitive operation power (kvar) ▸ Insulation level (kV) ▸ Breaking capacity (kA)

Diagram for choosing MV power factor correction equipment



9.4 Filtering

+i Section 10.1

10. Productivity improving

The relationship between the quantity of goods and services produced and the quantity of resources used, is known as productivity. Labour force, raw material, energy, invested capital, etc. are all resources.

$$\text{Productivity} = \frac{\text{N. of Goods and Services}}{\text{Resources}}$$

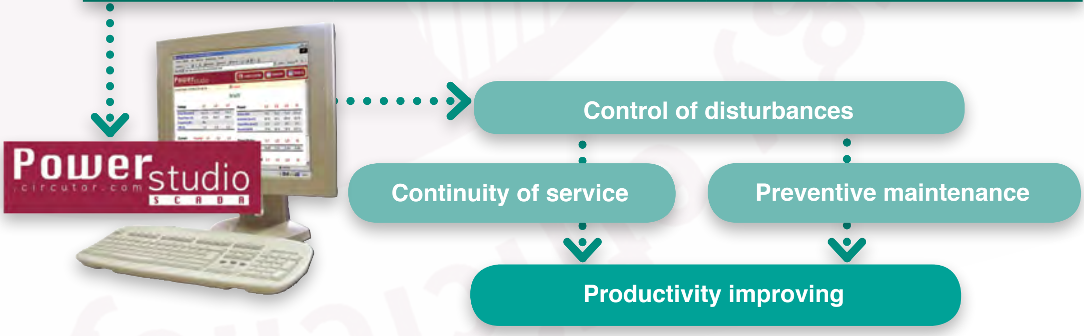
There are various methods to improve productivity in an organisation. However, electrically speaking, there are two important points:

- Proper costing for electrical energy consumed in processes (mentioned in submeters section)
- Economic losses caused by process stoppages as a result of disturbances in the installations

productivity improving					
Costing	Detection and elimination of disturbances				
Measurement	Measurement				
Energy	Leakage to earth	Harmonics		Unbalances	High frequency
Control	Management	Filtering		Compensation	Filtering
EDMk submeters	**CBS RGU-10** smart earth-leakage protection	**NETPASIVE** Passive filters	**NETACTIVE** Active filters	**NETACTIVE** Active filters	**EMC filters** High Frequency Filters

All of this is reflected in the following table, which displays problems produced by the receivers that most usually cause disturbances in the installations, and the proposed solutions for eliminating the problem.

	Disturbances	Harmonics	High frequency	Leakage to earth	Unbalances
	Effects	▸ Overloading ▸ Heating ▸ Breaker tripping ▸ Resonances	▸ Sensitive system shutdowns	▸ Differential protection tripping ▸ Risks to personnel and installations	▸ Overloading ▸ Under-utilising networks and transformers
Load types	**Computers and systems**	✓		✓	✓
	+ variable speed drives, UPS ..	✓	✓	✓	
	+ Lighting lines	✓		✓	✓
	+ Electronic equipment	✓		✓	
	= Transformer + installation	✓	✓	✓	✓
Solution		Harmonic filtering **NETACTIVE + NETPASSIVE**	High frequency filtering **EMC**	smart earth-leakage protection **RGU-CBS**	Multifunction compensator **APF-4W**



10.1 Filtering

What are filters

Filters are devices that accomplish various objectives:

- To eliminate harmonic currents
- To reduce high frequency signals
- Reactive power compensation in networks polluted with harmonics avoiding resonances

Furthermore, depending on the type of device used, the currents in an unbalanced three phase system can be balanced, and the neutral line conductors can be discharged.

What are the benefits of filters

Filters reduce the technical and hidden economical costs of an intallation.

Technical cost reduction or technical optimization of the installation

- Increases capacity of the distribution lines
- Discharges transformers
- Reduces losses and heating in lines and electrical machinery

When a filter is installed, the true RMS current value is reduced, thus:

- It reduces the *K* factor and increases transformer capacity

$$S_{useful} = \frac{S_{trafo}}{K}$$

- Reduces the harmonic overload factor, so that, reduces the apparent power (V·A) throughout the installation

$$F_C = \frac{S_1}{S_2} = \frac{I_1}{I_2}$$

Hidden cost reduction

- Improves productivity by reducing stoppages and breakdowns
- Assures that the extension of an intallation, due to insuficient capacity, is not necessary

Steps to selecting a filter

1	Study of the installation	Installation in operation: ‣ Measuring at the appropriate points ‣ Obtaining information from **PowerStudio Scada** Installation in project: ‣ Detecting harmonics generators as converters, discharge lighting, computer systems, etc. ‣ Grouping these loads in the minimum number of lines possible
2	To identify type of anomaly (See selection table according to the anomaly)	Installation in operation: ‣ To identify the existing problem according to the anomalies detected Installation in project: ‣ Avoiding problems by using the most suitable filter
3	To define the objective to achive	‣ Reactive energy compensation with detuned filters ‣ Harmonic filtering ‣ High frequency filtering ‣ The three previous points simultaneously
4	To choose the right equipment according the detected or forecasted anomaly	Definition of: ‣ Type of equipment ‣ Number of equipment
5	To define the correct location	‣ LV general panel ‣ Secondary panels ‣ Loads
6	Filter selection parameters	‣ True RMS value of current ‣ Harmonic spectrum
Considerations		
7	Auxiliary equipment	‣ **TP**, **TA**, etc. current transformers ‣ **RGU-10 C** smart earth-leakage protection ‣ Switches or breakers ‣ **CVM** network analyzers ‣ **AR5-L** portable analyzers

Choosing a filter according to the anomaly

Types of anomalies

Anomaly	Causes	Solutions	Equipment
After connecting the capacitors: • Overloading in capacitors • Problems with electronic controls • Transformer vibrations	Capacitor bank resonance with the transformer as a result of existing harmonics	To avoid the resonance	Capacitor banks with detuned filters, **FR**, **FRE**, **FAR Q**, **FARE Q**
Overloading the neutral line in the following: • Lighting • Computers	Flow of the third harmonic (homopolar)	Blocking filter or compensation of the third harmonic	• Blocking systems **TSA**, **FB3** • Active filters **NETACTIVE**
Heating due to the overload of: • Phase conductors • Transformers • Motors • Circuit breakers	Harmonics of different ranges	Harmonics filtering	• Absorption filters **FAR-H**, **LCL**, **FAR-Q** • Active filters **NETACTIVE**
Trip of earth-leakage protection	High frequency leakage currents. Originated in **EMI filters**	Immunization and filtering of the earth-leakage protection	• Reactors **LR**(1) • Immunized earth-leakage protection (2)
• Unbalanced lines + harmonics in neutral	Different single phase loads distribution	Phases balance and harmonic filtering	Multifunction active filter **NETACTIVE**
• Interferences in electronic equipment	High frequencies disturbances	High frequency filters (**EMI**)	• Filters **EMR** • Reactors **LR**

Considerations

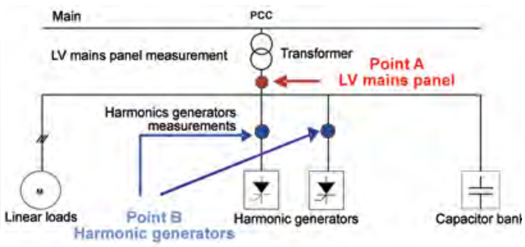
- Defining the appropriate filters is as much important as defining the location
- Using different types of filters simultaneously could be necessary. It is recommended to consult our technical services
- It is recommended to collect the information requested in the following drawing

Installation information

1 DRAWING

The following points should be displayed in the diagram:

- Points where the **AR5** portable network analyser measurements have been made
- Load distribution



2 GENERAL INFORMATION

- Single line drawing of the installation
- Signalling of the measurement points
- Type of industry process

No. of transformers	
S_n (Transformer Power)	V·A
Transformation ratio	V
U_{cc} (Short circuit voltage)	%

Measurements

3 MAIN PANEL

- Measurement active and reactive power
- Measurement harmonics

HARMONIC	1	3	5	7	11	13	∑ THD
U_n (%)	--						
I_n (%)	--						
I_n (A)							

- If there is a capacitor bank

With bank connected		**With bank disconnected**	
THD (*U*)	%	THD (*U*)	%
THD (*I*)	%	THD (*I*)	%
Q (bank)			kvar
P (installation)			kW

4 LOADS

- Measurements in power converter

HARMONIC	1	3	5	7	11	13	∑ THD
U_n (%)	--						
I_n (%)	--						
I_n (A)							

- Measurments in other harmonic generators

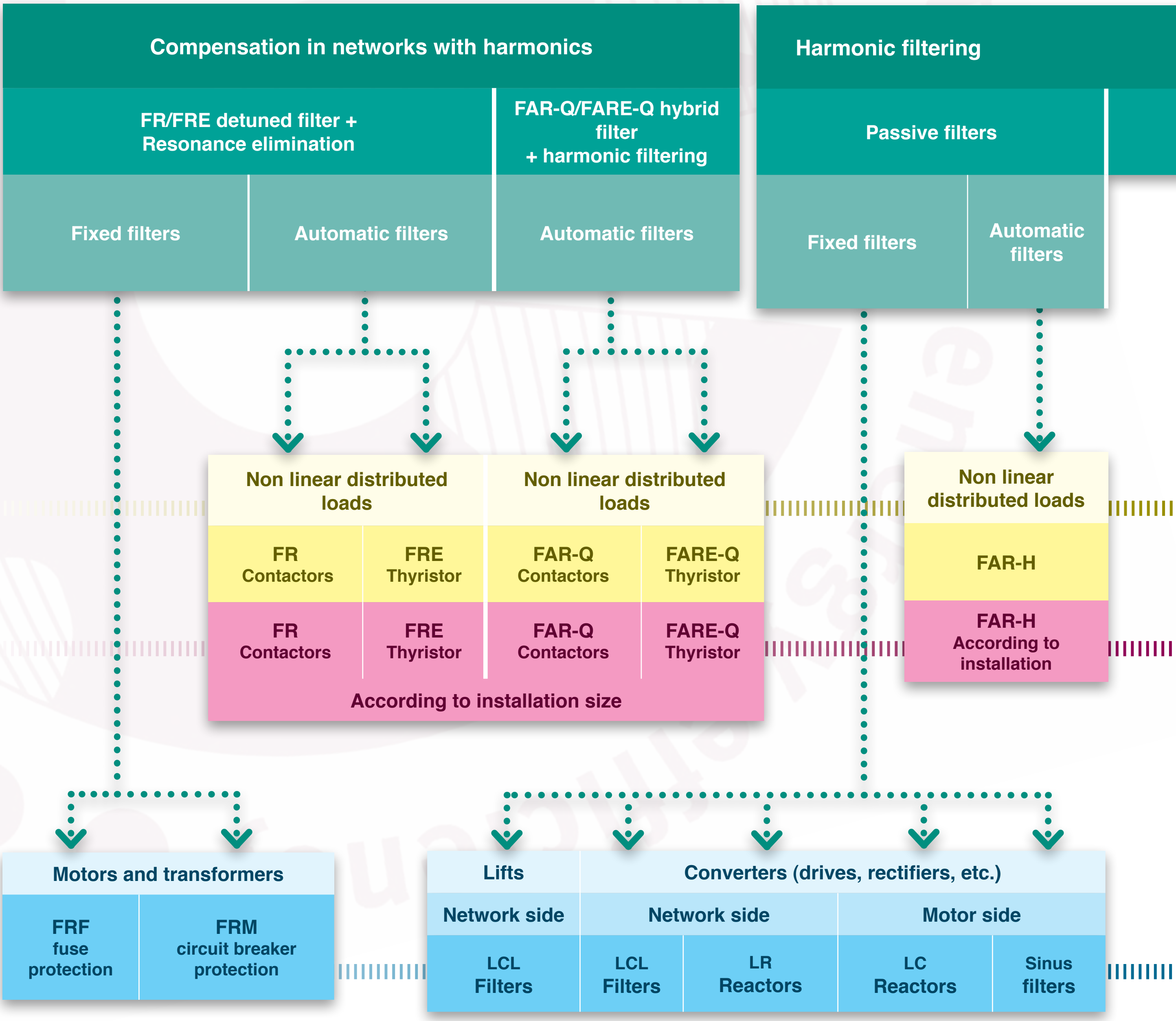
Description of the type of load: discharge lighting, welding equipment, computers, etc.

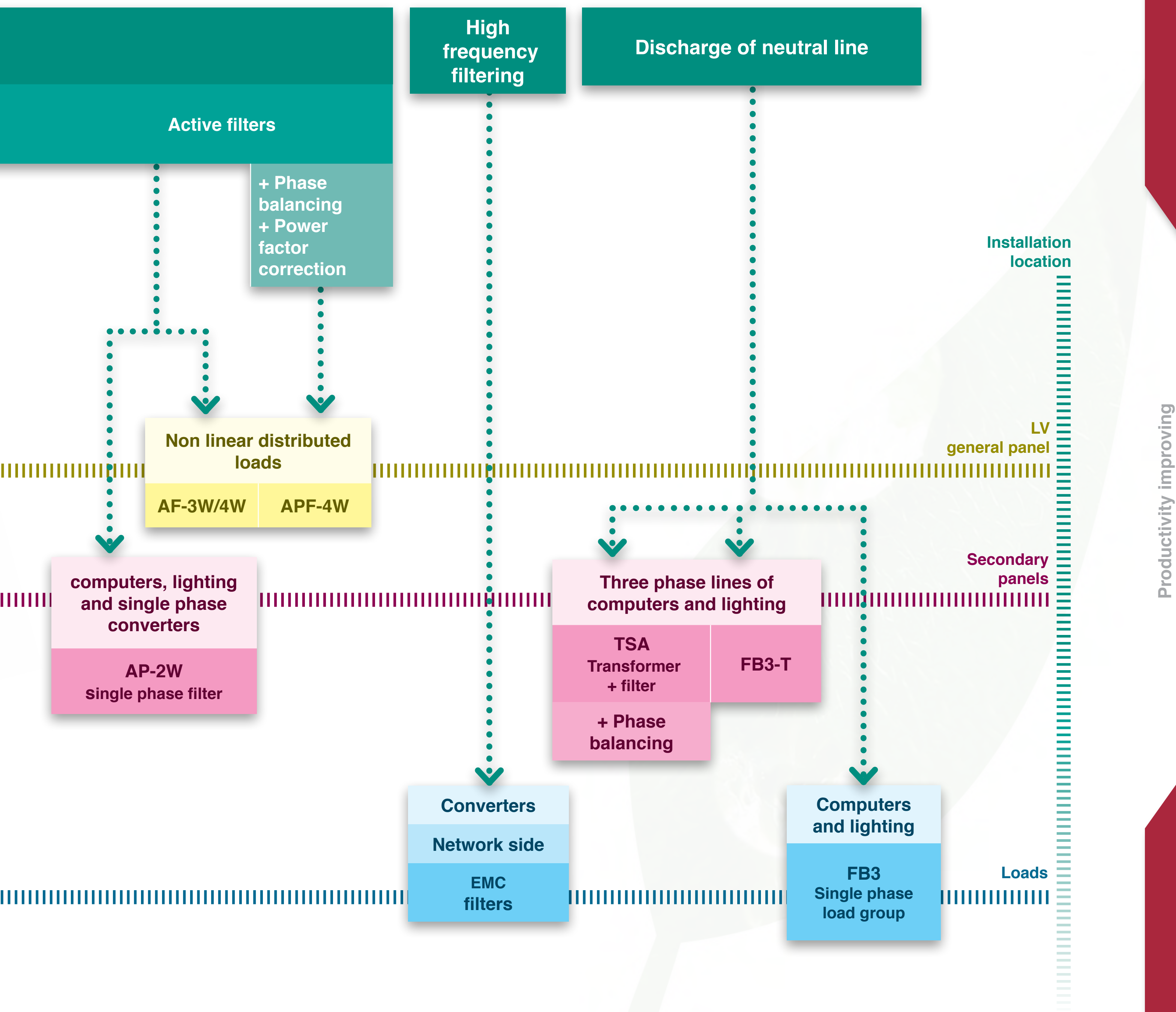
HARMONIC	1	3	5	7	11	13	∑ THD
U_n (%)	--						
I_n (%)	--						
I_n (A)							

+i R.5/6/7 P.1/2 *The rational use of electrical energy, J.Balcells*

Diagram for choosing a filter

In regard to the objectives to accomplish in the installation, the following diagram facilitates the choice of the type of filter according to its location within the facility, and the kind of load to be filtered.





Note:

- Using a combination of different types of filters in the same installation requires prior study. Consult **CIRCUTOR's** technical services.

10.2 Smart earth-leakage protection

What is smart earth-leakage protection

Smart leakage protection is a group of leakage relays (**RGU-10** series) and multipoint relays (**CBS** series) that provide the following characteristics in addition to already known functions of personnel and installation protection:

- Leakage current visual display
- Pre-alarms and alarms
- Possibility of a communications port
- Possibility of self-reclosing

Thus, they convert earth-leakage protection into a leakage current measurement system and as such, into a system capable of being integrated into a an energy and process supervision system.

It is important to remember that all of the **CIRCUTOR**'s earth-leakage protections are Class A and high immunity devices, so that, they can measure distorted and rectified currents with continuous component, typical of electronic equipment.

What does smart earth-leakage protection do

CIRCUTOR's ranges of smart earth-leakage protections make a great difference with the technology existing so far. The new applications derived from the new functions are:

- The capacity to integrate into the **PowerStudio Scada** management and supervision system**,** thanks to the RS-485 communication port

- Self-reclosing and remote management. The communications port permits the earth-leakage relay to:
  - To send measured information and events
  - To receive specific orders for its programming and operation

- Installation productivity is improved to guarantee the continuity of service without decreasing installation safety
  - Verification of the leakage current levels
  - Correct setting of the protection according to the real leakage
  - Preventive maintenance by pre-alarms
  - Establishing an alarm in **PowerStudio** once the leakage current threshold level is exceeded. If activated, it registers the tripping value and the time when it happens

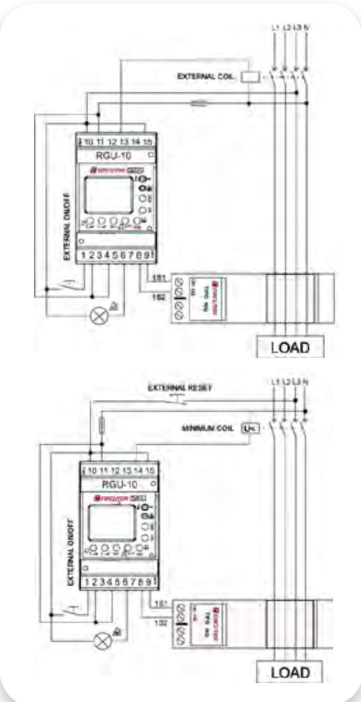
- Economy of space. Reducing assembly space in the panel using **CBS-4** and **CBS-8** multipoint relays. These are grouping, in a single system, 4 and 8 protections, respectively, thus reduce the dimensions of secondary electrical panels due to a reduced number of necessary poles

These particular characteristics make the earth-leakage protection indispensable in all installations because it optimises operating costs and guarantees continuity of service.

Steps to selecting a smart earth-leakage protection system

1	Place of assembly	▸ Main panel ▸ Secondary panels power ▸ Machines panels
2	Type of protection according to toroidal transformer location	▸ Transformer external to protection ▸ Cable output ▸ Bus bar output ▸ Transformer incorporated in the protection
3	Communications	▸ With RS-485 communications port ▸ Without communications
4	Remote control	System definition based on associated switchgear: ▸ Contactor ▸ Circuit breaker
5	Basic network parameters	▸ Auxiliary voltage 110 or 230 Vac Only for **RGU-10** ▸ Auxiliary voltage 125 Vdc ▸ Auxiliary voltage 48 Vac
Specific characteristics depending on the type of earth-leakage protection		
6	Number of protected lines	▸ **RGU-10**: 1 channel ▸ **CBS-4**: 4 channels ▸ **CBS-8**: 8 channels
7	Visual display	General ▸ Trip current with screen colour change (red) ▸ Leakage level indication. In multipoint relays, one per each channel ▸ Setting of parameters ▸ Transformer disconnection According the type of multipoint relay ▸ Recloser status ▸ Self-reclosing ▸ Communication port
Considerations		
8	Auxiliary equipment	▸ **WG** series toroidal transformers ▸ **RRM** reconnection relays ▸ Low voltage circuit breakers

Earth-leakage relay and multipoint relays connection diagrams



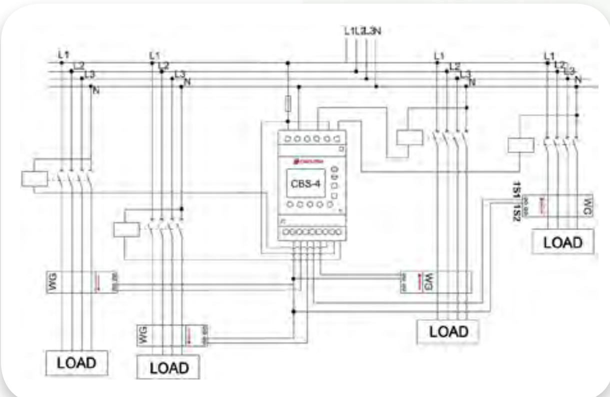
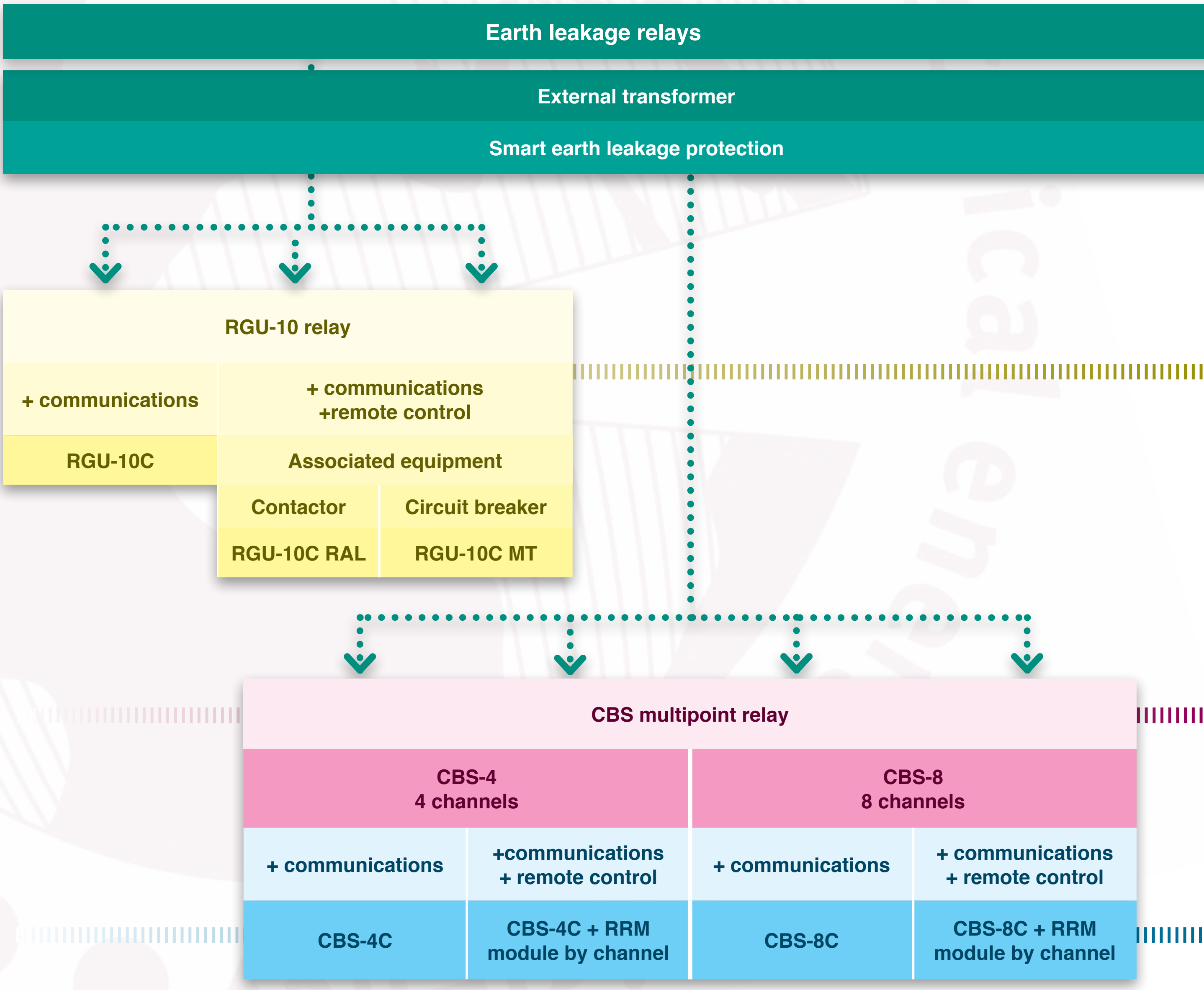
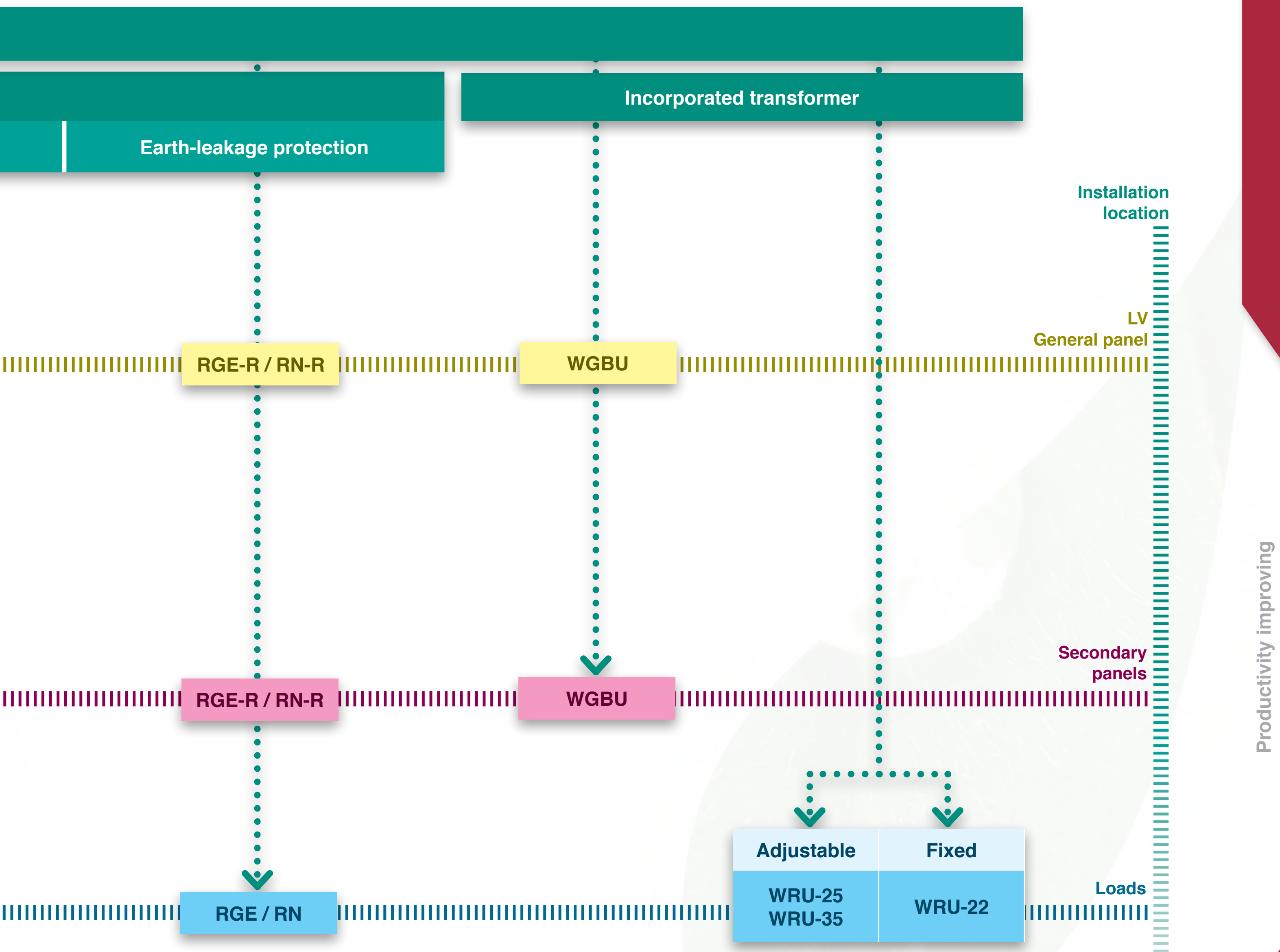


Diagram for choosing a smart earth leakage protection relays

In the following diagram is shown as well the smart earth-leakage protection, as the classic earth-leakage relay.



	Toroidal	Cables						
	RN type	WNS-20	WNS-30	WN-35	WN-70	WN-105	WN-140	WN-210
	RGU10-CBS-RGE type	WGS-20	WGS-30	WG-35	WG-70	WG-105	WG-140	WG-210
Three-phase	Useful diameter (mm)	20	30	35	70	105	140	210
	Rated current (A)	40	63	100	125	250-400	400-630	630-1250
Single-phase	Useful diameter (mm)	20						
	Rated current (A)	63						



	Bus bar			
	WG-70x175	WG-115x305	WG-150x350	WG-200x500
	70x175	115x305	150x350	200x500
	Depending on bus bar design			

Considerations

Despite of the current recommendation for the toroidal transformer, it is recommended to verify the real status of the cables by phase in order to select the appropriate diameter.

+i P.1

10.3 Smart automatic reclosers

What are automatic reclosers

Automatic reclosers are sets of earth-leakage protection or earth-leakage plus circuit breaker protection. Their objective is to reestablish service after the disconnections of one of the comented protections.

In a recloser, it is important to know what types of protections are installed, which can be reconnected and under what conditions they can be reconnected.

- Automatic reconnection systems function according to:
  - Leakage to ground current (earth leakage protection)
  - Leakage to ground current (earth leakage protection) + overload and short circuit protection

What do a recloser do

Automatic reclosers help to maintain the continuity of service in remote installations where there is no maintenance service.

Furthermore, the use of smart relays allows the remote management of the protections as well as the information registered.

Reclosers application places

In installations that normally do not have company personnel or have critical importance in the processes:

- Telecommunications installations
  - TV and radio antennas
  - Cable and mobile telephone receiver centres
- Critical receivers
  - UPS
  - Cold-storage rooms
  - Public lighting systems (roads, tunnels, lights, etc.)
- Security systems
  - Alarms
  - Security cameras

Components comprising an automatic reconnection system

◢ Earth-leakage transformer

It detects leakage to ground. It can be placed inside or outside the relay.

◢ Self-reclosing relay

Self-reclosing relays provide additional features to the reliability and safety demonstrated by the **U Series** earth-leakage protection relays.

The functions that they perform include:

- Detection of the problem (leakage to ground, overload or short circuit) with the signal that the transducer generates
- To analyze if this problem should generate an alarm according to the different parameters programmed
- To act on the switchgear that connects and disconnects the load

◢ Switchgear

Switchgear has always the function to operate or to operate and protect a load; it is external to the relay.

Switchgear that can be associated with the reclosing relays are:

- Motorised circuit breakers (low voltage series)
- Contactors
- Circuit breaker with remote control (**MCB** series), which has the double functions of circuit breaker and contactor

The charactersitics to define switchgear are:

- Rated current (in the contactors)
- Rated current and thermal protection chart (in circuit breakers)
- Features of comand inputs of the swithgear
- Breaking capacity
- NA or NC auxiliary signalling of the swithgear status

Reclosers with smart earth-leakage protection

The use of **RGU-10C** relays provide the option of communicating with remote control center. These relays allow to set a preventive maintenance. It avoids the disconnection of the monitored center of device, by means of:

- The follow up of the leakage current and alarms settings
- In case of trip off, to know whatkind of protection has been disconnected (earth-leakage relay or circuit breaker)

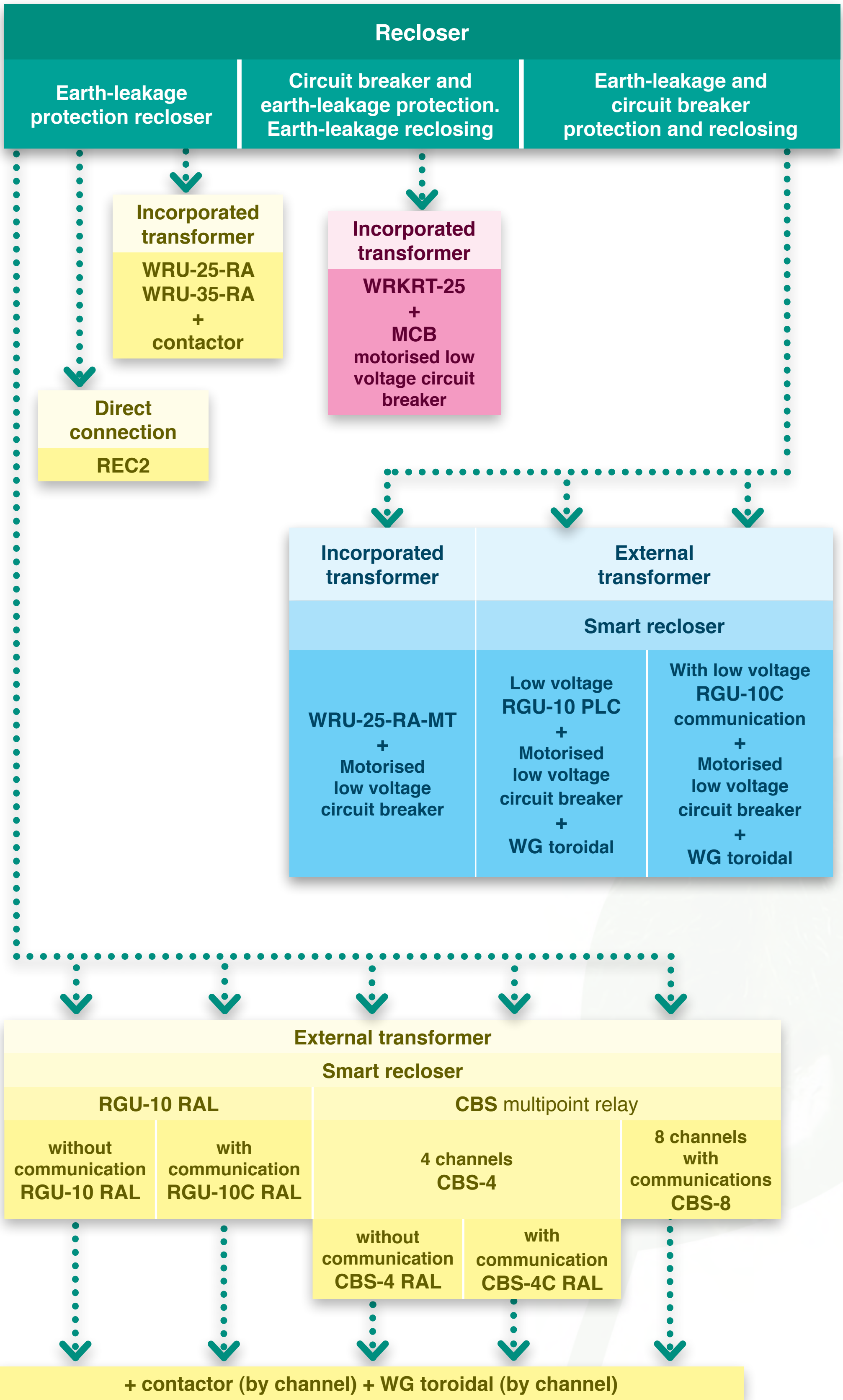
Steps to selecting a smart recloser

1	Definition of the type of protection to use	Earth-leakage protection Circuit breaker Both
2	Type of self-reclosing protection needed	Earth-leakage protection Circuit breaker Both
3	Type of switchgear associated with the protection	Contactor Miniature circuit breaker Molded case circuit breaker
4	Type of connection	Direct Incorporated toroidal transformer External toroidal transformer
5	Communications	With RS-485 communications port Without communications
6	Basic network parameters	Network voltage Auxiliary voltage 110, 230 or 400 AC Only for **RGU-10** 125 DC 48 AC
Specific characteristics depending on the type of smart recloser		
7	Time between reconnections and the number of reconnections	Depending on the series selected, fixed or adjustable
8	Visual display and optional communication function	**RGU-10C RAL** **RGU-10C MT** **CBS-4C RA** **CBS-8**
Considerations		
9	Auxiliary equipment	**WG** series toroidal transformers **RRM** reconnection relays Low voltage thermomagnetic switches Thermomagnetic switches

Selecting the recloser according to the type of installation

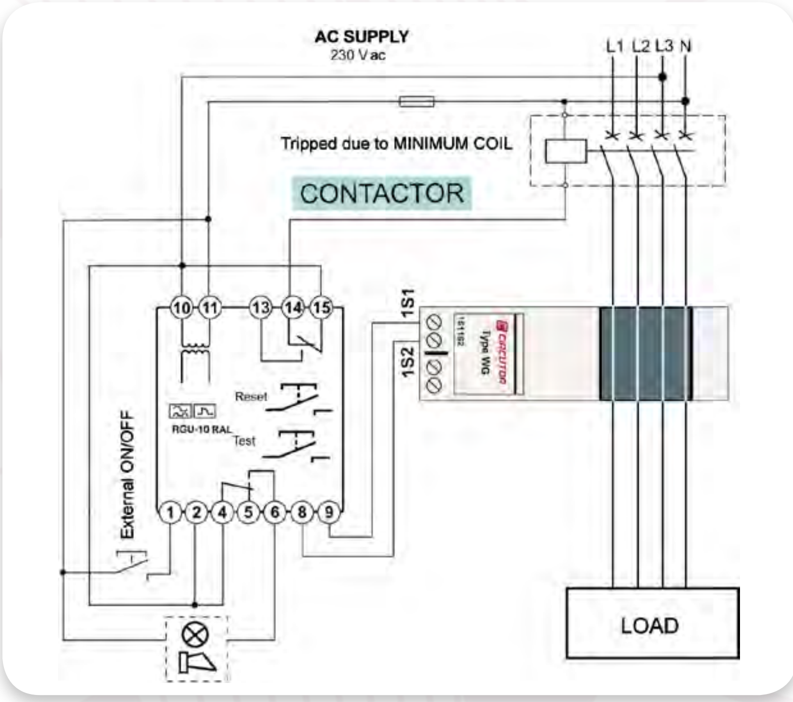
Type of Installation		Recloser	Smart recloser
Security systems	Alarms Security cameras	**REC2** **WRU-25 RA-MT** + **MT** circuit breaker	**RGU-10C RAL** + contactor **RGU-10C MT** + **MT** circuit breaker
Critical receivers	UPS Cold rooms	**WRU-25 RA-MT** + **MT** circuit breaker	**RGU-10C MT** + **MT** circuit breaker
Public lighting	Roads Tunnels	**WRU-25 2R** + contactor	**RGU-10C RAL** + contactor
Telecommunications	Telephony and cable receivers TV and radio antennas	**WRU-25 RA-MT** + **MT** circuit breaker	**RGU-10C MT** + **MT** circuit breaker

Diagram for choosing a recloser

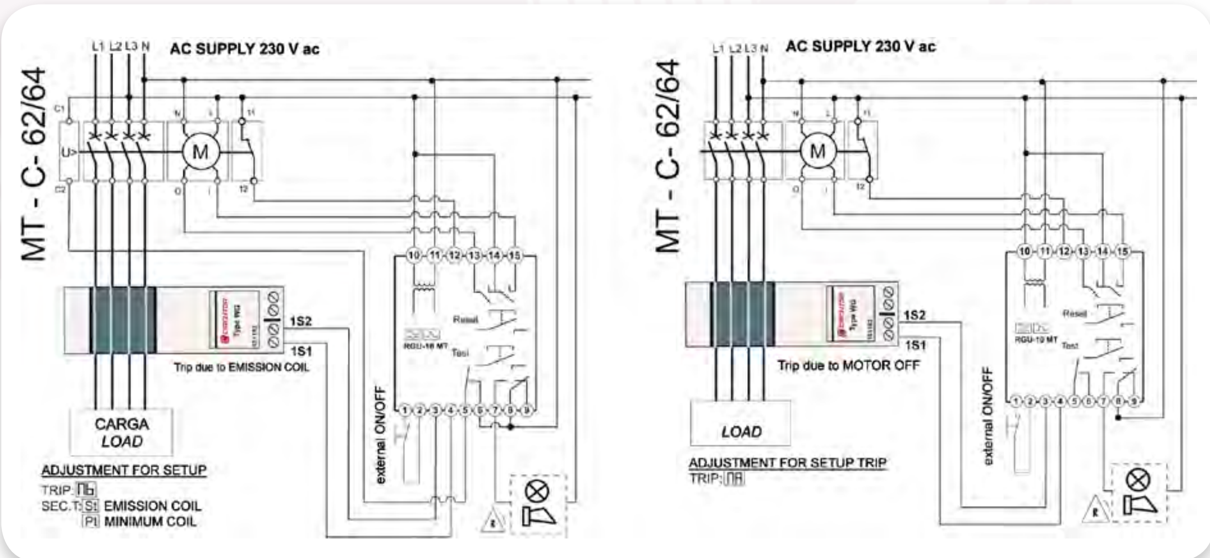


Recloser connection diagram

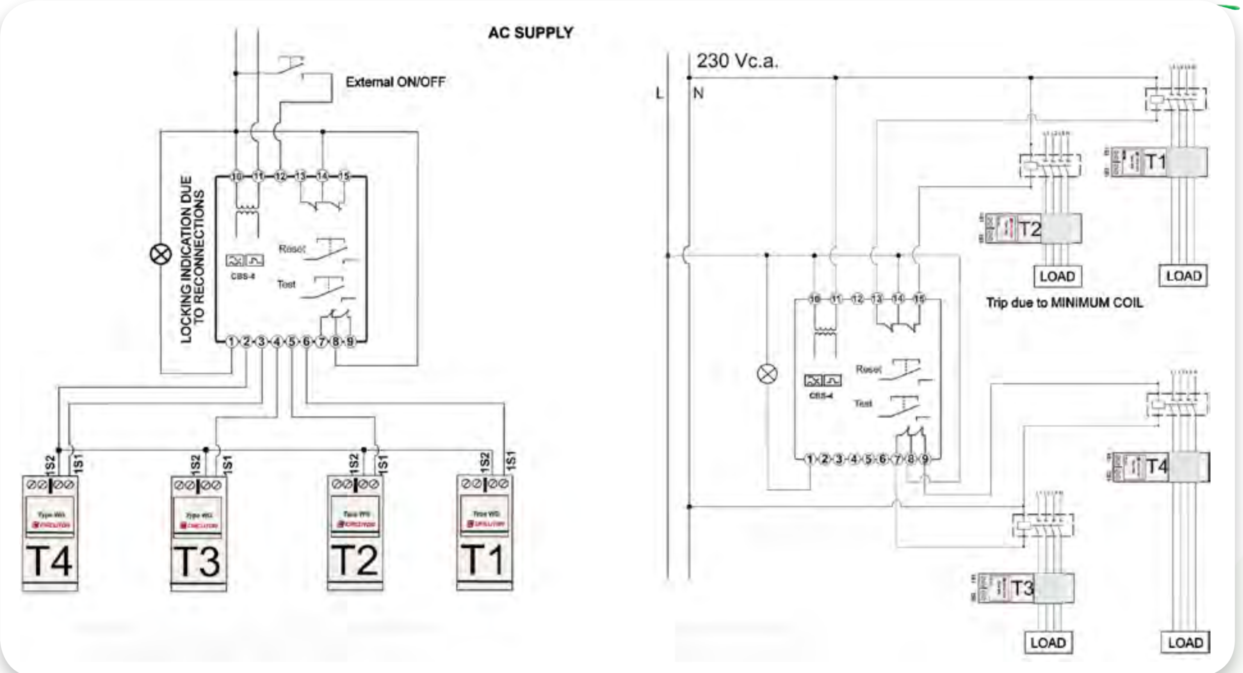
◢ RGU-10C RAL + contactor



◢ Low voltage RGU-10C + MT circuit breaker



◢ CBS-4C RA + contactor



Considerations

A switching and/or protection element should always be associated with a recloser.

+i P.2

Productivity improving

Application **notes**

- Standard diagrams of an installation
- Example of e³ study in a company
- Example of e³ in a MV distribution network

11. Application notes

11.1 Standard diagrams of an installation

The following diagrams show how to design a **PowerStudio Scada** application for an installation.

In doing so, they show as well the general panel as the secondary panels.

General comments about the diagrams

It is important to emphasise the following points:

- The diagram corresponding to the LV general panel is divided into three parts to correctly identify the equipment to be installed
    - Coupling point or connection to the utility. This is normally located in the transformer center
    - Income to the general panel
    - Output from general panel

- Two examples of LV general panels are provided. The first design is for a panel mounting system, while the second is for DIN rail installation in modular panels
- The existing diagrams of the different secondary panels correspond to those referenced in the LV general panel outputs
- Each panel has a communication bus to be integrated into **PowerStudio Scada**. This is indicated by using the comment “to HUB” in the outputs of the TCP2RS converters.

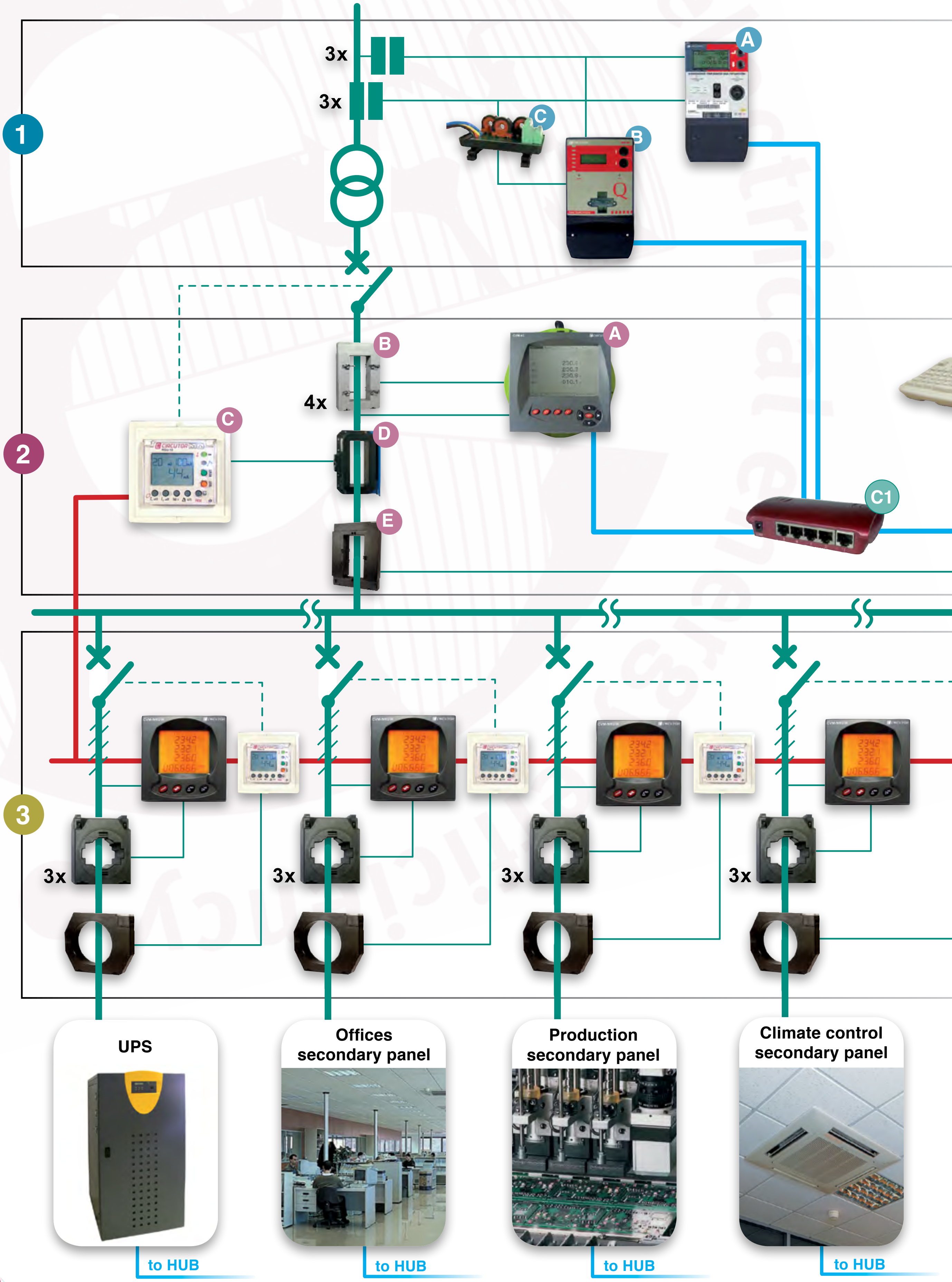
Diagrams comprehension

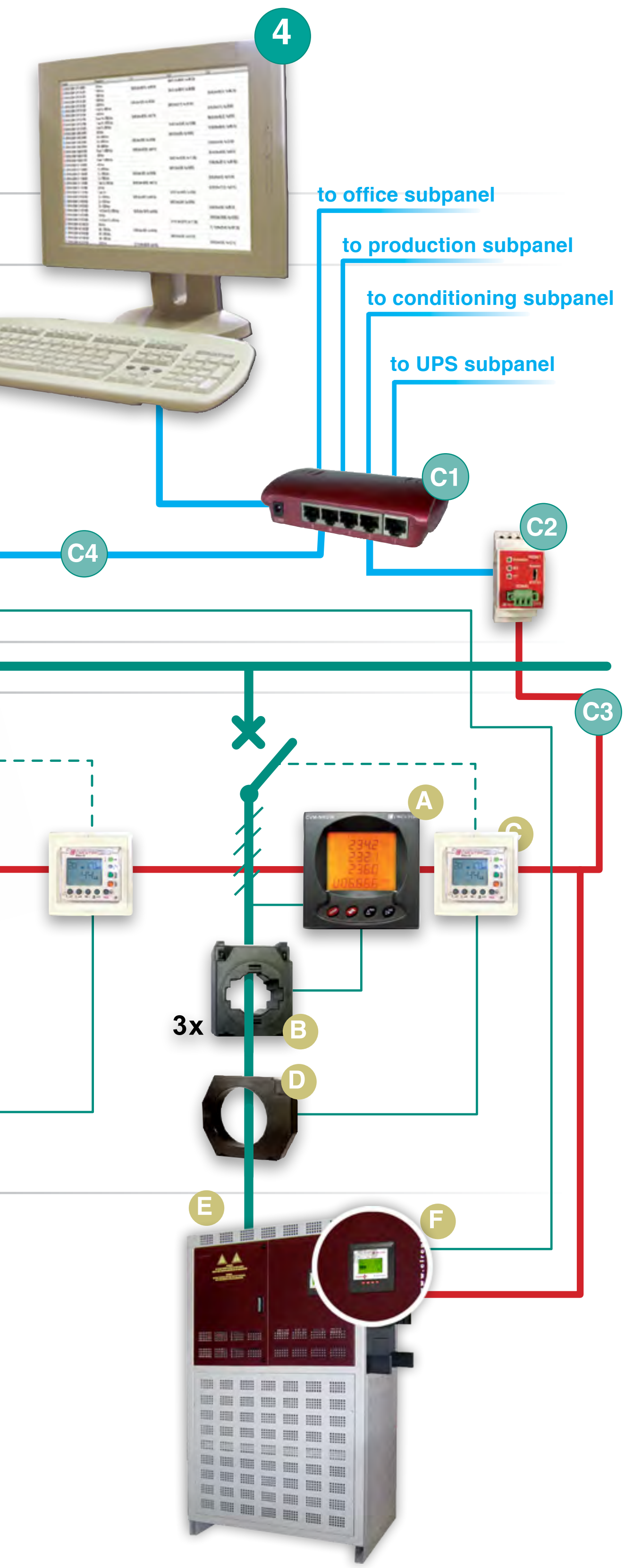
Each one of the panel diagram legends has the following parts:

- Objectives. Each diagram has a description of the design objectives. These determine the appropriate equipment in each case

- Materials list. The different equipment used are numbered. The total number of equipment to install is not numbered. Keep this in mind when executing a real project or application. The description of the communication converters or gateways, as well as the description of the type of communication bus proposed, are included in each list

Coupling point and LV general panel. Panel assembly





Design objectives

Energy billing control

- Active/reactive power and energy
- Demand charts
- Power quality

Electrical parameter control and alarms setting for preventive maintenance

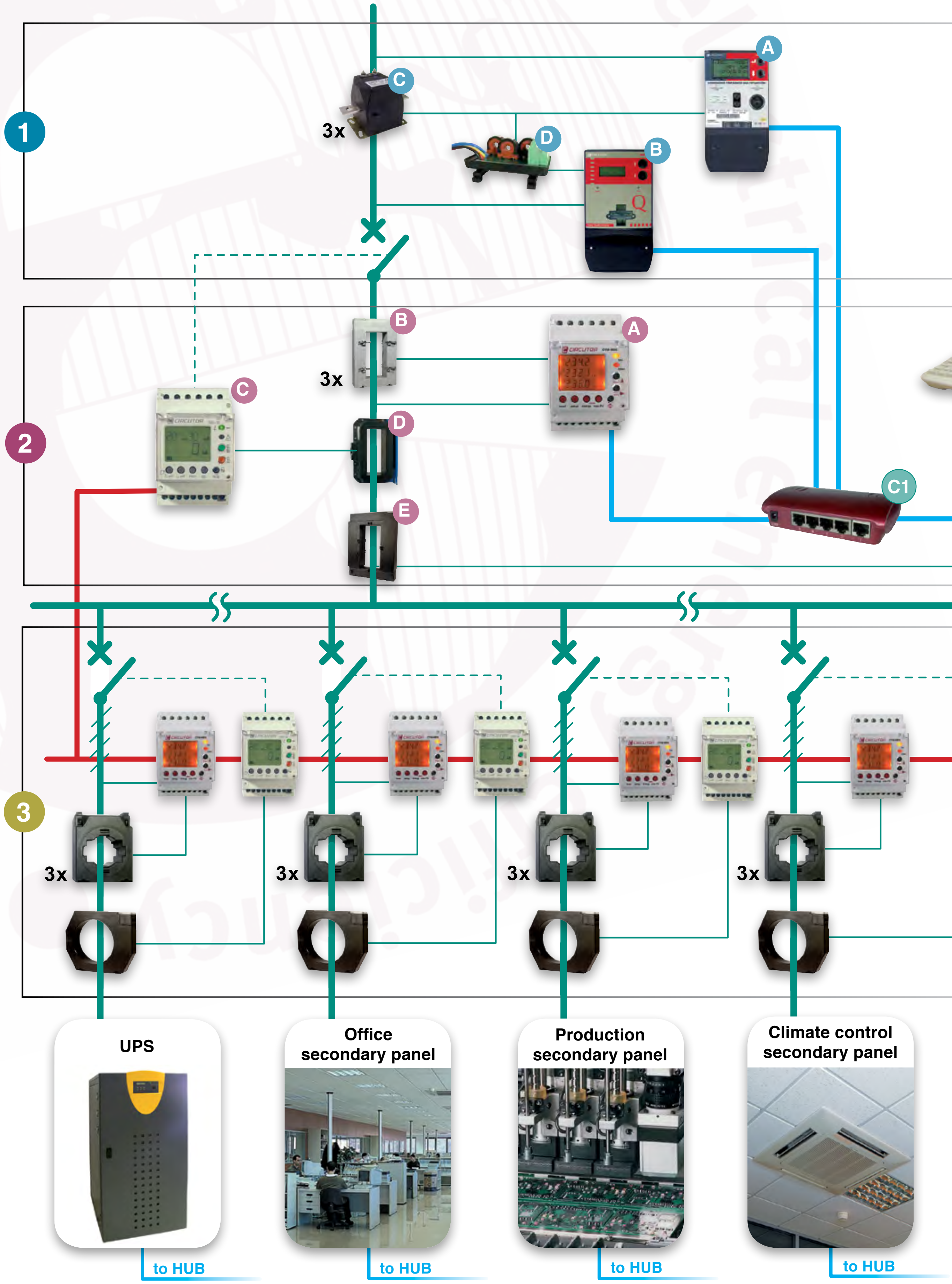
- Voltage and current
- THD
- Leakage to ground
- Insulation control

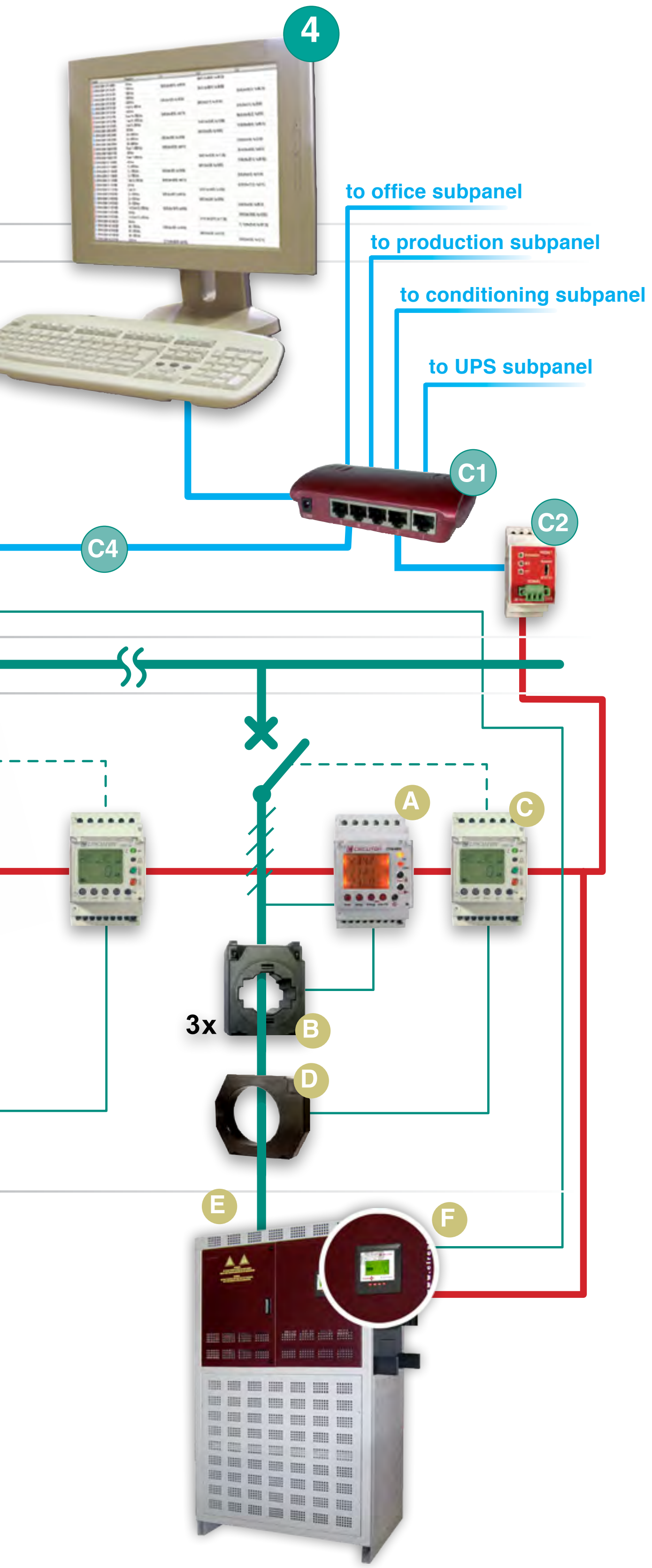
Control of electrical energy costs by power line

MATERIALS LIST

Coupling point			
1	A	1	**CIRWATT** meter
	B	1	**QNA 412** network analyzer
	C	1	external **ITF** module
Income to the general panel			
2	A	1	**CVMk2** network analyzer
	B	4	**TA** bus bar current transformers
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	split core **TP** transformer for capacitor bank
Output from general panel			
3	A	1	**CVM-NRG96** network analyzer
	B	3	**TC** current transformers, cable output
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	**FRE** Static capacitor bank with detuned filters
	F	1	**computer plus TF** power factor relay
4			**PowerStudio Scada** application
C1		2	HUB
C2		1	RS-485 / **TCP2RS** Ethernet converter
C3			RS-485 bus
C4			Ethernet bus

Coupling point and LV general panel. DIN rail assembly





Design objectives

Energy billing control

- Active/reactive power and energy
- Demand charts
- Power quality

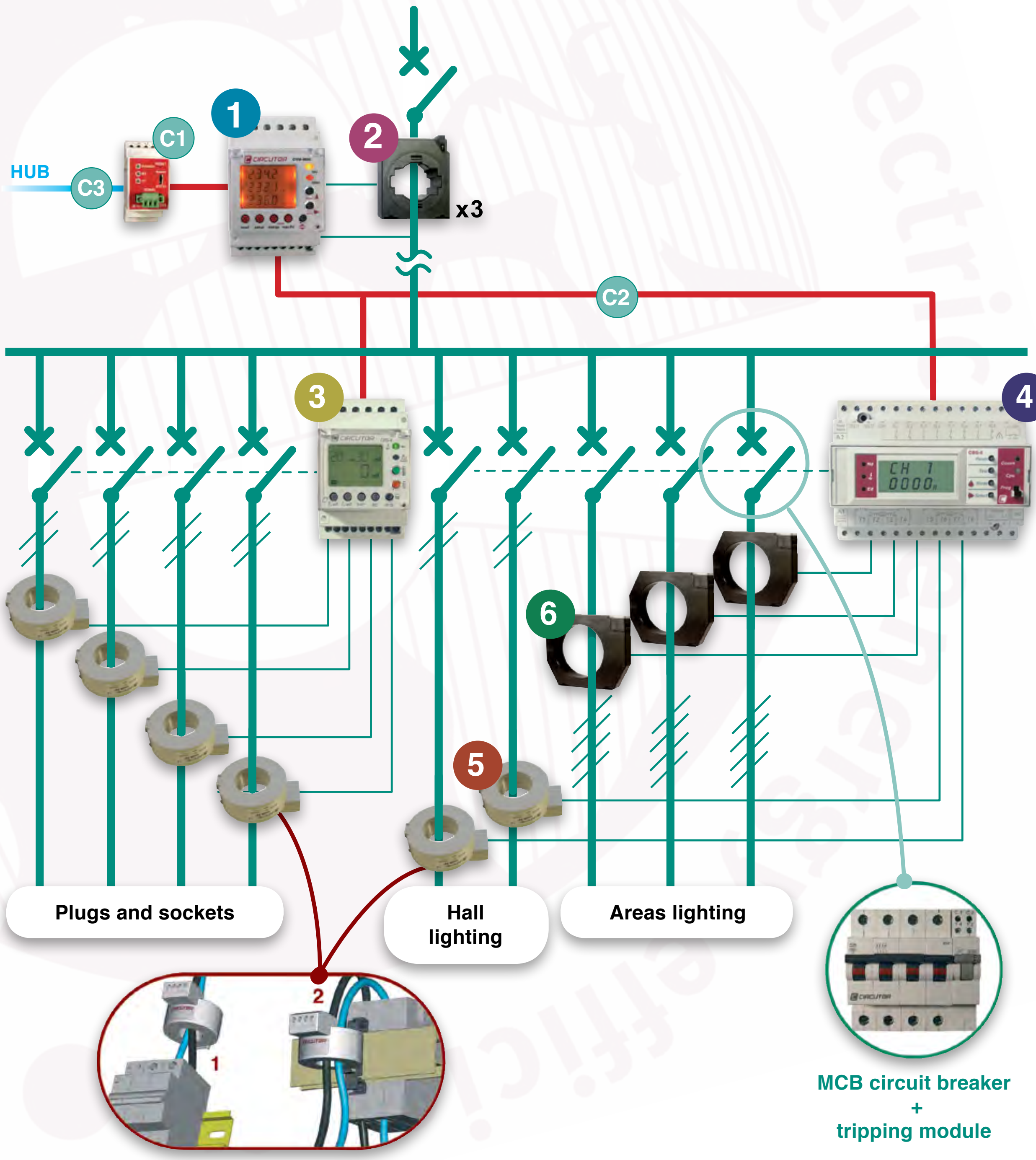
Electrical parameter control and alarms setting for preventive maintenance

- Voltage and current
- THD
- Leakage to ground
- Insulation control

Control of electrical energy costs by power line

MATERIALS LIST			
Coupling point			
1	A	1	**CIRWATT** meter
	B	1	**QNA 412** network analyzer
	C	3	**TRMC** transformers
	D	1	external **ITF** module
Income to the general panel			
2	A	1	**CVM MINI** network analyzer
	B	3	**TA** bus bar current transformers
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	split core **TP** transformer for capacitor bank
Output from general panel			
3	A	1	**CVM MINI** network analyzer
	B	3	**TC** current transformers, cable output
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	**FRE / PLUS FRE** static capacitor bank with detuned filters
	F	1	**computer plus TF** power factor relay
4			**PowerStudio Scada** application
C1		2	HUB
C2		1	RS-485 / **TCP2RS** Ethernet converter
C3			RS-485 bus
C4			Ethernet bus

Low voltage secondary panels - Offices



WGS applications

MCB circuit breaker
+
tripping module

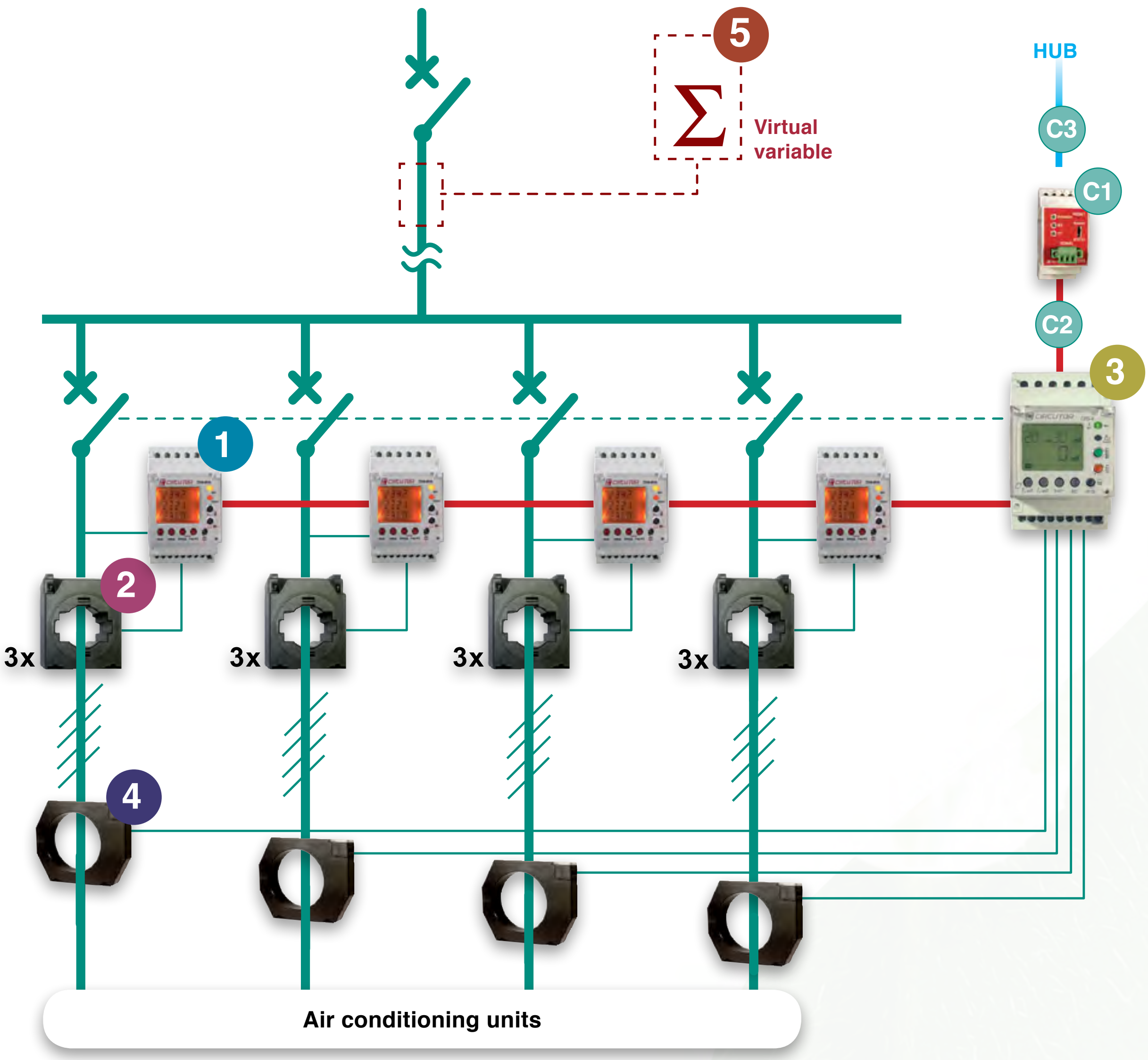
MATERIALS LIST	
1	**CVM MINI** DIN rail network analyzer
2	**TC** current transformer
3	4-channel **CBS-4** mutipoint relay
4	8-channel **CBS-8** mutipoint relay
5	**WGS** toroidal transformer
6	**WG** toroidal transformer

Design objectives

- Control of energy consumption in offices
- Leakage current monitoring
- Control of electrical parameters
- Control of distribution losses (CVM output General Panel - CVM MINI)

C1	Converter **TCP2RS** RS-485 / Ethernet
C2	RS-485 bus
C3	Ethernet bus

Low voltage secondary panels - Air conditioning

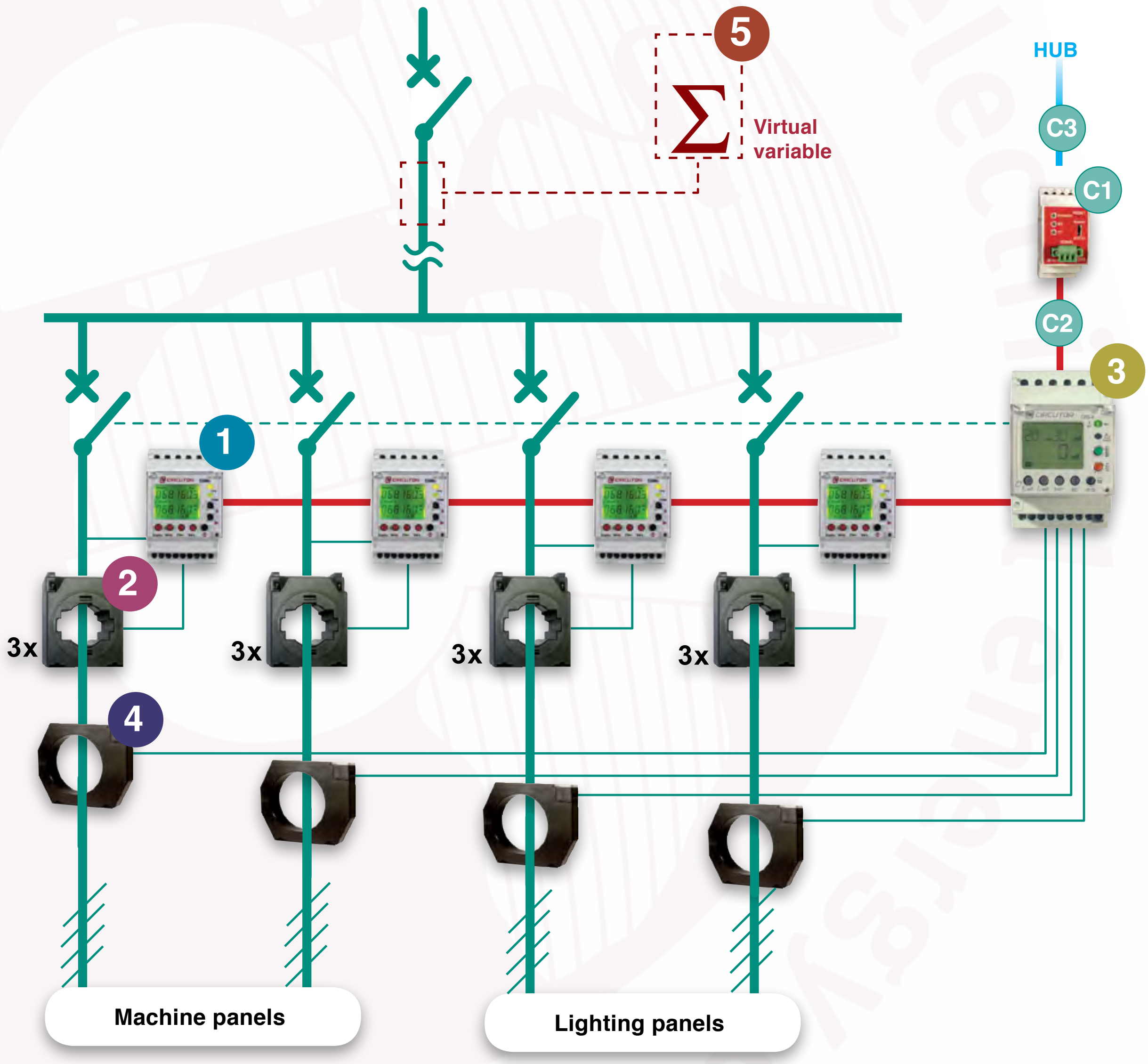


Design objectives

- Control of energy consumption in air-conditioned areas
- Control of electrical parameters
- Leakage current monitoring
- Control of distribution losses (CVM output Main Panel - Virtual variable)

MATERIALS LIST	
1	**CVM MINI** DIN rail network analyzer
2	**TC** current transformer
3	4-channel **CBS-4** multipoint relay
4	**WG** toroidal transformers
5	**PowerStudio Scada** virtual variable secondary panel total energy consumption
C1	**TCP2RS** RS-485 / Ethernet converter
C2	RS-485 bus
C3	Ethernet bus

Low voltage secondary panels - Production

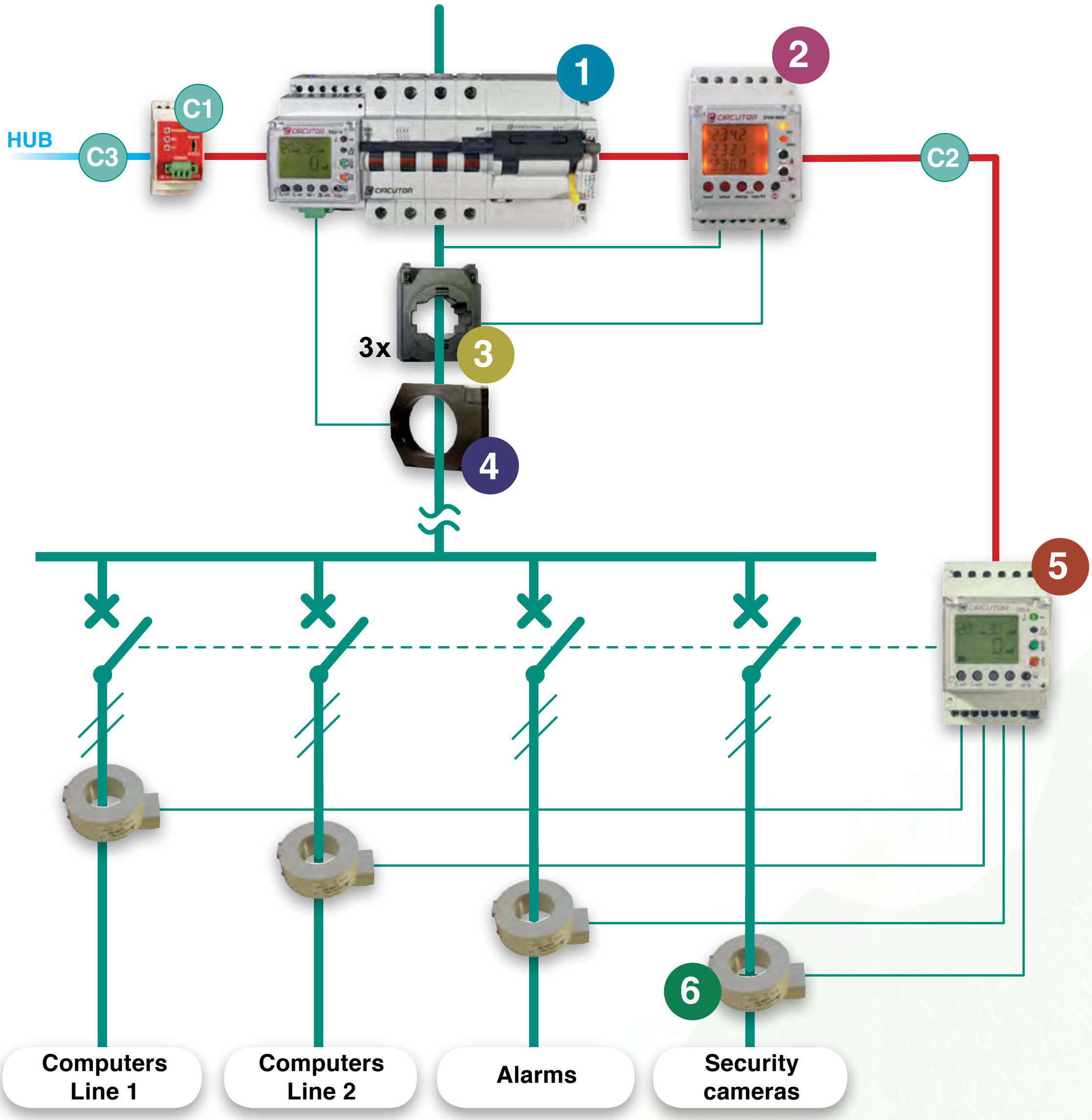


Design objectives

- Costs charge by manufacturing line for marginal costing
- Earth-leakage protection monitoring
- Control of distribution losses (CVM output General Panel - Virtual variable)

MATERIALS LIST	
1	**EDMk** DIN rail submeters
2	**TC** current transformer
3	4-channel **CBS-4** multipoint relay
4	**WG** toroidal transformers
5	**PowerStudio Scada** virtual variable subpanel global energy consumption
C1	**TCP2RS** RS-485 / Ethernet converter
C2	RS-485 bus
C3	Ethernet bus

Low voltage secondary panels - UPS



MATERIALS LIST	
1	**RGU-10C MT** recloser (motorised circuit breaker **MT** + **RGU-10C** earth-leakage relay)
2	**CVM-MINI** DIN rail network analyzer
3	**TC** current transformer
4	**WG** toroidal transformer
5	4-channel **CBS-4** switchboard
6	**WGS** toroidal transformer

Design objectives

- Control of electrical parameters
- UPS operation control
- Self-recolsing and remote control of the circuit breaker and the earth-leakage protection

C1	**TCP2RS** RS-485 / Ethernet converter
C2	RS-485 bus
C3	Ethernet bus

11.2 Example of e³ in a company

The bases for carrying out this study are the electric energy bills and the measurements taken in the installation. Nonetheless, the study of the different type of receivers is not provided.

Description of the installation

- Medium Voltage supply
- MV / LV Transformer: 630 kV·A 20/0.4 kV, P_F = 1.25 kW, P_J = 9 kW
- 400 V, 50 Hz low voltage distribution

Billing information

- Contracted power 500 kW
- Maximeter register of 600 kW (maximum demanded power)
- cos φ = 0,75

ELECTRICITY BILL

CONTRACT DETAILS

Customer: -			Date: -
Utility: -			Tariff: 3.1
Zone: -			Power invoicing: Mode 2
TRANSFORMING RATIOS			Contracted power: 500 kW
Pr. Current: 100		Sec. Current: 5	Hourly discrimination: Type 2
Pr. Voltage: 22 000		Sec. Voltage: 22 000	Meter number: 345XD34

READINGS AND CONSUMPTIONS: 01/07/2006 to 01/08/2006

Time	Previous	Current	Adjust	Escale	Total consumption
PEAK	301 324	309 826	0	x10	85 020 kW·h
FLAT+VALLEY	315 265	348 656	0	x10	333 910 kW·h
REACTIVE	79 685	83 370	0	x100	368 500 kvar·h
MAXIMETER		600 kW			

BILL CALCULATION

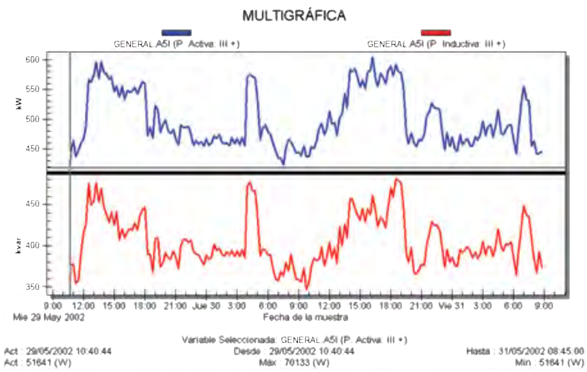
Power:	750 kW x 12,770703 €/kW x 1 mes	9587,03
Active energy:	418 930 kW·h x 0,060824 €/kW·h	25 481,00
	Subtotal	**35 059,03**
Hourly discrimination:	85 020 kW·h x 40% x 0,060824 €/kW·h	2 068,50
Reactive:	15.84 kr% x 35 059,03	5 553,35
	Total	**42 680,88**
Electricity tax:	42 680,88 x 4,864% x 1,05113	2 182,14
Taxable base		44 863,02
VAT	16%	7 178,08
TOTAL		**52 041,10**

Measurements

- Point of measurement, income of the general panel
- Measurements on the different general panel output lines
- Subject of the measurement, power, energies, power factor and harmonics

Graphic evolution of active and reactive power

To carry out this study, it is needed to have the power demand chart of the installation. It is obtained, either a supervision system fitted with **CVM** analyzers and **PowerStudio Scada** software, or by means of a measurement taken with an **AR5-L** portable analyzer. In this examples the chart was got by means of an **AR5-L**.



Harmonic spectrum

One of the instantaneous measurements is attached.

Data	
Transformer	630 kV·A
Active power	580 kW
cos φ	0.78

AR5-L measurement	
$I_{fundamental}$	1.088,5 A
THD *I*	34.5 %
I	1.151,4 A

	Individual rate (%)	Current (A)
1	100	1.088,5
2	0,01	0,1
3	7,45	81,1
4	0,16	1,8
5	30,32	330,0
6	0,15	1,6
7	12,82	139,6
8	0,13	1,5
9	0,23	2,5
10	0,12	1,3
11	5,02	54,7
12	0,11	1,2
13	3,88	42,3

	Individual rate (%)	Current (A)
14	0,11	1,2
15	0,13	1,4
16	0,12	1,3
17	1,83	19,9
18	0,05	0,6
19	2,05	22,3
20	0,08	0,8
21	0,36	3,9
22	0,01	0,1
23	0,89	9,7
24	0,04	0,5
25	1,15	12,5

Technical situation of the installation

- Reactive power demand

$$Q = P \cdot \text{tg}\,\varphi = 580 \cdot 0.80 = 465 \text{ kvar}$$

- Residual harmonic current

$$I_{res} = \sqrt{1151^2 - 1088^2} = 375 \text{ A}$$

- Distortion power

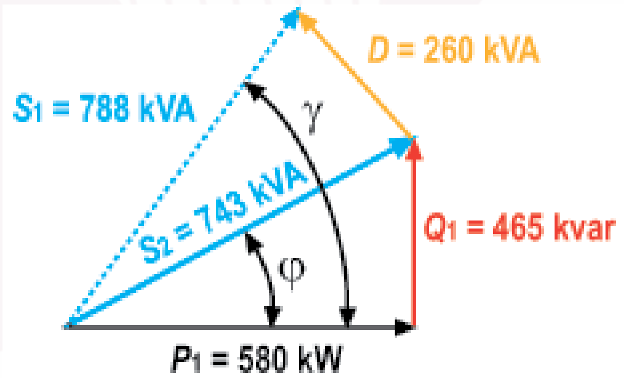
$$D = \sqrt{3} \cdot I_{res} \cdot U = \sqrt{3} \cdot 375 \cdot 400 = 260 \text{ kV·A}$$

- Apparent power

$$S = \sqrt{P^2 + Q^2 + D^2} = \sqrt{580^2 + 465^2 + 260^2} = 788 \text{ kV·A}$$

- Power factor

$$PF = \cos\varphi = \frac{580}{\sqrt{580^2 + 465^2 + 260^2}} = 0.74$$



- *K* Factor

$$K = \sqrt{1 + \frac{0.1}{0.1 + 1} \cdot \left(\frac{1088}{1151}\right)^2 \cdot \left[3^{1.7} \cdot \left(\frac{81.1}{1088}\right)^2 + 5^{1.7} \cdot \left(\frac{330}{1088}\right)^2 + \ldots + \right]} = 1{,}13$$

It means a power reduction of:

$$\left(1 - \frac{1}{1.13}\right) \cdot 100 = 11{,}54\ \%$$

Therefore, the apparent useful power recommended for the transformer is as follows:

$$S_{useful} = \frac{630}{1.13} = 558 \text{ kV·A}$$

- Transformer overload

Overload with respect to the rated power is:

$$F_C = \frac{788}{630} = 1.25$$

However, given the existence of harmonics, in order to not overheat the transformer the calculation is made with respect to the reduced useful power.

$$F_C = \frac{788}{469} = 1.41$$

- Transformer efficiency

$$C = \frac{S}{S_n} = \frac{788}{630} = 1.25$$ ‣ Transformer load index

$$\eta = \frac{C \cdot S \cdot \cos\gamma}{C \cdot S \cdot \cos\gamma + P_{Fc} \cdot K + C^2 \cdot P_J} =$$

$$= \frac{1{,}25 \cdot 630 \cdot 0{,}71}{1.25 \cdot 630 \cdot 0.71 + 1.25 \cdot 1.13 + 1.25^2 \cdot 9} = 97.42\ \%$$

Hidden economical costs

- Need to change the MV/LV transformer for an 800 kV·A transformer or for a complete fider with a second 630 kV·A transformer (MV cabin, cable connections, transformer, civil jobs, etc.)
- Excessive consumption of power and energy not needed
- Risk of stoppage of the installation due to breakdowns resulting from the high harmonic content and earth leakage currents
- Stoppage due to transformer overload. Risk of breakdowns

Visible economical costs

- Penalty of reactive energy: 5.533,35 €
- Extra charge for energy consumption during peak hours 2.068,5 €
- Extra charge due to maximum demand. Billing of 750 kW instead of 500 kW: (750-500) x 12.770703 = 3,192.67 €

TOTAL VISIBLE COSTS 10,794.52 € (25.29 % of the total invoice not including taxes)

Solution

◢ Measurement system

Once the study has been done, it has been proposed to carry out a measurement and supervision system. Here three levels have been put forward:

- Billing parameters and power quality control
- Technical and energy management
- Cost charge in manufacturing processes and offices (lighting, air conditioning, etc.)

See details of the equipment in the "energy management system" diagram

◢ Demand management

See details of the connections in the "demand management system" diagram.

Reactive energy compensation

Installation of two power factor correction equipment fitted with detuned reactors. Although the installation will have active and pasive filters, it is compulsory that capacitor banks must have detuned reactors for operating correctly.

Recommended equipment

- 40 kvar fixed capacitor, with detuned reactors and a circuit breaker, for transformer compensation. **FRM-40-400** type
- 360 kvar capacitor bank with detuned reactors **FR** type
- One current transformer, split core, ratio 1000/5 A, class 1, burden 15 V·A, **TP-816** type

Filtering

Process 1 secondary panel

Installation of an active filter for the harmonic compensation of seven 40 CV pumps.
To make the choice:

- The real efficient value of the total current in the panel is calculated by considering that all the machines are working 48,3 · 7 = 338 A
- Value of the THD I = 54,3 %
- Calculation of the filter current:

$$I_{filter} = I_{ef} \cdot \sqrt{\frac{THD\,I^2}{THD\,I^2 + 100^2}} \cdot \text{Safety factor} = 338 \cdot \sqrt{\frac{54{,}3^2}{54{,}3^2 + 100^2}} \cdot 1.2 = 92\ A$$

It is recommended to use a safety factor of 1,2.

Recommended equipment

- **AF** active filter with a value of current the closest superior to the calculated value.
  Code: **AF-3W5-100-400**
- 3 current transformers, for the measurement of the active filter, with a ratio 2000/1, class 0.5, burden 10 V·A, **TCH** type

Process 2 secondary panel

LCL filter installation in each 90 CV (66 kW) pumps. To make the choice:

- Calculation of the motor current for cos $\varphi = 1$. $I = 95$ A
- Increase this value by 10 %. $I = 95 \cdot 1.1 = 105$ A
- Filter recommended of 110 A. LCL35-110 A-400 type

Outdoor lighting secondary panel

Installation of three FB3-T filter for blocking the third harmonic. For defining the rated value of the filter, at least the rated current has to be the rated value of the circuit breaker. So the choosen filter has a rated current of 25 A. Concretely **FB3T-5-25-00** type.

Office secondary panel

Installation of 6 filters **FB3** for printers and computers.

Maximum demand control

Once the prior study has been carried out to select the dispensable loads, the following decision was taken:

- Three of the 7 pumps of 40 CV can be stopped
- The outdoor lighting does not need to be connected, therefore its connection can be blocked during the hours of daylight
- Of the 7 air conditioning lines, it is possible to disconnect one of them in each different working areas. Hall and corridors lighting must be connected always.

So, the following load disconnection sequence is carried out:

- Firstly the 30 CV pumps are disconnected one by one
- Then, the air conditioning lines are gradually disconnected
- Outdoor lighting is also blocked

Recommended equipment

- 1 **CA-4** load controller
- 3 **MR-3** expansion modules
- **PowerC** software

Communication bus

- For the maximum demand control system is required RS-485 bus among expansion modules **MR-3** and the load controller **CA-4**
- Between the **CA-4** load controller and the control computer the connection is made with a RS-232 bus

Results

◢ Technical cost reduction

Once the solutions have been applied, the results observed are the following:

- Final current distortion rate. THD I = 5%
- Final $I_{residual} = 51$ A
- Final distortion power $D = 35$ kV·A

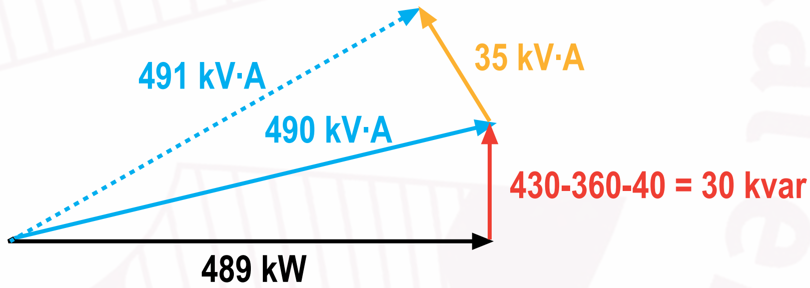
- Efficient power:

$$P_{ef} = P_{current} - P_{peak} - \Delta P_{class\ A} - losses =$$

$$= 600 - 75 - 30 - 6 = 489\ kW$$

> **N.B.:**
> - The efficient power has been considered as the one measured by the maximeter
> - It has been considered that the change of the existings receivers for a more efficient ones, it is going to decrease the value of active power in 30 kW
> - According the study, it has been estimated that losses will be reduced around 6 kW.

- Power factor and cos φ



$$PF = \frac{489}{\sqrt{489^2 + 30^2 + 35^2}} = 0.99$$

$$\cos \varphi = \frac{489}{\sqrt{489^2 + 30^2}} = 1$$

> **N.B.:**
> - Having optimised the active power, the capacitor bank has been calculated
> - Based on 489 kW with cos $\varphi = 0.75$, the reactive power demand is 430 kvar
> - If the compensation of the reactive is done, but not harmonic filtering, we would have cos $\varphi = 1$, but an $PF = 0'88$

- Transformer efficiency

$$\eta = \frac{0{,}78 \cdot 630 \cdot 0{,}98}{0{,}78 \cdot 630 \cdot 0{,}98 + 1{,}25 \cdot 1{,}09 + 0{,}78^2 \cdot 9} \cdot 100 = 98.6\ \%$$

- Real power demanded from the network:

> - We have reduced the demand from 788 to 491 kV·A. Therefore, the final apparent power demand has been reduced by 37 %. So there are still 139 kV·A available
> - Power factor values and cos φ are practically the same
> - Increase of the voltage in the main bus bar by 3.2 %

Visible cost reduction

Once the technical costs have been optimised, the simulation of the electrical bill can be made easily. So, in the following improved bill it is observerd the economical saving.

BILL CALCULATION

Power:	489 kW x 12,770703 €/kW x 1 mes	6.244,87
Active energy:	368.659 kW·h x 0,060824 €/kW·h	22.423,32
	Subtotal	**28.668,19**
Hourly discrimination:	46.311 kW·h x 40% x 0,060824 €/kW·h	1.126,73
Reactive:	- 4 kr% x 28.668,19	-1.146,73
	Total	**28.648,19**
Electricity tax:	28.648,19 x 4,864% x 1,05113	1.464,69
Taxable base		30.112,88
		4.891,83
		34.930,95

BILL CALCULATION

Power:	750 kW x 12,770703 €/kW x 1 mes	9587,03
Active energy:	418 930 kW·h x 0,060824 €/kW·h	25 481,00
	Subtotal	**35 059,03**
Hourly discrimination:	85 020 kW·h x 40% x 0,060824 €/kW·h	2 068,50
Reactive:	15.84 kr% x 35 059,03	5 553,35
	Total	**42 680,88**
Electricity tax:	42 680,88 x 4,864% x 1,05113	2 182,14
Taxable base		44 863,02
VAT	16%	7 178,08
TOTAL		**52 041,10**

Visible cost reduction per maximum demand control

Having a maximum demand value of 105 % of the contracted power without extra charge, it means 525 kW, the electricity bill has as the billable power, the value obtained from the efficient power of 489 kW.

Economic saving is 3,192.67 €.

Visible cost reduction per reactive energy

In this case, with a final cos φ of 1 the bonus will be as follows:

$$K_r = \frac{37{,}026}{1} - 41{,}026 = -4\,\%$$

Economic saving of 5,535.35 € initially, plus a extra bonus of 1,146.73 €.

Visible cost reduction of peak hours consumption

In this case, on eliminating a major part of the maximum demand at peak hours, and thanks to the change carried out in efficient receivers (lamps, etc.) the demand of active energy was reduced by 12 %. With a 77 % reduction in energy consumed at peak time.

Economic saving of 2,068.50 - 1,127.73 = 941.77 €.

Conclusions

◢ **Technical cost reduction**

- Not necessary the extension of the installation due to lack of capacity
- Extra available capacity of the installation

◢ **Visible cost reduction**

The monthly reduced total by means of the three tariff concepts is 17,100.15 €. So, it represents 33 % of the total bill.
Considering that the 12 months of the year have a similar consumption, the annual saving in 205,321.18€

◢ **Hidden cost reduction**

By means of the actions put forward, the following points are avoided:

- Installation stoppages due to the overload of the transformer
- Need to extend the transformation centre and the subsequent demand for a power increase.
- Process stoppage due to leakage and bad waveform quality
- Unnecessary energy payment

◢ **Ecological cost reduction**

The monthly active energy reduction is 50,271 kW·h, so 603,252 kW·h per year. Therefore, considering a mixed electrical energy system (1 MW·h = 0.6 T of CO_2), the reduction in greenhouse effect gasses is 362 T.

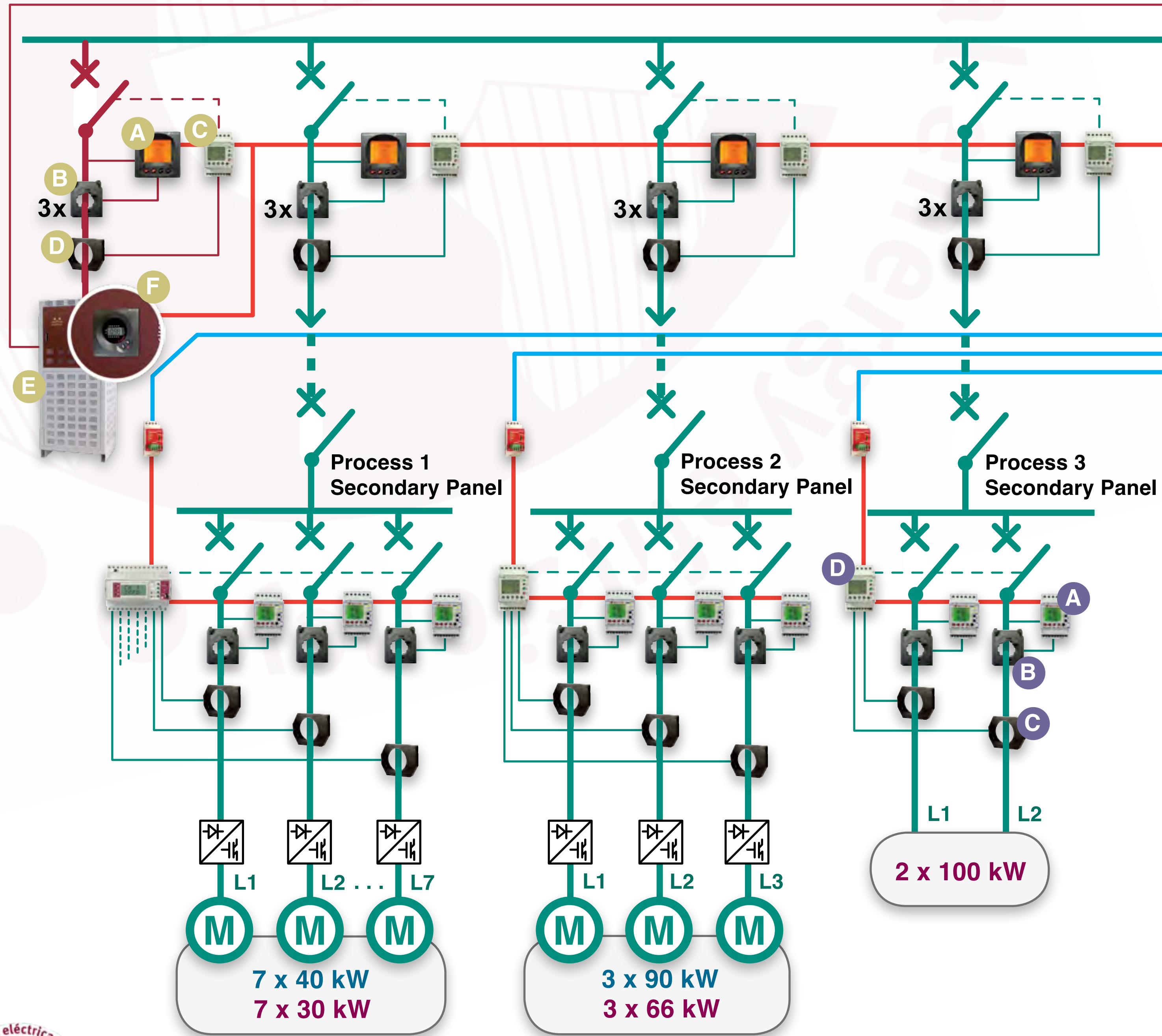
Recommendation

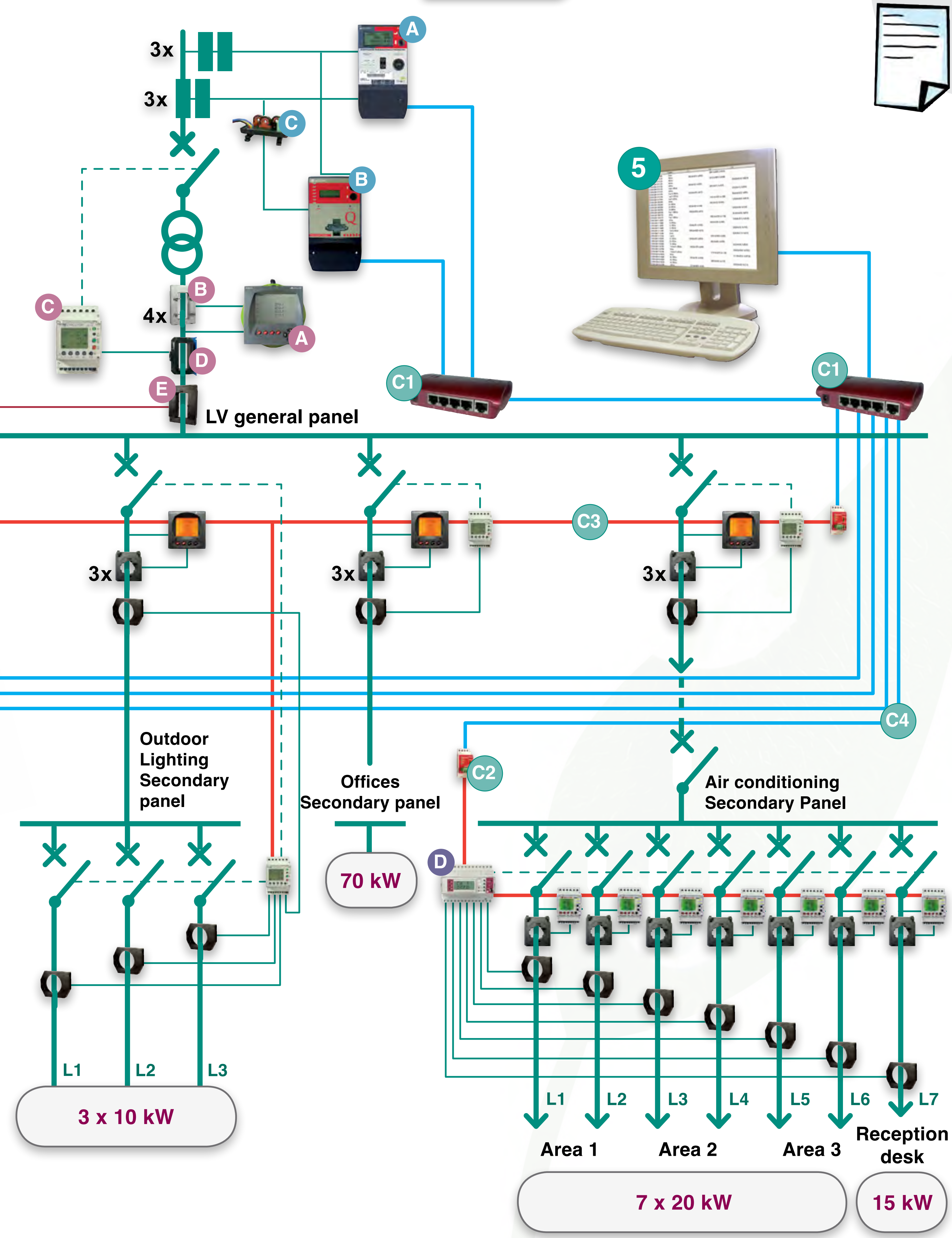
It is very important to carry out an energy diagnosis and audit of the installation subject to study.

Energy management system

LIST OF MATERIALS			
Main panel income			
2	A	1	**CVMk2** network analyzer
	B	4	**TA** bus bar current transformers
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	**TP** split core transformer for capacitor bank
Main panel outputs			
3	A	1	**CVM NRG 96** network analyzer
	B	3	**TC** current transformer, cable output
	C	1	**RGU-10 C** smart earth-leakage protection relay
	D	1	**WG** toroidal transformer
	E	1	**FR** static capacitor bank with detuned reactors
	F	1	**computer 14-d** power factor relay

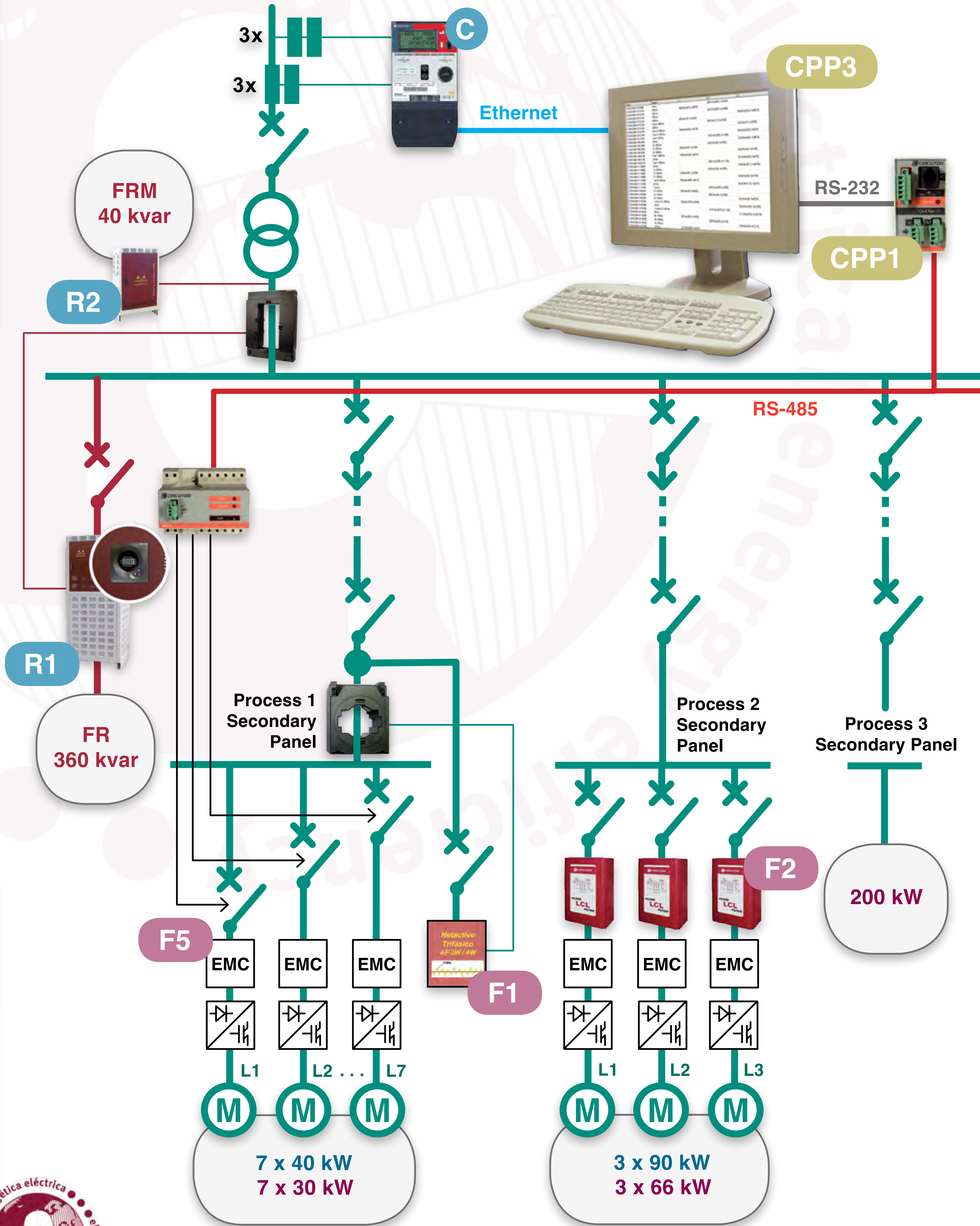
Coupling point			
1	A	1	**CIRWATT** meter
	B	1	**QNA 412** power quality analyzer
	C	1	external **ITF** module
Secondary panels			
4	A	1	**EDMk** submeter
	B	1	**TC** current transformer, cable output
	C	1	**WG** toroidal transformer
	D	1	**CBS-4/CBS-8** multipoint earth-leakage relay
5			**PowerStudio Scada** application
C1		2	HUB
C2		1	RS-485 converter / Ethernet **TCP2RS**
C3			RS-485 bus
C4			Ethernet bus



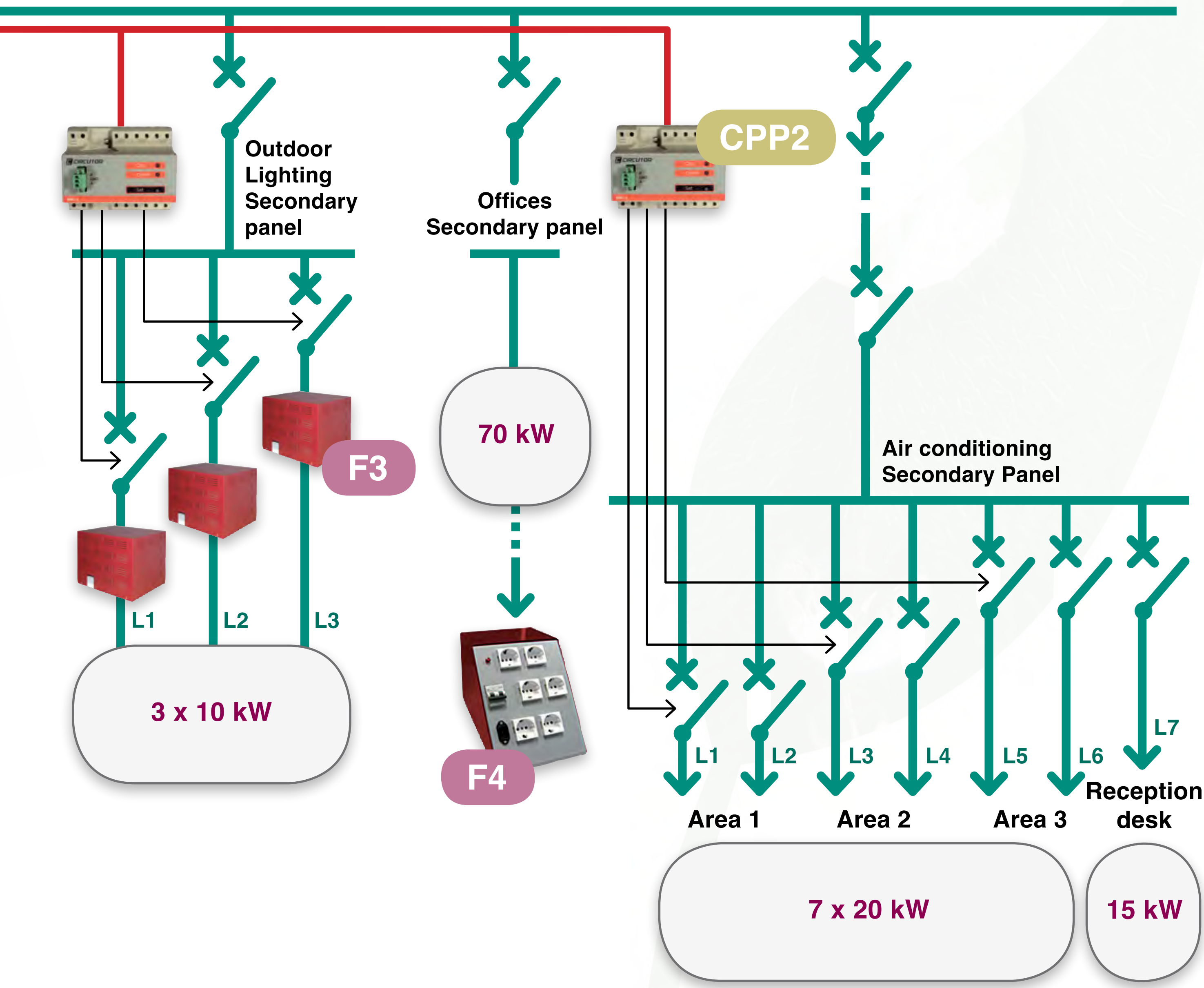


A
3x
3x
C
B
5
C
B
4x
A
D
C1
C1
E
LV general panel
3x
3x
C3
3x
C4
Outdoor
Lighting
Secondary
panel
Offices
Secondary panel
C2
Air conditioning
Secondary Panel
D
70 kW
L1
L2
L3
3 x 10 kW
L1
L2
L3
L4
L5
L6
L7
Area 1
Area 2
Area 3
Reception
desk
7 x 20 kW
15 kW

Demand management system



LIST OF MATERIALS	
R1	**FR** static capacitor bank with detuned reactors
R2	**FRM** Fixed capacitor with detuned reactors and circuit breaker
C	**CIRWATT** meter
F1	**NETACTIVE** active filter
F2	**LCL** filter for converters
F3	**FB3-T** three-phase third harmonic blocking filter
F4	**FB3** single-phase third harmonic blocking filter
F5	**EMC** filter for high frequencies
CPP1	**CA-4** load controller
CPP2	**MR-3** expansion modules
CPP3	**PowerC** software

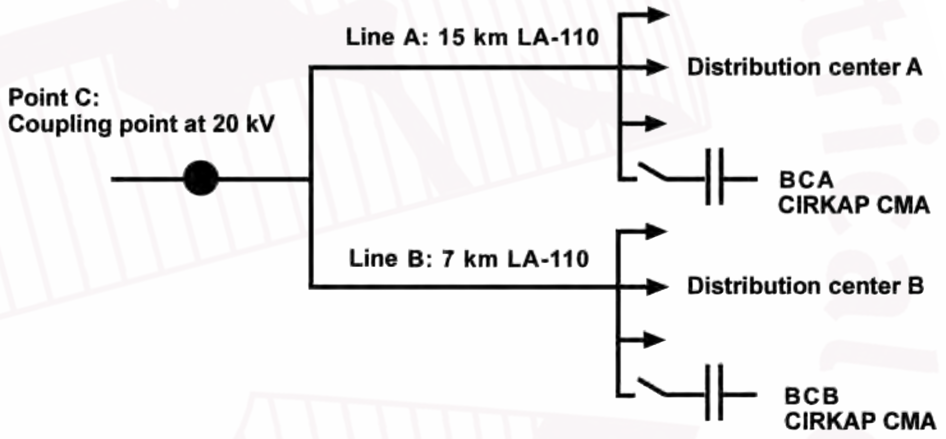


11.3 Example of e³ on a MV distribution network

Reduction of Joule losses in a MV distribution system

In the following example, it is studied the evolution of the losses level, and the voltage drop in an overhead MV distribution network, with and without a MV capacitor bank.

Concretely, the example deals with a MV line and two ditribution centers located in a rural area.



Power demands without capacitor banks connected

The demand state is as it is shown in the following datasheet:

	Coupling point C	Distribution centre A	Distribution centre B
Active power (MW)	7.39	2.7	4.39
Reactive power (Mvar)	3.70	1.23	2.13
Apparent power (MV·A)	8.26	2.97	4.88
cos φ	0.89	0.91	0.9
Joule losses (kW)	-	114.5	185
Reactive consumed by the line (Kvar)	-	129	208
Voltage drop (%)	-	5.2	5.25

As shown. the demand conditions in the coupling point are not good. The value of apparent power is high, and the value of cos φ is low.

Power demand with capacitors banks connected

To decrease the demand, a **CIRKAP CMA** bank of 1100 kvar at 20 kV is connected in the distribution centre A (BCA) and a **CIRKAP CMA** bank of 2000 kvar at 20 kV in distribution centre B (BCB).

The demand remains modified as can be observed in the following datasheet:

	Coupling point C	Distribution centre A with BCA	Distribution centre B with BCB
Active power (MW)	7.33	2.7	4.39
Reactive Power (Mvar)	0.54	0.13	0.13
Apparent power (MV·A)	7.36	2.7	4.39
cos φ	0.99	0.99	0.99
Joule losses (kW)	-	94	150
Reactive consumed by the line (Kvar)	-	106	170
Voltage drop (%)	-	3.9 %	3.8%

In this case, it can be observed that in C the conditions have become optimised in a substantial manner. In addition, the losses due to the joule effect have decreased, and the voltage levels have increased in the distribution centres.

In this way the operation and efficiency of the line have been optimized, and the level of voltage is guaranteed.

Active power calculation in C

$$P_C = P_A + P_B + Losses_{line\ A} + Losses_{line\ B}$$

Reactive power calculation in C

$$Q_C = Q_A + Q_B + Q_{line\ A} + Q_{line\ B}$$

It is important to point out the decrease due to the Joule effect. In fact, taking into acount A and B lines, the global losses have gone from 300 to 244 kW. It represents a decrease of 56 kW.

Depending on the number of hours, and obviously depending on the real demand of the lines, the economic and ecological costs reductions can be calculated.

Considering that for 8,760 hours per year the lines work at this demand level, it presents a losses decrease of 490.000 kw-h. Therefore:

- A hidden economic decrease of 39,200 €. The average price has been calculated at 0.08 €/kW-h
- An ecological cost reduction of 294 T of CO_2. (0,6 T of $C0^2$ = 1 MW-h)

It is true that the real demand of the network is variable and not always is a full load. So that, this example can be taken as approximated.

Application Notes

Technic **application** files

- Infrastructures
  - Aigües de Terrassa
- Industry
  - NUPIK
- Building
  - Universidad Pablo de Olavide
  - ZURICH
  - CIRCUTOR

12. PowerStudio Scada technic application files

12.1 Infrastructures application: Aigües de Terrassa

Application

- Company: AIGÜES DE TERRASSA
- Activity sector: drinking water collection, treating, pumping and ditribution
- Date: June 2006

Description of the activity

The water pumping station of “Aigües de Terrassa” develop the following functions:

- Treat and makes water apt for domestic, industrial, commercial and council use.
- Pumps the treated water to the heigth of the main distribution tanks.
- Supplies a population of, approximately, 240,000 inhabitants (Terrassa and surrounding towns).

Objectives

Control the efficiency of the plant and to follow up the processes.
Specifically:

- To control the basic raw materials:
  - Water (Extracted and Sent)
  - Energy (Contracted power around 3.5 MW, 6 periods)

- To improve the safety of the water treatment process:
  - Most accurate control in the addition of reactives: Redundant system

Description of the application

The developped application contemplates the following functions:

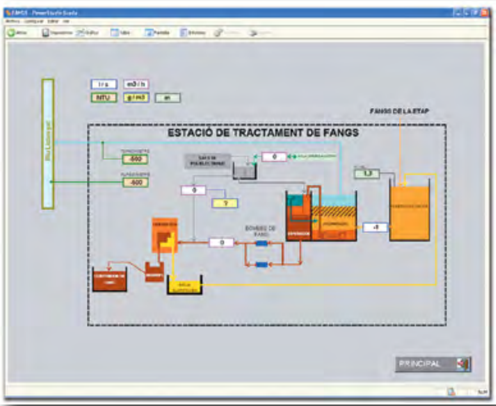
- Monitoring and registering of the water treatment and pumping processes:
  - Flows, reactives control, concentration of chlorines, pipe pressure , monitoring of sludge treatment from filtering
- Monitoring and register of the energy consumption of the plant:
  - Total and partial consumption of energy
  - Instant power of the plant and the main loads
  - Ratio between the power and the flow of the pumped clean water
  - Displaying and control of the earth-leakage protection
- To make reports and statistics
- Water and energy demand tables and charts
- Alarms

Results

- Operation cost control. Improve the ratio power/flow to increase the efficiency of the pumps
- Study and Monitoring of all the production data, such as reactive consumptions, operating ratios, etc.
- Reduction in the cost of the energy by the follow up of:
    - the energy consumption per each tariff, and pumping the maximum quantity of water in valley hours
    - the cos φ of the installation
- Improvement in Maintenance:
    - Detection of overloads in machines
    - Verification of the suitable flow for each machine
    - Verification of the non-return valves
    - Forecast of the preventive maintenance of the pumps after a certain number of worked hours
    - Verification of the electrical insulation

List of the used materials

Number of Equipment	Type:
40	**CVM BD** Network analyzers
3	**CBS-8** multipoint earth-leakage relays
10	**CVM R8-A** Network analyzers
4	**LM-24-M** pulse centraliser
3	**MRT** sets of radio communication equipment + antennas
4	**TCP2RS** ethernet converters
4	Amplifiers RS-485/RS-485
120	Current transformers **TC**



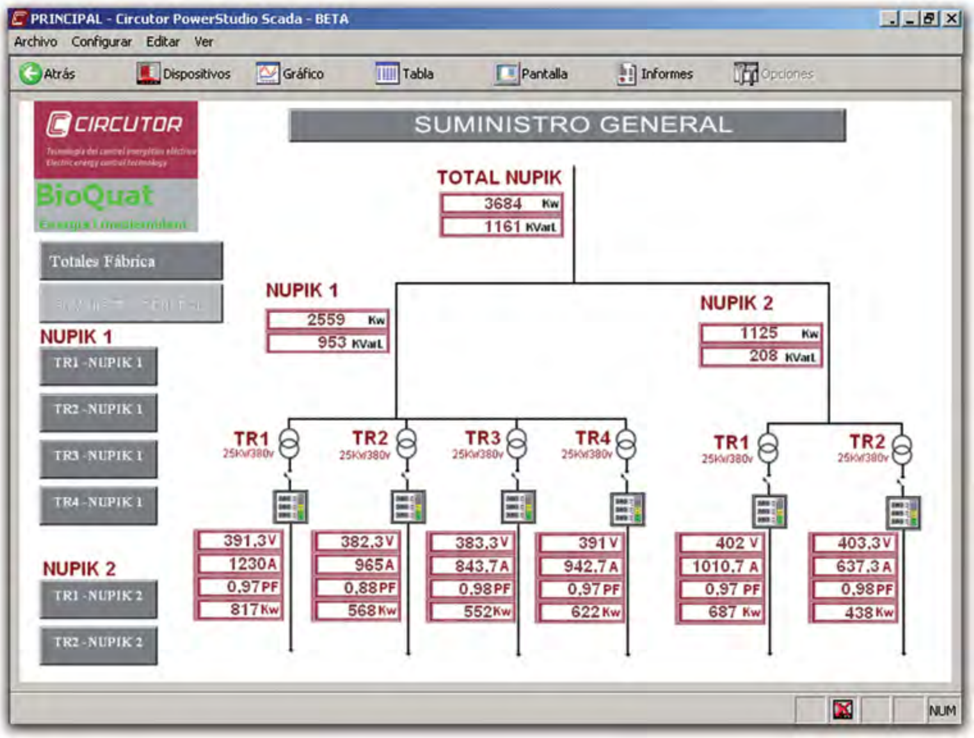
12.2 Industry application: NUPIK

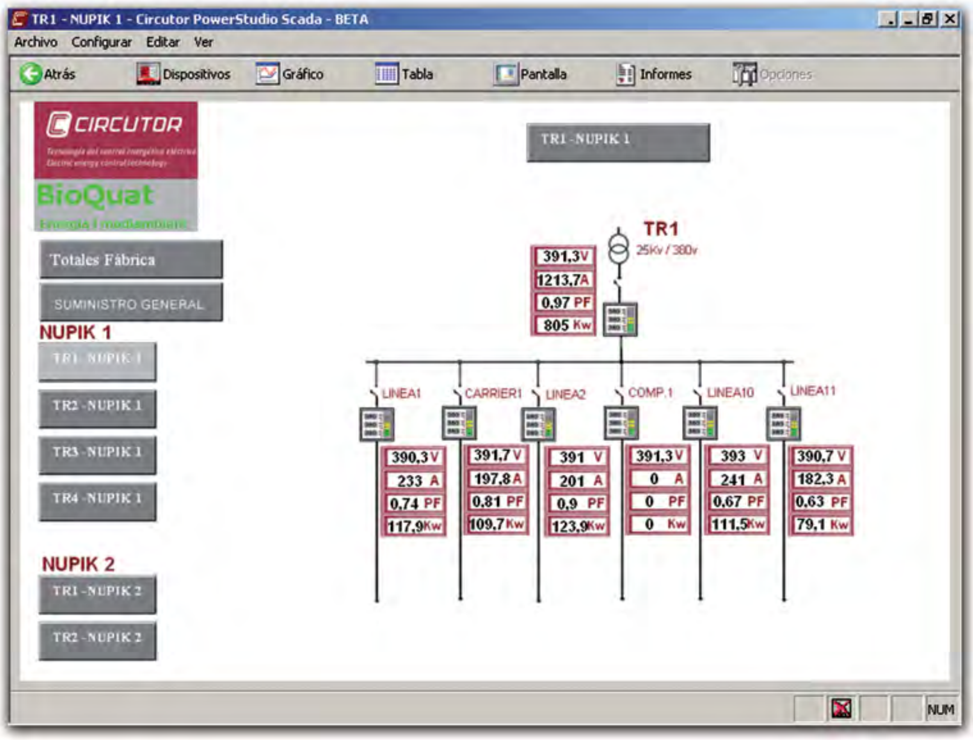
Application carried out

- Company: NUPIK
- Activity sector: Plastic thermoconforming
- Date: January 2006
- Developed by: BIOQUAT

Description of the activity of the company

Company dedicated to the design, manufacturing, and commercialisation of thermoconformed plastic, such as glasses, plates, and cutlery.





Objectives

The objectives for designing the application of **PowerStudio Scada** are:

- Energy management of the industry and the subsequent reduction in the cost of the electrical energy, by controlling the power factor, peaks of maximum demand and hourly energy consumption
- Charge of electrical energy costs per unit produced
- Automatic drawing up of electricity bill simulation reports and cost charges (departmental and marginal costs of products)

Description of the application

Application of **Power Studio Scada** by means a system of electrical energy management and costs charges of:

- 6 transformation centers
- Offices
- 13 production lines
- loading bay lighting lines
- Compressors and cooling units
- Warehouses

Results

- 5% reduction in the active energy consumption due to the information obtained from the **PowerStudio Scada** system. Mainly carried out through the production line control, avoiding running on empty
- Power factor optimization
- Correct charge of energy costs in manufactured products

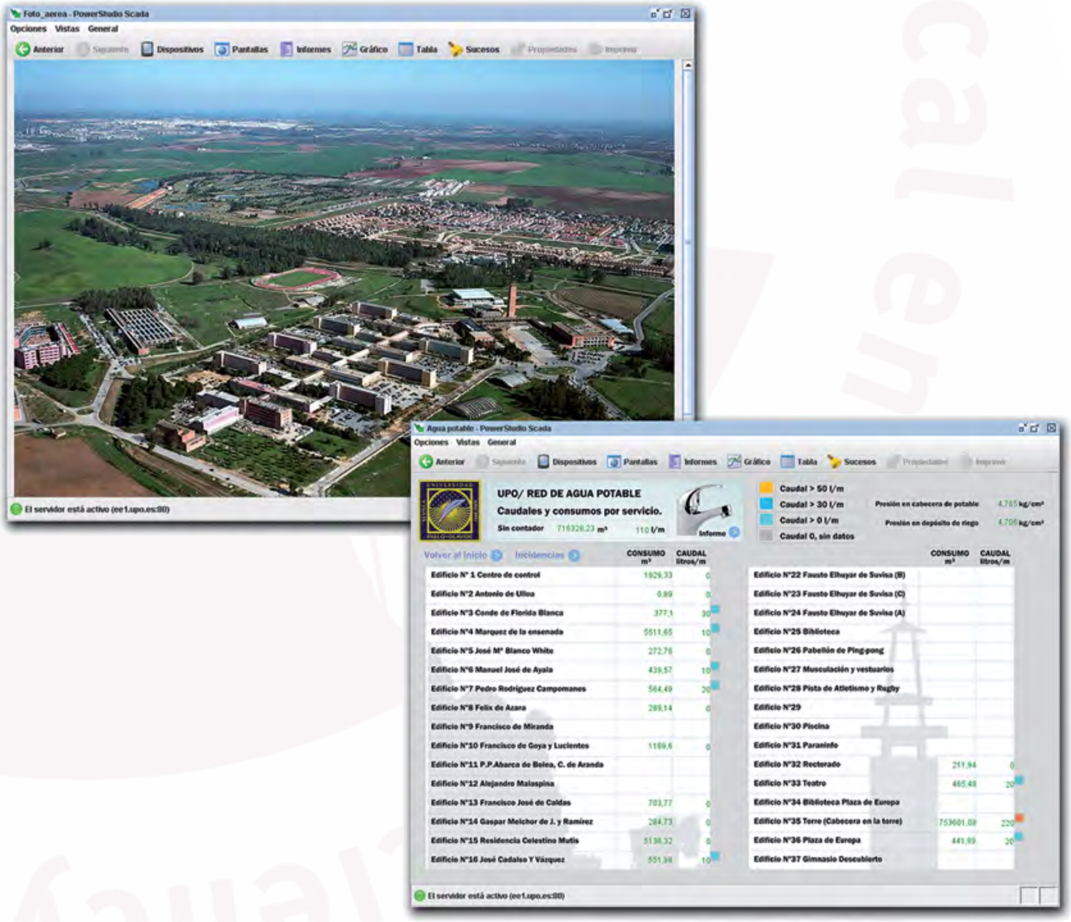
List of the materials used

Number of PowerStudio Scada	Type:
1	**PowerStudio Scada v2.5**
38	**CVM-k**
2	Ethernet converters
2	Amplifier RS485/RS485
114	**TC** Current transformer

12.3 Building application: Universidad Pablo de Olavide

Application carried out

- Company: UNIVERSIDAD PABLO DE OLAVIDE
- Activity sector: Teaching and research
- Update: November 2006
- Developed by: SERVICIO DE INFRAESTRUCTURAS



Objectives

Complete control of the installations of the campus within 45 buildings and a surface of 14 hectares, approximately 10,000 people among students, teachers, administration personnel and services.

- Consumption control for water, gas, energy, etc.
- Monitored maintenance of the installations
- Alarm management via SMS or e-mail of the incidences

Remote switching on and off of the installations by the maintenance services, security, concierge, etc.

Working tool for the students at the University as they can consult on-line the consumption data and the parameters of the different buildings in work-related studies.

Description of the application

- The **PowerStudio Scada** application contemplates the points described in the objective section for the different types of infrastructure :
  - Buildings : classes, library, halls, residences, etc.
  - Campus service: refectories, kiosks, sports, nurseries, etc.
  - Outdoor path lighting
  - Water network
  - Electricity network: transformation centre and distribution panels

For more information visit http://ee1.upo.es

Results Obtained

- Energy saving in approximately 40%, by stopping the installation thanks to presence control and the totally automatic management of switching on and off the installations
- Saving in the consumption of drinking water around 50% by detecting water leaks in real time and communicating the breakdown to service personnel via e-mail and SMS, for immediate action to be taken
- Greater efficiency in maintenance, doing more with less people. Saving on preventive maintenance due to the monitoring of the critical parameters in real time.
- Real use of the installations (transformers, cooling plants, etc.) due to the accurate knowledge of their real state, thanks to analizers and submeters
- Increase in the expectancy of life of the equipment. As the manipulation is generally automatic, it avoids misuses and sabotage

List of the materials used

Number of PowerStudio Scada	Type:
2	**PowerStudio Scada v2.5**
5	**CBS-4**
2	**CVM-144**
7	**CVM-96**
34	**CVM-BD**
5	**CVM-BC**
3	**CVM MINI**
20	**WGS** toroidal transformers

Number of Equipment	Type:
5	**CVM-k**
1	**CVM-NRG96**
56	**CVM-R8 (D-C) + CVMR10C**
6	**LM24M** concentrator
10	Ethernet converters
10	**MK** pulse container
4	RS-485/RS-485 amplifiers
339	**TC** current transformers

12.4 Building application: ZURICH

Application carried out

- Company: ZURICH
- Activity sector: Insurance
- Date: Updating June 2007
- Developed by: CYGESA INGENIEROS

Description of the activity of the company

Company dedicated to the commercialisation of different types of assurances for both, enterprises and individuals.

Objectives

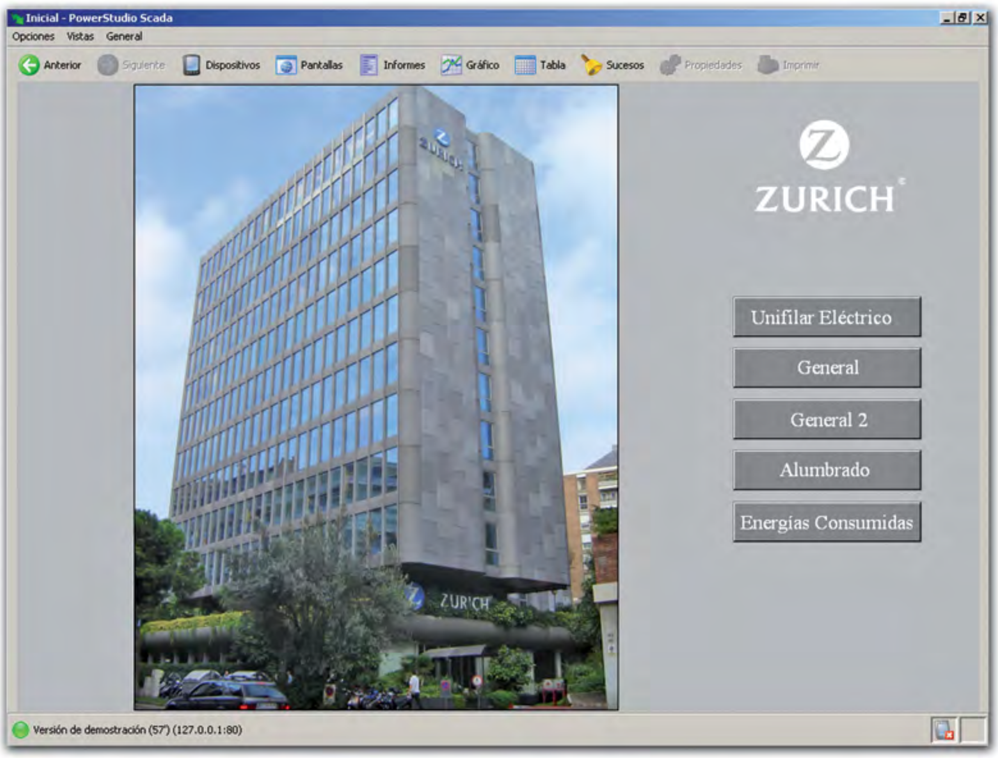
The objectives for designing the application of **PowerStudio Scada** are:

- Correct charge of energy costs per department and working area
- Energy management of the building and the consequent reduction of the cost of the electrical energy
- Control of the electrical power quality
- Technical management of the network, follow up of power for being able to manage the capacity of the installation

Description of the application

Application of **PowerStudio Scada** for having a system of electrical energy management and correct charge of energy costs. The monitored places are:

- Offices
- Computer rooms
- Machinery: lifts and conditioning
- Lighting
- UPS
- Power station



Results

The energy management system has provided details of the energy consumption by area, which has meant a greater awareness and a more rational use of electrical energy.

Charge of energy costs per department, thanks to the tool for drawing up energy reports on **PowerStudio Scada**.

Real time knowledge of the power demand, state of the power factor, incoming voltage, harmonic levels, etc.

The registered information and its consequent analysis have allowed to reach an energy saving around 25% regarding with the starting values.

List of the materials

Number of PowerStudio Scada	Type
1	**PowerStudio Scada v2.5**
23	**CVM MINI** network analyzers
1	Ethernet converters
1	Amplifier RS-485/RS-485
69	**TC** current transformer

12.5 Building application: CIRCUTOR

Application carried out

- Company: CIRCUTOR
- Activity sector: Manufacturer of electric material
- Date: Updating of the application September 2006

Description of the activity of the company

Company dedicated to design, manufacturing and commercialisation of electrical material for control and electrical energy efficiency

Objectives

- The objective for designing the application of **PowerStudio Scada** were:
  - Control of the power quality
  - Energy management of the building
  - Optimization of the electrical energy consumption
  - Charge of electrical energy costs per department

Description of the application

Application of **PowerStudio Scada** for having a system of electrical energy management and charge of energy costs, in the different areas of the company such as:

- Coupling point (measurement and power quality supply)
- Low voltage main panel
- Sections of the building:
  - Offices
  - Warehouse

- Workshops
- Kitchen and dining room
- General services
  - Outdoor and emergency lighting
  - Loading bay lighting lines
  - Conditioning machines

Results

- 11% reduction in the active energy consumption in the building
- Charge of costs to the different departments and factories existing in the facilities
- Harmonic filtering and monitoring of the evolution of the distortion rate
- Control and monitoring of leakage current
- Power factor correction

List of the materials

Number of	PowerStudio Scada
1	**PowerStudio Scada v2.5**
1	**QNA 412** power quality analyzer
2	**CVMk2** network analyzers
13	**CVM B/BD** network analyzers
1	**CVM B/BD** network analyzers
1	**computer C-14d** power factor relay
1	**DH 96** digital instrument
5	Converters
2	Amplifier RS-485/RS-485
1	**CIRWATT C 410-UT5C** meter
3	**CBS-8** centralizer
24	**WGS** toroidal transformer
48	**TC** current transformer
1	**TA** current transformer
1	**CIRVAC** capacitor bank

More information: http://powerstudio.circutor.com


Visit the new e3
website of CIRCUTOR
http://energyefficiency.circutor.com
http://eficienciaenergetica.circutor.es
http://eficienciaenergetica.circutor.cat
Electrical Energy Efficiency
CIRCUTOR
Introduction
What is it?
Documentation
Events
The current huge increase in energy requirements as well as the existing short-term forecasts show that there are a series of serious problems on a world scale:
Serious damage to the environment
Scarcity of fossil fuels
Repercussions on economies
There are basically two reasons which have given rise to this analysis. Firstly, the very high percentage dependency on fossil fuels such as the ones described below:
80 % fossil fuels
10 % traditional biomass
6 % nuclear energy
2 % water turbine energy
2 % renewable energy
Secondly, the use of 53% of the energy generated by 15% of the worldwide population. This means that there will be a huge increase in energy demand from emerging economies.
Therefore, there are two main areas of action in order to maintain current and future energy requirements, limiting the impact on the environment and economies:
That introduction of renewable energy
A more rational and conscious use of energy, or in other words, the need for strong Energy Efficiency policies
CIRCUTOR will give advice on of obtaining an electrical energy efficient installation
35 years investing in control and energy efficiency
What is it? | Why is it necessary? | How is this achieved?
Distribution system
Contract management
Measurement
Supervision and control
Demand management
Improving productivity
Financial optimisation
Technical optimisation
Days | Trade fairs | Press releases | Recommended links
2006
Municipal Energy Management Day
Energy Congress
Energy Efficiency
Energy Efficiencya
Energy costs, efficiency and savings
Savings and energy efficiency
2007
Saving energy