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WHITE PAPER ON MEDIUM VOLTAGE POWERLINE COMMUNICATION (PLC) NETWORKS

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(Broadband PLC)

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1.1 INTRODUCTION

It is undisputed that energy is a valuable good. Recent incidents such as energy supply shortages due to long-lasting heat periods in summer or large-scale blackouts (e.g. New York area 08/03, Italy 09/03, Sweden 09/03) due to overloads in the distribution grid clearly show how dependent modern society is on a reliable energy supply.

The current boundary conditions of the energy market are the following:

- Increasing demand for energy, especially electricity, due to the increasing "electrification" of life and despite the energy-saving progress of technology.
- Increasing costs for primary energy, especially fossil sources, as well as for the maintenance of energy supply equipment.
- A strong tendency towards liberalization, which increases the economical pressure on the energy suppliers.
- Minimize energy loss/leakage (intentional/non-intentional) and increase distribution efficiency.

The natural consequence of these boundary conditions is that the efficiency of energy production and distribution must be improved to benefit from costs savings. Only this will ensure survival in an increasingly competitive market environment. Apart from technological advances, one key to get an increased efficiency is information about the status of the distribution network and the available resources in a reasonably fine time resolution. In turn, this requires a suitable communication infrastructure to gather all relevant pieces of information and that is where PLC technology can help. This network must be aligned with the needs of energy distribution networks.

Power Line Communications (PLC) is a broadband access technology that uses the low and medium voltage electricity grid to provide telecommunication services. Using the existing electrical network infrastructure, it is now possible to design a telecom network to offer applications such as broadband Internet access, telephony over IP, multimedia and audiovisual services, in-home services and, of course, energy related applications.

During the last few years, global interest in PLC technology has been growing considerably. Between 2001 and 2004, over 100 trials in 40 different countries worldwide were successfully completed, confirming the viability of a PLC network and creating momentum to launch commercial initiatives. Both commercial and energy-related services have been tested during these trials.

The PLC industry is testing a new generation products (up to 200 Mbit/s) to be commercially available early 2005, increasing several times the bandwidth currently offered and providing new functionalities, thus improving performance and competitiveness of this technology.

1.2 CORE BUSINESS SERVICES AND APPLICATIONS

Electrical Distribution Companies operating in a competitive deregulated environment and facing up the previously commented boundary conditions, must combine costs optimization with customer and regulators requirements to improve Quality of Service (QoS) and Energy Efficiency.

Creating an Intelligent Distribution Networks may help to achieve this objective. One of the most important components of an intelligent grid is a bi-directional telecommunication network being able to work in real time. Broadband Power Line Communications over the MV grid as channel for general purposes could be essential in this challenge. PLC technology adds to the typical applications in the provision of communication channel for network automation, metering, surveillance, etc. the possibility of being used as a diagnostic tool to detect possible failure in cables, isolators, arresters and other MV infrastructure elements. This can be possible because the PLC telecommunication channel is the electrical MV power cable. It is easy to think in the thousands of kilometres of underground MV cables that are in use with a value of millions of Euro. Any extension of the lifespan of cables and to pass from a programmed maintenance scheme to condition based maintenance can save investment costs and increase QoS, this becomes more important when we are talking about dense urban areas.

One of the goals of a Power Line based Communication system is to create an infrastructure for energy management that should enable the enhancement of existing applications like automatic meter reading, distribution grid management and remote control. Therefore the system allows for direct communications at customer's premises via two stage hierarchical power line communication system and an IP (Internet Protocol) private network. Special aspects that are being considered in the system are network performance, security and system reliability.

Different utilities have built telecommunications networks based on MV PLC technology in more than two hundred transformer stations in order to analyze the behaviour of different applications running over this PLC network and verifying the capability to detect in advance an infrastructure failure (over common elements in MV network). Parameters such as availability, security, time response, integration with Distribution Control Centre Systems, among others, are under analysis. Also, an economical analysis is necessary to quantify profits in MV Network Operation, maintenance, knowledge in real time of the network, future integration of demand services prior to including the costs of massive deployment.

PLC technology has demonstrated its reliability and can help in the design, operation and maintenance of new medium and low voltage networks. More suitable implementations of these networks increase efficiency of energy production and distribution, increasing benefits from costs savings. Investigations on this area can aggregate new functions and services over the electrical network.

The electric power industry is moving in the direction of automating its distribution systems. Consequently, new security challenges will emerge. In the past, cyber threats from external intrusions and attacks were not an issue. Today and in the future, systems that use intelligent equipment and communications must incorporate security management to prevent disruptive attacks on newer controls systems.

1.3 COMMERCIAL TELECOMMUNICATION SERVICES

Among other characteristics, PLC networks can give these fully integrated services with the precepts of our "information society" requirements: reliability, high performance and universal access. Furthermore, using existing infrastructure allows a rapid network roll out, especially considering that PLC technology and equipment installation have evolved considerably during the past years.

The lack of alternative telecommunications infrastructure in Europe holds back competition from operators reducing the downward pressure on prices and therefore hindering Internet broadband penetration. During the past years, it has been difficult for new entrants to build and deploy their own facilities to end users with a national coverage, given the long lead times and return on investment.

PLC is an alternative access technology that could compete and/or complement existing access technologies in the market and could help the development of Information Society, helping to overcome the digital divide. Nevertheless, the window of opportunity is limited, varying from country to country depending on the competitive environment and broadband penetration.

1.4 CONCLUSION

Broadband PLC means a great opportunity for utilities, which would maximize the value of their core assets (the existing electricity grid), in several ways.

Broadband PLC could generate a new source of revenues by offering broadband Internet access, telephony and other value added services to existing electric customers. The broadband market is increasing significantly and constitutes the main driver of growth in the telecom market. PLC operators could take a portion of the broadband market, thus increasing the revenue per client for utilities.

Furthermore, Broadband PLC would allow utilities the introduction of applications able to improve the efficiency of their core business: automatic meter reading, network monitoring and management, etc.

2 INTRODUCTION

2.1 OBJECTIVE

The objective of this document is to describe the state of the art of Medium Voltage (MV) Power Line Communication (PLC) technologies as it is called in Europe, or BPL (Broadband over Powerline) as it is called in USA, topologies and deployments. This information shall help utilities use "best practices" when deploying MV PLC networks.

2.2 SCOPE

The document is focused only on MV PLC networks. Although in many cases, Low voltage PLC networks will be deployed in conjunction with MV PLC networks, LV PLC networks are not within the scope of this document.

This document describes the communication architecture, as well as the components and services that shall constitute a PLC network system, based on Medium Voltage electrical network. It first takes a look at a general description of a MV network and the different electrical topologies we can find. PLC networks deployed in Europe are also described as well as a deep description of the elements that build a MV PLC network. Aspects related to regulations and standards are also given.

2.3 BACKGROUND

This document has been elaborated under the framework of CIGRE SC D2 Working Group (WG) 14 "Broadband PLC".

This WG held its first meeting in July 2002 and was officially presented to the CIGRE community in the "2002 Paris Session" in August 2002. The two main lines of action defined for this Working Group were MV PLC and energy-related services based on PLC, finally only the first line has been developed during these three years.

WG 14 members are active professionals in the field of broadband PLC and work for electricity distribution companies and equipment manufacturers. The work developed in WG 14 aims to take advantage of the comprehensive view of the industry provided by WG 14 members.

3 THE MV ELECTRICITY DISTRIBUTION NETWORK

3.1 INTRODUCTION TO THE MV ELECTRICITY DISTRIBUTION NETWORK

Electrical power networks are composed of several different parts: power plants, transmission networks, substations, distribution networks and customers. Figure 1 shows a typical electrical power grid that can be divided into:

- Transmission grid (High Voltage)
- Distribution grid
    - Primary distribution grid (High Voltage)
    - Secondary distribution grid (Medium Voltage)
- Access grid (Low Voltage)

The transmission grid connects the production centres (power plants) with the High Voltage Substations. It comprises almost exclusively aerial lines at voltage levels from 220 to 400 kV. The distribution grid binds consumer installations and the national transport network.

Electric distribution networks are composed of a number of levels, typically two. Each level has a progressively reduced operating voltage down to the level supplied to the domestic consumer. This is a necessary requirement for the efficient transmission of electricity over long distances.

The first level, where MV-PLC is typically applied, is between 11 kV and 25 kV medium voltage (MV) network. The MV network distributes power directly to larger commercial/industrial users, and to domestic and small commercial consumers via a large number of distribution transformers, as it is shown in the following picture.

It is in these distribution transformers that the voltage is transformed from three phase 11kV to three phase 400V. The 400V network is very extensive, is known as the Low Voltage (LV) network and supplies 230V single phase to domestic consumers, depending on the country, and also supplies for 380V three phase clients.

PLC technology enables the use of the existing Medium Voltage and Low Voltage (LV) electrical grid as the transmission media to build telecom networks. In order to understand the behaviour of PLC MV networks, an analysis of the Medium Voltage Electricity Distribution Network is thus required.

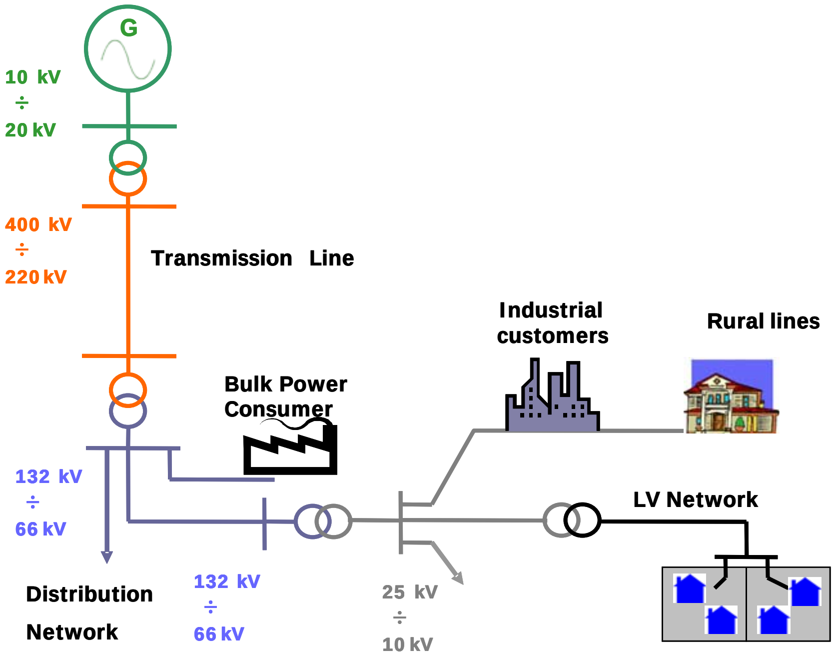


Figure 3-1 Basic Electrical Network Structure

3.1.1 Distribution Network Structure

European configuration of a medium-voltage (MV) distribution system is characterized by the widespread use of a three-phase, three-wire configuration where consumers are generally served by relatively few transformers of a higher capacity. Single-phase distribution relies on supplying loads with two rather than all three (phase) conductors. Only recently has single-phase distribution been more widely used for supplying rural areas. Single wire earth return (SWER) schemes are also in use in remote areas.

Utilities utilize various types of distribution systems to serve their customers with reliable and quality power. The most commonly used distribution system is a simple radial circuit that can be either 100% overhead or underground, or a combination of both. The following items summarize the most common distribution feeder characteristics and classifications:

1. The distribution voltage classes vary from country to country although some typical values are5kV, 15kV, 25kV, and 35kV.

2. The length of radial distribution lines can be less than a kilometre to in excess of 30 kilometres. This distance is from the substation to the furthest service point, not the total mileage of all branches.

3. A distribution line load can be as high as 600 amperes but the range of 300-400 amperes is common.

4. The short circuit duty at each distribution substation varies depending on the transformer size and the voltage class, but typical short circuit duties are on the order of magnitude of 10,000 amperes. This probably is a correct statement for many substations that supply “radial” distribution. However, for many urban area substations that supply low-voltage networks, three-phase fault currents on the substation bus are much higher, up to 40,000 amperes.

5. Distribution feeders include various control devices. The most common control devices are shunt capacitors to meet local VAR requirements or to support voltage regulation. Voltage boosters or voltage regulators are also used to maintain adequate line voltage. Series reactors can be employed to limit the fault current. An auto-transformer on the feeder may be used to change the distribution voltage class. Today, and probably in a short-medium future, most of the transformers which are used out on the feeders are two winding transformers rather than auto transformers. Early in these applications auto transformers were used, but it was difficult to obtain adequate through fault withstand with the auto transformers.

6. Multi-grounded, uni-grounded, ungrounded, resistively or reactively grounded distribution systems are some of the grounding techniques that are used in the industry. The multi-grounded four-wire distribution system and uni-grounded three-wire distribution systems are most common in North America.

7. Various protective devices are installed on distribution feeders to mitigate potential safety hazards to the public, prevent or minimize damage to equipment and improve service reliability by clearing an abnormal condition through removal of a small section of the circuit for a given fault. Protection of a distribution feeder consists of a circuit breaker at the substation with line reclosers, sectionalizers, interrupters and fuses at intermediate locations along the main feeders and laterals.

3.1.2 Urban – rural line differences

There is one major issue that differentiates the characteristics of Medium Voltage European Distribution Network (MVEDN): its urban or rural nature. Urban networks are usually short and underground; rural networks are usually long (but not necessary overhead: some European countries are changing from aerial to underground in rural networks).

The structures of MV network are mainly meshable, so that feeders can be back feed by adjacent lines. Urban networks are almost completely meshable, but that is not the case of rural networks for obvious reasons of cost. The percentage of rural networks that can be back feed varies between 50% and 90%.

3.1.2.1 Primary substations

Primary substations (HV/MV substations) have generally from 1 to 4 power transformers. Two transformers is the most typical framework.

The average number of MV feeders per substation varies between 4 and 20, most typical values being around 10. Usually we find differences in the typical numbers of feeders of rural and urban substations, but the trends are different from one utility to another.

3.1.2.2 MV feeder profile

Rural MV feeders are much longer than urban MV feeders. Average values vary from 10 to 35 km for rural feeders, and from 3 to 10km for the urban ones.

Regarding the typical load of a MV feeder, there is no obvious trend to differentiate urban and rural lines. Some utilities design rural feeders more loaded than urban ones, other utilities do the contrary, and sometimes there is no significant difference. Typical loads of rural feeders vary from 1 to 8 MVA while typical loads of urban ones vary from 1 to 10MVA.

MV networks are almost always 3-phased but exists some areas where the utility use 2-phase branches to feed low-consumption rural areas.

3.1.2.3 Secondary substation

The average numbers of secondary substations (MV/LV) per MV feeder are different for rural and urban feeders:

- Averages from 5 to 15 secondary substations per urban MV feeder
- Averages from 5 to 50 secondary substations per rural MV feeder

The average number of LV customers by secondary substation varies from 40 to 200, the maximal number being always under 500.

3.2 MEDIUM VOLTAGE FEEDER TYPE

The MVEDN is generally a mesh network composed of several rings of Medium to Low Voltage Transformers connected to the High to Medium Voltage Substations. Generally, either a Ring topology or a T-topology can be found. The next figure shows a typical ring MV feeder opened in the middle:

Points of connection to the medium-voltage networks are either customer-owned stations supplying a direct customer at medium-voltage, or MV/LV substations for the supply of low-voltage customers.

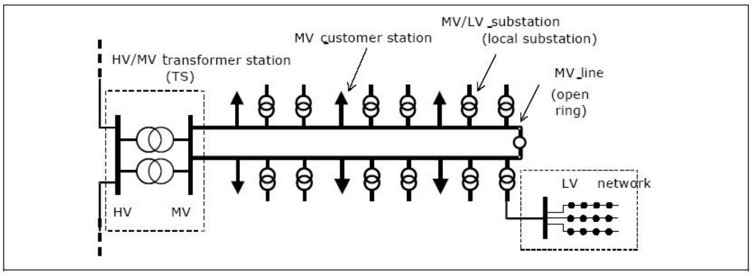


Figure 3-2 Basic structure of medium voltage-network

Looking inside MV/LV substation we can find this scheme in basic ring topology:

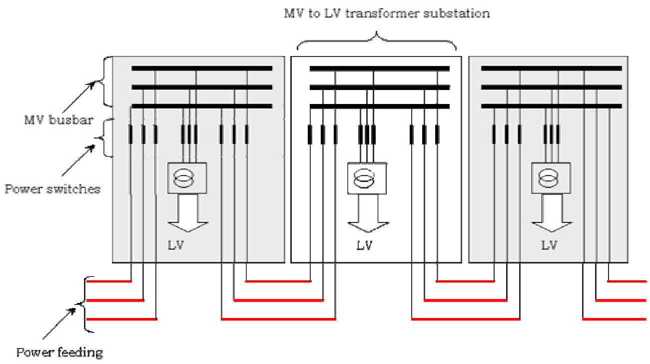


Figure 3-3 Basic ring topology of medium voltage-network

A bit more complex structure in MV consists of adding a secondary ring to give redundancy to all MV network ring:

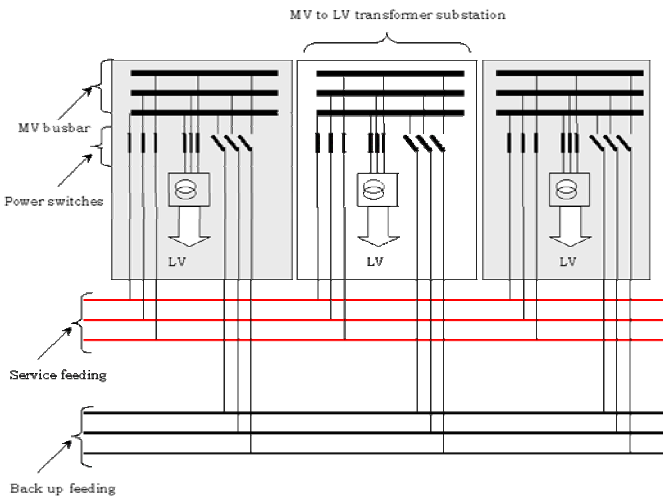


Figure 3-4 Redundancy ring topology of medium voltage-network

The topology of MVEDN networks may vary from country to country and a thorough analysis of the specific topology of the country will be required.

Using the MVEDN as the transmission media to build telecom networks has advantages and drawbacks. For example, one of the main advantages is that MV PLC telecom networks use the inherent redundancy of the MVEDN to build a high redundant telecom network.

3.3 ELEMENTS OF A SECONDARY MEDIUM VOLTAGE NETWORK

The main elements of the MVEDN that will have an impact on the MV telecom network to be deployed are: type of MV cables, MV/LV transformers and MV cells. Therefore a description of the different types of these elements is required.

3.3.1 Description of MV cables

The medium voltage cables can be classified according to several criteria:

- According to the number of conductors inside the cable: single or multiple.
- According to the material of the conductor: Copper, Aluminium
- According to the type of insulation: XLPE, EPR, Oil paper

For more information, see Annex A.

3.3.2 Description of MV/LV Transformer Stations

A MV/LV transformer is where the transformation from medium voltage to low voltage is done. The main elements that can be found in these substations are the transformer, medium voltage lines and medium voltage line cells, transformer protection cells, low voltage bus-bars and feeders, protection elements, measurement elements, and earth network.

Transformer substations can be firstly classified into:

- *Indoor* MV/LV transformer stations
- *Outdoor* MV/LV transformer stations and
- *Underground* MV/LV transformer stations

A second classification can be made depending on the size of the transformer station:

- *Air* transformer stations
- *Modular* transformer stations and
- *Compact* transformer stations

RING MAIN UNIT – RMU

A ring main unit is a typical topology configuration in electrical distribution networks, composed of 2 feeders and 1 Protection function, as shown in the following figure:

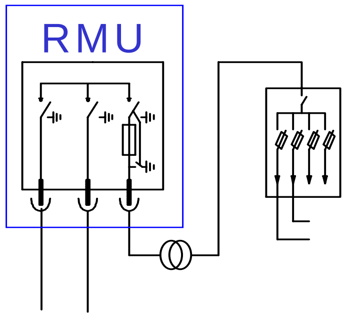


Figure 3-5 Ring Main Unit diagram

For more information, see annex A.

3.3.3 Description of MV cells

MV cells are usually comprised of: switchgear compartment, bus-bar compartment and connection compartment.

3.3.3.1 Switchgear compartment

The Switchgear compartment is separated from the bus-bar compartment and the connection compartment by the enclosure surrounding the switch, the disconnector and the grounding switch.

Some of the switches that can be found are:

- Oil insulated switches
- Pneumatic switches, based on compressed air
- Magnetic blow-out switches
- Sulfur Hexafluoride (SF6) switches
- Vacuum switches

Some gases, like SF6, have dielectric properties and it is much better than air and oil insulator. Its dielectric properties, as well as its behavior when arc happens, make SF6 becomes the most outstanding insulator and arc extinguisher.

3.3.3.2 Bus-bar compartment

The bus-bars interconnect all the switchgears and the transformer. The bus-bars can be air insulated or SF6 insulated.

3.3.3.3 Connection compartment

The network cables are connected to the terminals of the switch, to the lower fuse holders or to the connection pads of the circuit breaker. The PLC signal is injected at this point.

4 THE PLC MV NETWORK

Broadband Power Line Communications (PLC or BPL) have been heralded as the "3rd wire" to every home. Recent activity has indicated this technology is just on the threshold for achieving commercialization, with numerous pilot trials, demos, and limited deployments underway around the world.

PLC is not a new technology per se. Utilities have been transmitting communications signals over power lines for many decades, mainly for control purposes. The signals usually operated at kilohertz ranges, and offered only modest transmission capacity, sometimes less than a kilobit per second. However, a relatively new idea has been to transmit broadband signals for communications purposes, i.e., broadband over power lines (BPL). Power lines are attractive at one level because of their ubiquity and connectivity into virtually every end-user premise. The technology is fundamentally based on modulating and demodulating information off a carrier signal which operates at high frequency ranges. Typically, the physical layer and coding is based on Orthogonal Frequency Division Multiplexing (OFDM), and sometimes spread-spectrum techniques. OFDM offers not only spectral efficiency, but also robustness against interference, a major concern in noisy electrical networks. Based on Shannon's Theorem, which indicates greater data carrying capacity with greater bandwidth availability, most modern PLC solutions operate with a carrier frequency range somewhere in 1-30 megahertz (MHz).

Access PLC systems carry high-speed data and voice signals outdoors over the medium voltage line from a point where there is a connection to a telecommunications network. This point of connection may be at a power substation or at an intermediate point between substations, depending on the network topology. Near the distribution point to a residential neighbourhood, a coupler or bridge circuit module is installed to enable the transfer of high-frequency digital signals across the low voltage distribution transformer. Finally, the high-speed communication signals are brought to the home over the exterior service power cable from the bridge across the distribution transformer, either directly, or via an Access PLC adaptor module.

PLC technology suits perfectly to mesh topology MV networks. Its adaptability and flexibility makes PLC the best choice to deploy a utility's telecommunication network using power lines. PLC system can be deployed in cell-like fashion over a large area served by existing MV lines, installing repeaters wherever is necessary to cover the desired area.

Internal utility applications can use PLC networks to manage operations over MVEDN. Power plants, electrical components and other assets can be monitored using PLC. Moreover, precise diagnosis of faults can be achieved due the inherent capacity of the PLC network to collect a huge volume of data.

The control centre can constantly receive binary information, measured values, commands and counter values over the entire area over which the PLC is deployed..

The advantage of PLC systems quite clearly lies in their independence of telecommunications service providers, and their use of MVEDN as a free-of-charge communications medium. All kind of applications can be added over this "transparent" communication system, letting utilities growing **intelligent MV network** on their own.

4.1 ELEMENTS OF A PLC NETWORK

A typical architecture for a PLC Network is shown in the following figure:

Figure 4-1 Typical PLC network architecture

The architecture will be constituted by three main sections:

- Access Network: based on Low Voltage PLC technology
- Distribution Network: based on Optical Fibre primary ring (option for network resilience) and Medium Voltage PLC secondary rings or branches.
- Interconnection point with the WAN.

4.1.1 MV Nodes

MV nodes can be installed on utilities' premises that have access to the MV lines, typically MV-to-LV transformers or HV-to-MV transformers. One or more of the transformers must be connected to a WAN link in order to gain access to the backbone network. The other transformers are connected to the backbone through their MV links.

4.1.2 MV Nodes with integrated LV Head End

This type of MV Node provides connectivity to both the MV and LV networks.

4.1.3 Low Voltage Communication Equipments

Although this type of equipments is not the objective of our document, a brief description is needed for clarifying the interconnection between MV and LV networks:

- LV Controller: Injects the signal coming from the backbone over the power line grid.
- LV Repeater: Improves PLC coverage by means of repeating techniques, and allows in-home LAN applications if needed.
- LV Customer Premises Equipment: Has the suitable interfaces to connect to the user's applications.

4.1.4 Medium Voltage Couplers

MV Couplers are those necessary elements for connecting MV Communication Equipment to the MV line:

Figure 4-2 MV coupler

- PLC signal is usually injected at one of the three phases of the MV line, and received on the same phase at the other end of the line, although other methods to inject the signal are being tested. Typical coupling scheme is phase-to-ground, but in some cases it is useful to use a phase-to-phase coupling scheme.
- Normally the MV Coupler is installed before the switchgear in order to have a communication channel independent of the operation of the MV electrical system.

Different types of MV Couplers will be widely described in chapter 6.

4.1.5 Description of PLC modem technology

The main issue PLC systems have to face is the broadband data transmission over a electrical grid that has inherent interferences and perturbations within the frequency range from 1.6 MHz up to 30 MHz.

In order to overcome this, two different modulation techniques have been used for the time being, depending on the technology manufacturer.

The first approach, used in first generation equipments, is Direct Sequence Spread Spectrum (DSSS). The basis of this technique is the use of "codes" that, combined with the signal result in the spread of it, keeping the spectral power density very low. The channel is shared by all the equipments using time division, as well as for transmission and reception, that cannot be done simultaneously.

The second approach is OFDM. This transmission technique has been used for first generation equipments as well, and it is widely used in second generation PLC equipments as it is the most efficient proven technique for PLC. It is based on the use of multiple sub-carriers with orthogonal multiplexing. An OFDM system enables adaptive bit loading per sub-channel, which capacity is defined by its Signal-to-Noise Ratio (SNR). Each sub-carrier of an OFDM system can be masked adaptively, enabling to avoid using noisy or distorted sub-channel for keeping proper bit error rate, and to avoid undesirable interferences. First generation equipments using OFDM have split the PLC spectrum into bands to allow frequency re-use for concatenated MV PLC links. Inside each band, there is also different frequency allocation for upstream and downstream. The second generation equipments improve this feature by avoiding upstream and downstream frequency split. The possibility of using either several bands for frequency re-use or just one band in time division is also added.

The physical bit rates achieved with 1st generation PLC modems stretches from 2.5 Mbit/s up to 45 Mbit/s. 2nd generation equipments are expected to provide up to 200 Mbit/s.

4.2 PLC NETWORK TOPOLOGIES

Typically, point-to-point links are established in each line from transformer to transformer, as it is shown in the following figures:

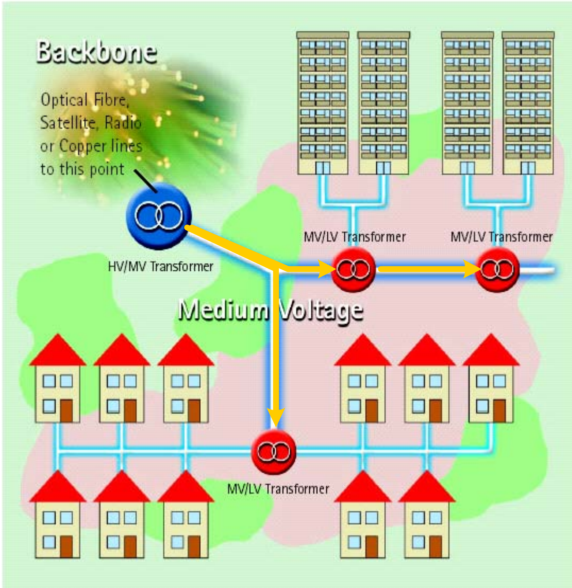


Figure 4-3 Point-to-point links between Transformers

In certain topologies, point-to-multipoint is also possible from one transformer to several transformers, thus reducing investments.

When deploying Frequency Division Duplexing (FDD) systems in either of the topologies, actions (e.g. frequency plan, filters,...) for frequency re-use, case has to be taken in order to avoid interference between neighbours links. Attenuation per meter increases with frequency, so it is better to reserve low frequencies for long distances and high frequencies for short distances.

When deploying Time Division Duplexing (TDD) systems in either of the topologies, actions must be taken to optimize time re-use.

4.3 MV PLC NETWORK LIFE CYCLE

During a first deployment phase with a low number of customers, in hundreds or even a few thousands, all areas can be provided with MV PLC with very low initial investments (only the cost of the equipment associated).

Higher capacity optical fiber is installed only on those selected areas in which the high number of customers, tens of thousands, is saturating the MV links. The risk of higher investments is equal to zero, because the customer base is already guaranteed in those areas.

All the areas with a low number of customers will be served by MV links, and costly investments will never be necessary.

It can be said that the expected performance increase in MV technology allows delaying optical investments “forever” in some areas.

4.4 ADVANTAGES OF MV PLC TELECOM NETWORKS

The main advantages of PLC MV Telecommunication solution are:

- It requires no new deployment or infrastructure for the utilities. They only need to install PLC equipments.
- It avoids civil works, and consequently the associated expenses and delays.
- It avoids dependency on telecommunication operators (incumbent or not).
- It allows a very rapid deployment, and thus time-to-market.
- Costs are moderated:
    - Even for high density areas, MV PLC has enough bandwidth for providing broadband services to several hundred users.
    - Investments in optical fiber can be delayed up to the time in which MV PLC does not provide enough bandwidth
    - Optical fiber is only installed when a high number of customers have already joined the service (guaranteed revenue).

Just now the industry is being activated in order to improve the capabilities of the Medium Voltage PLC solutions and in order to obtain coupling methods for every Medium Voltage grid, without having any effecting in the main purpose of the electrical grid (the distribution of electrical energy).

These informal remarks sum up some observations that have been made from measurements being made since early 2000 in all the deployments and trials.

4.4.1 Overhead MV PLC

The characteristics of overhead lines include essentially loss less insulation and large effective conductor cross-section, leading to low dissipative loss. Attenuation, termed “path loss,” is due to coupling impedance mismatch, radiation and energy reflection and absorption at points of attachment of lumped impedances and at branches.

For overhead lines, couplers must not only operate safely at the nominal operating voltage and current, but must also pass a series of stress tests, be user friendly to linemen, and be designed for long term outdoor use. Stress tests include dry and wet continuous voltage withstands, Basic Impulse Level (BIL) pulse tests, and partial discharge or radio influence voltage. To be user friendly for installation on live wires, the mechanisms must be linemen-tested for gloved and hot-stick installation, and safety procedures must be in place to allow verification of coupler insulation during the installation. Failsafe design must insure that coupler failure does not allow fault current to flow to modems or other sensitive entities.

4.4.2 Underground MV PLC

Underground medium voltage cables are mostly insulated with XLPE (Cross-Linked Polyethylene) or EPR (Ethylene Propylene Rubber). XLPE cables have very low attenuation and resemble rf coax, while EPR has an attenuation which rapidly increases with frequency and is usable only over short lengths.

Inductive couplers can be placed on energized insulated phase conductors without interrupting power, or at various points involving the neutral conductor. Thus, the coupler itself does not have to be heavily insulated and can be relatively compact and inexpensive. The low impedance of underground MV cables, typically in the 20 to 40 ohm range, also facilitates efficient inductive coupling and a low value of low frequency roll-off. Distances on XLPE may exceed one kilometer without excess path loss.

Inductive couplers are not exposed to the full fault energy of underground lines, such at the energy of the charge on the cable’s considerable capacitance. Thus, they are inherently safer for placement at pad-mounted distribution transformers covered with thin steel covers and placed in residential lawns and gardens. Inductive couplers are typically placed on energized MV cables adjacent to an elbow connector by a lineman wearing gloves.

5 DEPLOYMENTS

5.1 INTRODUCTION

Main Utilities all around the world have developed some PLC trial and initiatives. It is difficult to be very precise, but one can safely say than up to 100 PLC deployments have been deployed since 2000.

The following picture shows major part of these deployments:

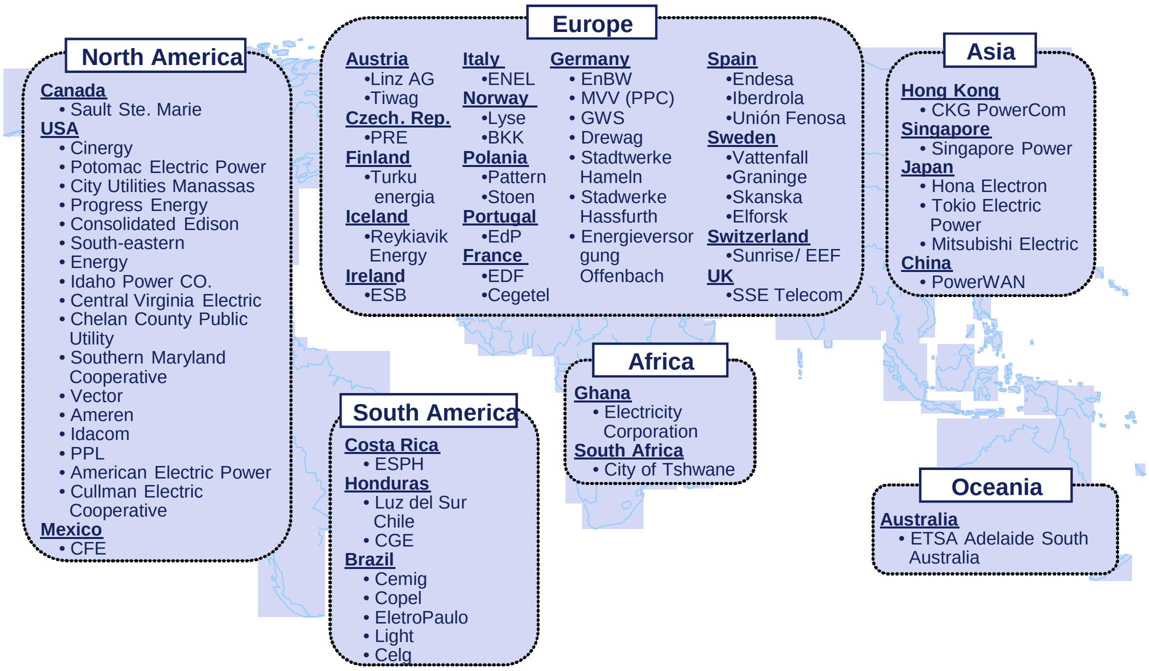


Figure 5-1 Worldwide PLC Trials and commercial initiatives (not exhaustive). **Source: White Paper on Powerline Communications (PLC) 2004 (PUA).**

5.2 DEPLOYMENTS IN AUSTRIA

The first commercial PLC installation with 4000 end users was installed in Linz, Austria. The operator of the PLC network in Linz is LINZ AG. LINZ AG is the Power Utility of the city of Linz. Supplier of the PLC equipment, including electronic and coupling devices, is Power Plus Communications from Germany.

LINZ AG is operating 11 MV PLC lines in Linz. The lines are used as backbone for the installed LV PLC System. Most of the lines are installed in the 20 kV MV grid with capacitive couplers of PPC. There is also one PLC link installed on a 30 kV MV line with inductive couplers of Eichhoff.

5.3 DEPLOYMENTS IN FRANCE

On March 2003, Electricité de France (EdF) had four MV PLC links working on MV underground cables.

The maximum distance achieved with maximum throughput is 400 meters, with 5 Mbit/s upstream and 6 Mbit/s downstream.

At this moment EdF is only allowed to install inductive couplers, although EdF is working in order to obtain permission to use capacitive couplers similar to those used in other countries.

The following details are related to some deployments made by Electricité de France (EDF) and updated March 2004.Two types of areas have been equipped to test PLC technology on MV and LV networks: in urban dense area and in rural area (digital divide zone).

- The first area, urban dense, includes the city of Courbevoie (Paris suburban area) and 100 MV/LV transformer substations have been equipped. They use inductive core couplers only, and the substations are linked together in a MV T-structure network (also called in French “double derivation”).

  This corresponds to 1000 users using M@in.net modems based on spread spectrum technique (TDD), are used on the LV side, whereas M@in.net modems based on OFDM technique, are installed on the MV side.

  Some data throughput tests have been performed and 3 to 5 Mbit/s are obtained on the MV side, between two interconnected subestations.

- As far as the rural area is concerned, EDF tests in La Manche (Normandie region) and in Vercors (close to Grenoble). In total, there are around 10 MV/LV substations equipped. These substations are linked in a ring structure. The coupling technique is the same as in Courbevoie.

Note: none of these sites are using capacitive coupling, since EDF – D EGS (The distribution part) doesn’t allow the installation of capacitive core coupling units. This is why only inductive clamp couplers are installed.

The main technical drawback we have noticed that clamp coupler’s performances depend on power switches which may happen quite often on the network. Nevertheless, a solution to this problem consists in introducing an additional amplifier between the clamp coupler and the modem.

5.4 DEPLOYMENTS IN GERMANY

In Germany around 10.000 end users are using already commercial internet services over LV-PLC.

85 % of the end customers are using the PLC-technology of Power Plus Communications AG (PPC). This technology based on the PLC – System of Main.net Ltd. Israel.

PPC is system integrator for Powerline equipment and has on March 2005 in several commercial and test installations all over Germany 103 MV PLC links have been installed for a number of operators.

In Germany, Medium Voltage Powerline will be used in most cases as backbone in the LV PLC network for substations, which have no direct connection to the fibre backbone.

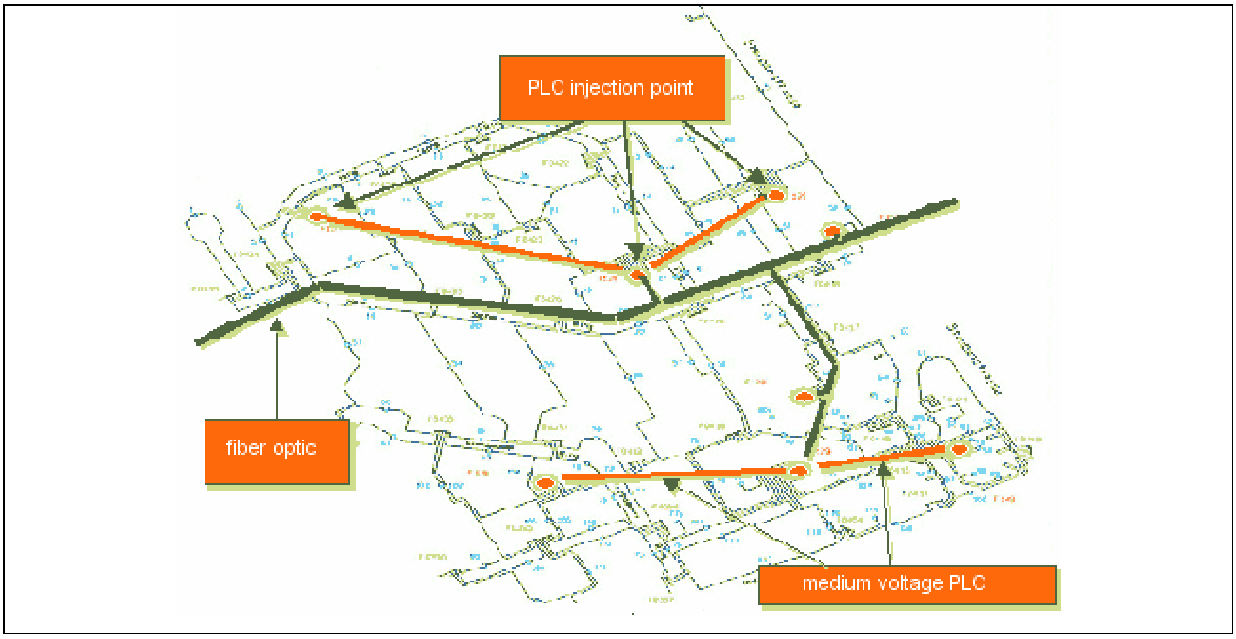


Figure 5-2 PLC architecture network in PPC´s deployment

80 % of the lines are used as backbone for an installed LV PLC System and 20 % as rented or least lines for professional industrial customers.

101 of the lines are realized with different types of capacitive coupling devices of PPC. In two test installations, inductive couplers supplied by Eichhoff have been installed.

PPC has equipped a wide spectrum of MV cells with PLC equipment. The MV cells differs in Voltage range and insulation of the cell itself. The Voltage range varies from 6 – 30 kV.

The pictures below are showing typical MV PLC installations in Germany for air and gas insulated (SF6) cells equipped with capacitive couplers.

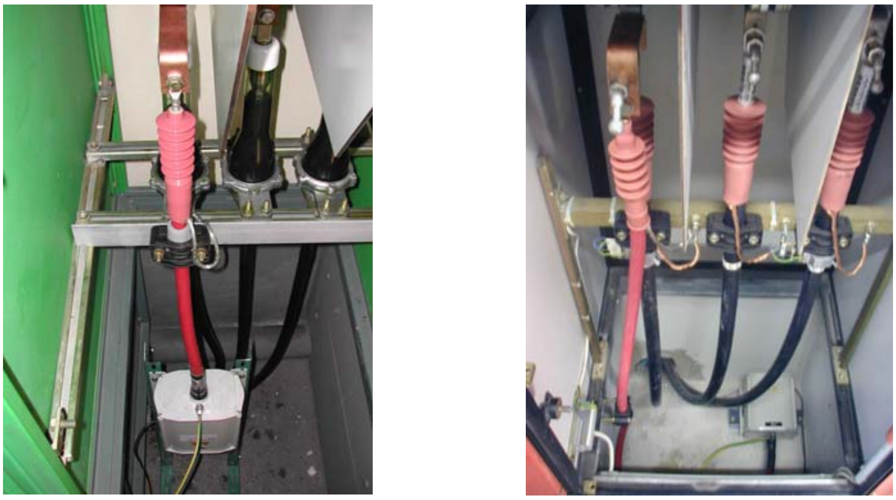


Figure 5-3 Capacitive coupling in air insulated MV cells

Figure 5-4 Capacitive coupling in gas insulated MV cells

The maximum throughput is 3 -5 Mbit/s depending on line condition.

5.5 DEPLOYMENTS IN PORTUGAL

In December of 2002 EDP/ONI started a technical pilot to test the Powerline technology provided by DS2. The Pilot was implemented in two major residential areas of Lisbon, EXPO and TELHEIRAS.

The first area is a new buildings area and the second is an area with buildings that have in average 15-20 years.

The overall project has the following coverage:

- 1.560 homes passed

- 286 clients connected.

All clients have voice and internet connection and the voice switching is supported by a Softwitch from SONUS. This VoIP switching structure is then connected to the class 5 PSTN (Public Switched Telephone Network) switches from ONI. The SONUS platform supports all the VoIP traffic from the business and corporate clients from ONI.

The Telheiras area is currently connected to ONI's backbone via the Medium Voltage solution. Only one of the 5 Transformer stations is connected via Fiber Optic cable.

The MV network includes 4 MV Links, working on different frequencies (see figure 5 - 5).

In the EXPO area the transformer stations are connected via HDSL (High bit-rate Digital Subscriber Line) lines to the HV/MV substation (see figure 5 - 5).

The maximum MV distance used in the pilot in the Telheiras area is 442m (with one transformer in between but without MV repeater) with an average PLC (physical layer) bandwidth of 34Mb/s (with 23Mb/s down and 11Mb/s up). The IP bandwidth is a few Mb/s lower than this value.

For the Medium Voltage links the average delay in IP transmission is 10 ms with a small jitter. This proved to be quite good for the support of voice and data transmission over IP.

Although in the pilot only capacitive couplers were used, in the electrical grid of EDP there is already a lot of circuit breakers with modular SF6 blocks. Therefore inductive couplers are very important.

The MV cables are underground lines, the most typical MV lines inside Portuguese cities. The coupling method used for the MV network was capacitive.

Additionally there is also MV test link of 400m that we use for the testing of various types of equipments and couplers.

The equipments tested were provided by Sumitomo, Mitsubishi and Toyocom.

The couplers tested were provided by Eichhoff, Arteche, DS2 (all inductive) and DIMAT/Ormazabal (capacitive).

The tests made with inductive couplers produced results which are 10-20% worse than the capacitive couplers. These results were measured both in terms of FTP traffic and UDP traffic.

At the moment the MV network in the pilot is running with no major problems and with good stability.

The following picture shows the MV architecture:

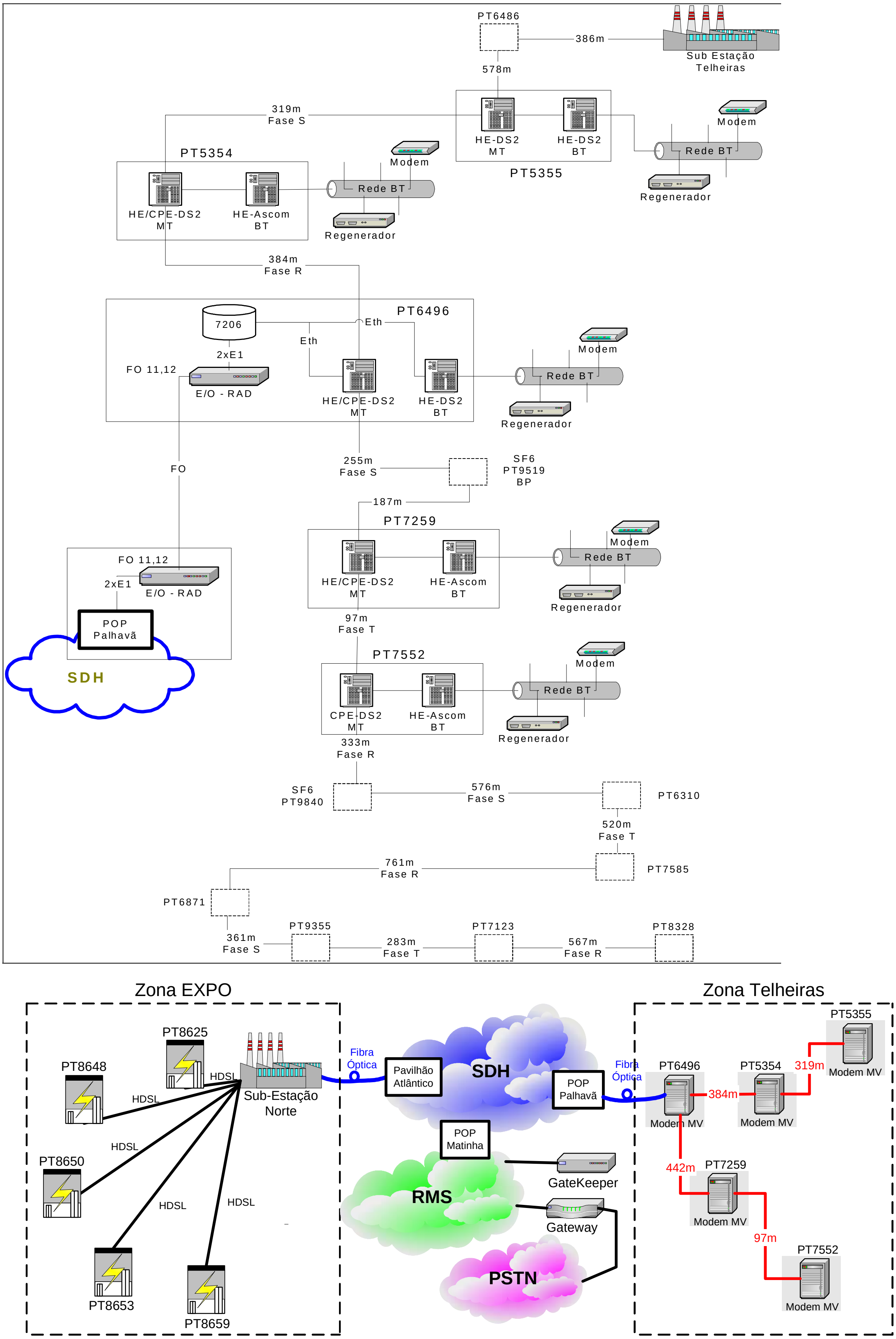


Figure 5-5 Overall pilot architecture

5.6 DEPLOYMENTS IN SPAIN

In Spain, three of the main utilities deploy access PLC: Endesa, Iberdrola and Unión Fenosa.

5.6.1 Deployments of Endesa

On November 2004, a total of 210 working MV PLC links existed. Nearly almost all the MV lines tested are underground lines, the most typical MV lines in Spanish towns.

The 80% of the Transformer Stations (B-Dxxxx) connected by Endesa Net Factory in Barcelona and Zaragoza are connected by MV links, and the rest by optical fibre. The maximum number of MV hops achieved in cascade has been thirteen hops.

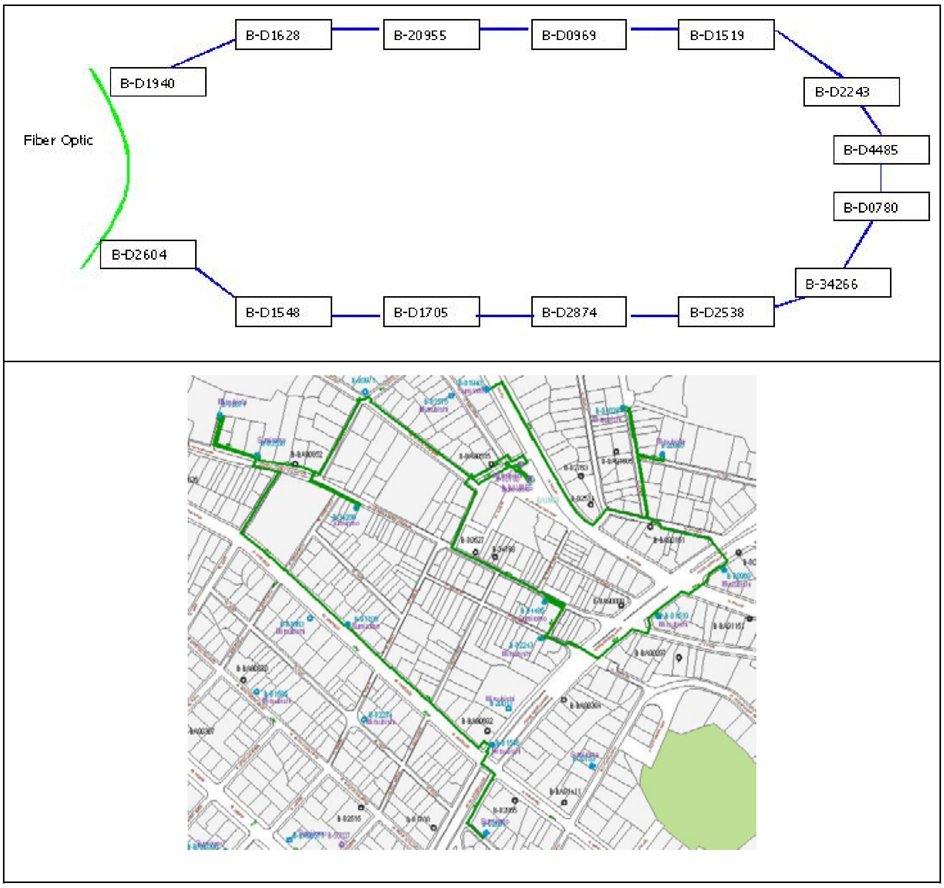


Figure 5-6 Zone in Barcelona where 13 MV hops are located

In the figure above, each box represents a Transformer Station (TS) and all of them are connected by MV, except the two fibre optic nodes that mark the origin and end of the PLC MV network.

The maximum distance achieved with maximum throughput in Spain is 552 meters, with 11 Mbit/s upstream and 16 Mbit/s downstream, in a phase to phase configuration.

All the Spanish tests are based on DS2 technology, which uses OFDM modulation to deliver a throughput of 45 Mbit/s in approximately 10 MHz of spectrum.

5.6.1.1 Introduction

Endesa, the main utility power in Spain is conducting two commercial trials of communications services over the power lines in two different cities in Spain: Barcelona and Zaragoza. Among these trials, Endesa is developing a complete characterization of electrical power networks to improve equipments, materials and all elements involve in a PLC network.

5.6.1.2 Commercial trials

Zaragoza commercial trial involves 1200 commercial subscriber and pass 12,000 homes. The principal advantages confirmed during the pilot test are the rapidity of the deployment, the utilization of existing infrastructures and the use of the conventional sockets as a broadband way of connection. To achieve these milestones, it has been necessary to connect 140 electrical substations (85 of which across PLC medium voltage links) and 330 meter rooms.

In Barcelona Endesa has deployed an urban area to give PLC services over 9,000 passed homes. This goal has been possible because of the interconnection about 120 substations (distribution layer) and 260 meter rooms (access layer).

5.6.1.3 Electrical Power networks improvements

The services given by Endesa have been not only Internet broadband access and telephony, but because PLC is being used for internal energy purposes to provide automatic meter reading services, load management and outage reporting. PLC also adds intelligent networking capabilities to the electric power distribution grid.

Endesa is investigating possible electric utility-focused applications include outage detection, home energy management, distribution transformer overload analysis, demand side management, Substation Control and Data Acquisition (.SCADA.) data transmission, monitoring of non-SCADA controlled substations, replacement of traditional intrautility-based communications systems (copper wire and microwave), safety checks for isolated circuits, power quality monitoring, detection and diagnosis of events at capacitors and regulators, phase loss detection, line testing, outage localization and fault characterization. All these work lines means more efficient, reliable and secure electric distribution systems.

5.6.1.4 System Architecture

The system architecture in both cities is the same: Consists of the backhaul data network that connects the PLC network to the global telecommunications network as well as to Endesa data center.

The backhaul data network is the telecommunications backbone to which the PLC-empowered distribution system is connected. Endesa has already installed fiber-optic cables with excess capacity, which can then serve as the telecommunications backbone or backhaul data network for PLC. Such fiber capability frequently extends to substations, providing a convenient and cost effective location for the PLC enabling connection.

These, or other leased high-speed data links from third party telecommunications service providers are used to link the PLC communications system to the global data and voice networks. This same backhaul data network can also meet a variety of utility operational needs, such as monitoring of the substation and voice communications with field personnel.

The PLC network works using electrical distribution system as physical framework. As with most high-speed data communications technologies, PLC requires the use of routers, switches and repeaters to provide segmentation of the network dependent upon bandwidth, number of users and services provided.

The system is designed to permit sequential installations and expansions corresponding to actual customer demand. This is a major advantage of Endesa's implementation plan in that installation costs are minimized, and the time between investment and realization of revenues is shortened.

To maintain bandwidth at higher subscriber densities, additional backhaul connectivity points may be utilized. Most network devices will be "intelligent," meaning that they will support network management and other services. This support enables network monitoring to gather statistics on data rates, for instance. Monitoring of specific utility devices and conditions can also be incorporated into the network devices. Concerns with data security and data integrity are considered and addressed at all levels of the system, ensuring the security of the network and the data carried on the network. Security for each subscriber will provide peace of mind that transactions are private.

5.6.1.5 Network architectures

Two different network architectures have been implemented in Barcelona and Zaragoza. In the following picture is shown the architecture implemented in Zaragoza.

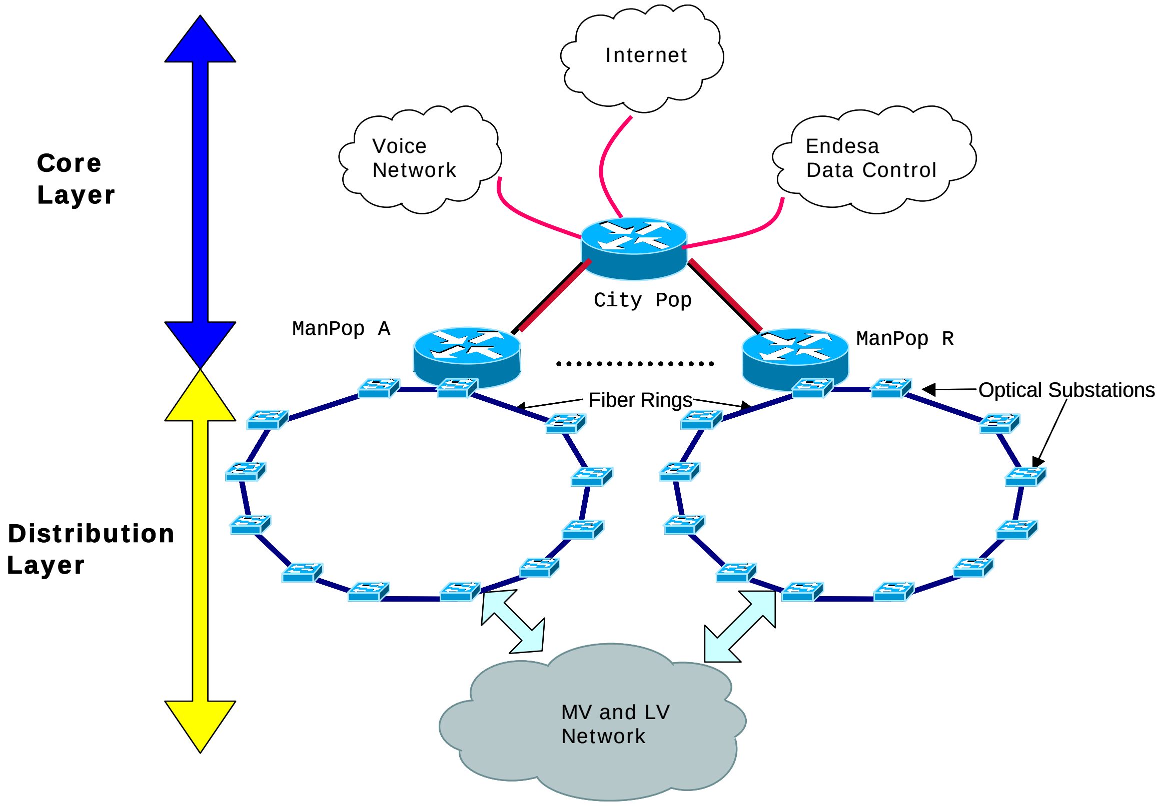


Figure 5-7 PLC architecture network in Zaragoza deployment

In Zaragoza Endesa has one point of presence (PoP) called City PoP and various Man PoPs distributed along the city. The City PoP is the main point where all the traffic of one city is aggregated and interconnected to the national traffic or to the final interconnection. A Man Pop is a point in the network, connected to the City Pop, where is aggregated the traffic of a big area. All City PoPs are linked by optical fibre to the City PoP and every City PoP can ends one or more fibre rings. Every fibre ring belongs to a determinate town area and it is formed by various optical substations. Each Man PoP could have one or many fibre rings interconnecting MV substations, and all substations will belong to a Medium Voltage ring to improve reliability in all telecommunication services.

Different kinds of PLC equipments (or nodes) are deployed at various points in the distribution network to overlay a communications network on the power lines. These devices are characterized as "network layer components" and are uniquely designed to accomplish specific tasks along the network.

Distribution networks are divided into two parts: medium voltage (MV) networks and low voltage (LV) networks.

Each optical substation is the “head” of a MV branch, making a tree topology, from MV substation to LV layer that reaches users.

Voice Internet and carrier connections are located in the City PoP.

IEEE 802.1p/Q has been implemented in the network to provide service prioritization (voice and management traffic over Internet traffic) and VLAN (Virtual LAN) scheme has been used to distribute all traffic in a controlled manner.

Security is guaranteed due to an appropriate VLAN administration with different VLAN ID for every service. There is no visibility between different VLANs so it is guaranteed no visibility between PLC users.

Network design provides scalability, redundancy, security and it is resilience to extensions. Also, main systems are duplicated to provide full redundancy.

In Barcelona network design has suffered a little variation. Instead of ending all traffic in the City PoP, each VLAN traffic is sent to the relevant VLANs owner traffic operator. This design lets Endesa to be as flexible as possible in a multi operator scenario. Next figure will illustrate this design:

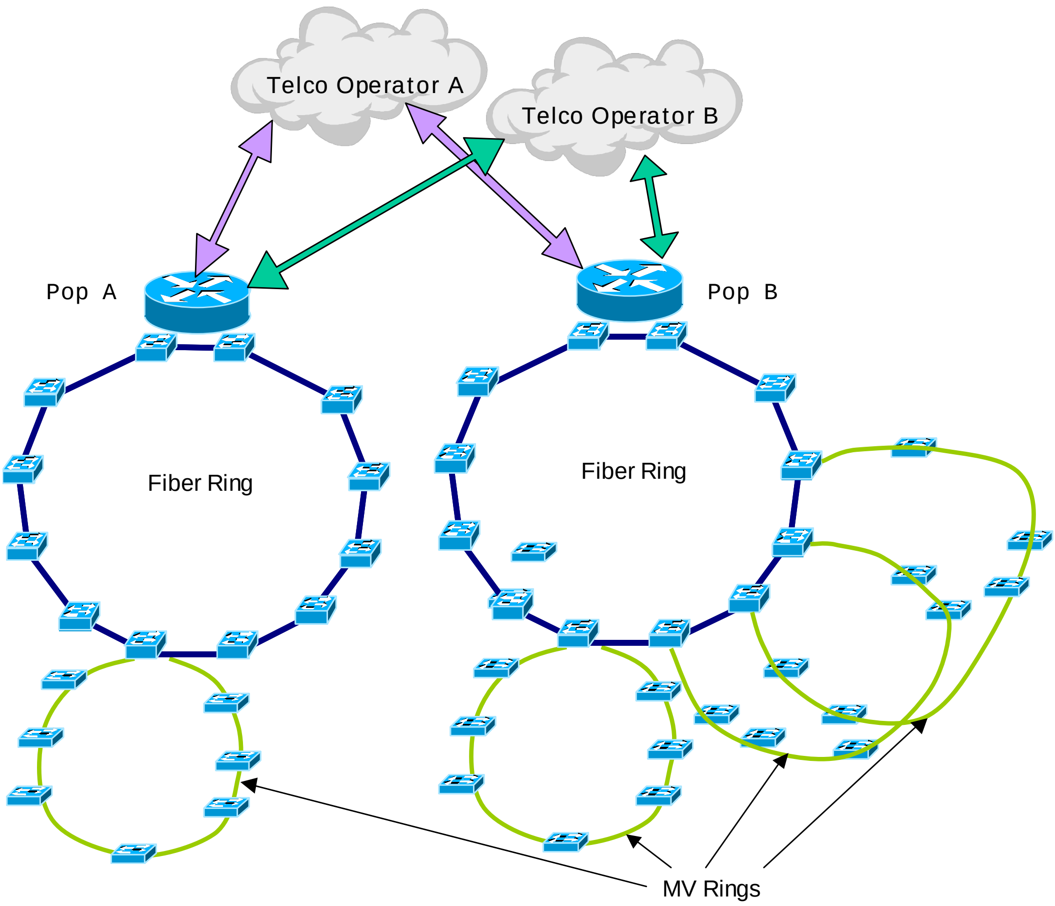


Figure 5-8 PLC architecture network in Barcelona deployment

On each PoP Endesa brings layer 2 traffic to operators that use PLC infrastructure to access to local loop. This scheme consequently permits having different operators' customers in the same building.

Apart of this, all network characteristics in Zaragoza are also implemented in Barcelona.

Provisioning system is already with redundant platforms. Basically, Endesa is in a multi carrier environment, once one CPE is connected the repeater learns automatically its MAC address (auto provisioning feature). The repeater asks RADIUS (Remote Authentication Dial-In User Service) Server is this CPE is allowed to connect to PLC network. Once RADIUS authenticates the MAC (Medium Access Control), the repeater allows DHCP (Dynamic Host Configuration Protocol) server to give an IP address to this CPE. Besides IP address, DHCP server also sends an appropriate profile making a search in a LDAP (Lightweight Directory Access Protocol) system and finally CPE receives its configuration. Voice service is activated in this final step.

Internet service is using a PPPoE (Point-to-Point Protocol over Ethernet) scheme to authenticate service.

This network design provides scalability, redundancy, security and it is resilience to extensions. Also main systems are duplicated in order to provide full redundancy.

5.6.1.6 Devices used in PLC networks

Fiber-optic transformation node – FO-Substation:

Some facilities are often connected to a fibre-optic network. Accordingly, the substation is the optimal position to connect the backhaul network to the PLC network, and the FO-Node facilitates that connection.

The FO-Node supports a variety of interfaces to accommodate backhaul connections via the utility's private (fibre-optic) network or other high-speed data links. The F0-Node also supports multiple power line interfaces (i.e., PLC Modems) to connect to all of the feeder lines at the substation. Multiple connections to backhaul links, protection switching, and redundancy are part of the design to alleviate single points of failure. Using Medium Voltage rings lets to give redundancy taking advantage of grid electrical layer on all services provided.

Terminal Equipment Node - T-Node:

Utilities typically have numerous feeder lines radiating from substations. The T-Node can provide two functions: to transfer data between medium voltage and low voltage lines and as a repeater along the medium voltage line. Designing PLC networks with MV redundancy, Endesa has used as much inductive as capacitive coupling units on distribution network and has also mixed both systems. The results have been the following in Barcelona's deployment:

- Capacitive - Capacitive Links: 17
- Capacitive - Inductive Links: 29
- Inductive - Inductive Links: 47

These coupling units let us to connect 130 substations in Barcelona in a small period of time and with all security requirements; it means electrical service has a 100% of availability during deployment.

Repeater Equipment - RE-Node:

The Repeater Node is used to provide greater reach on long lines or lines with high attenuation. This equipment is normally installed in Meter rooms to regenerate PLC signal and connect properly final users.

In Barcelona Endesa have installed 260 repeaters to reach 9000 passed homes.

CPE Equipment - CPE:

This equipment lets the user to access to all services offered by an operator simply connecting to a power socket.

In Zaragoza the total number of commercial customers rises to more than one thousand.

5.6.1.7 Physical Layer

The physical layer represents the actual devices connected to the power line to add or extract the data signal. The interface components are:

1. PLC Modem
2. coupling devices
3. line conditioners

The following paragraphs provide a description of each of the components, their characteristics and their positioning on the power distribution network.

5.6.1.8 PLC Modem

Modems used in PLC are an integral part of the nodes that are positioned at strategic points of the utility distribution network. These devices perform the task of converting the data to communication signals appropriate for the physical medium, the power lines in this case. The modem also provides error correction and security mechanisms at the physical layer.

5.6.1.9 Couplers

Couplers provide the means to transmit on and receive the modem signals from the power line. There are two methods for coupling the signal to the line - capacitive and inductive coupling.

Characteristics Capacitive Coupler:

- Low maintenance
- Must interrupt power service to install. Can only be used inside underground power distribution substation
- Low Insertion Loss
- Expensive
- Better performance that inductive couplers

Characteristics Capacitive Coupler:

- Low maintenance
- Easy to install (without interrupting power service). Can be used as much as inside or outside (expose to atmosphere conditions)
- High Insertion Loss (depends on power line topology)
- Inexpensive
- Worse performance that inductive couplers

Both can support high level of voltage but the main difference aside the price is the better performance that capacitor couplings achieve respect inductive. Over links of medium and high length, channel behaviour with capacitive coupling is superior than inductive. One of the main disadvantages of inductive coupler is its dependence on power network topology: signal return path always depends on line distributed capacity. This weakness reduces the application opportunity of inductive couplers.

5.6.1.10 Conclusions

Endesa has demonstrated that a telecommunication network deployment employing MV rings over distribution power layer is possible using PLC technology with actual devices. One of the main shortfalls is the small number of firms that can provide coupling units. The absence of competition avoids developing improvements and it stops the evolution of these products. Making cheaper, more efficient units and completing the good list will allow more PLC initiatives to be carried out.

Despite this handicap, a complete deployment can be done offering a good service level agreement on all provided services, as Endesa has done in Barcelona and Zaragoza.

5.6.2 Deployments of Iberdrola

5.6.2.1 Introduction

Iberdrola has the biggest MV PLC deployment known to date. Taking data from April 2005, there are 643 working MV PLC links mainly distributed in the urban areas of cities like Madrid and Valencia.

These MV PLC links are all established on underground MV lines, as the most typical configurations use aerial lines only for semi-urban and rural distribution, which are not the target of Iberdrola's commercial deployment. Tests carried out in aerial lines have been scarce up to date, although one specific test installed in a 2km-long aerial line, with two prototype capacitive couplers, has been known to work at full capacity of DS2's second-generation technology. No definitive conclusions however can be extracted at the moment, because of the small number of tests performed.

At physical level, the equipment deployed uses DS2's Adaptive QAM Orthogonal Frequency Division Multiplexing technique, and Frequency Division Duplex so for each MV PLC link we can define independent speeds for upstream and downstream.

5.6.2.2 Iberdrola MV grid description

To understand Iberdrola's method of planning and deploying MV PLC networks it first useful to take a brief look to Iberdrola's MV Distribution grid. A survey was conducted inside Iberdrola's own database to gain further understanding of its own electrical infrastructure, taking into account two main parameters: distance between transformers and type of switchgears. Some summarized results are presented here.

Information about the distribution of switchgears according to its type is provided next.

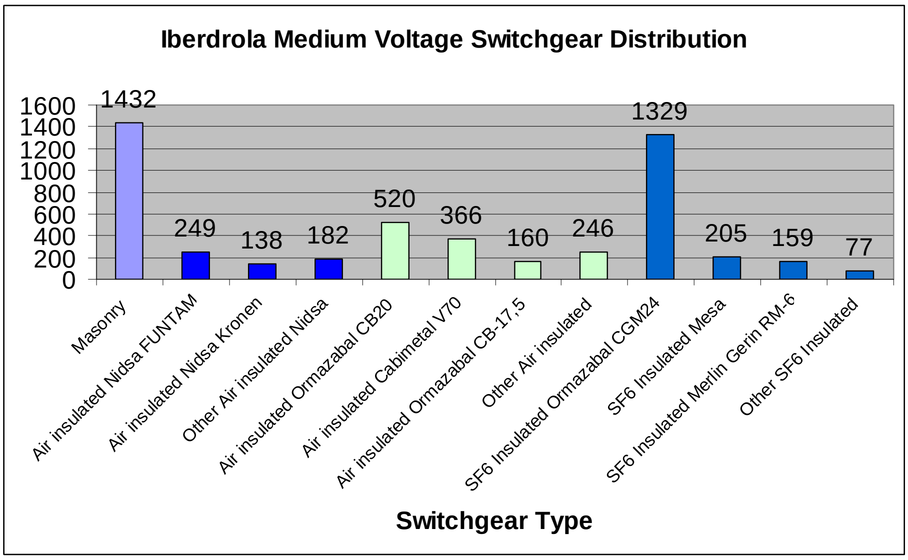


Figure 5-9 Switchgear types – absolute

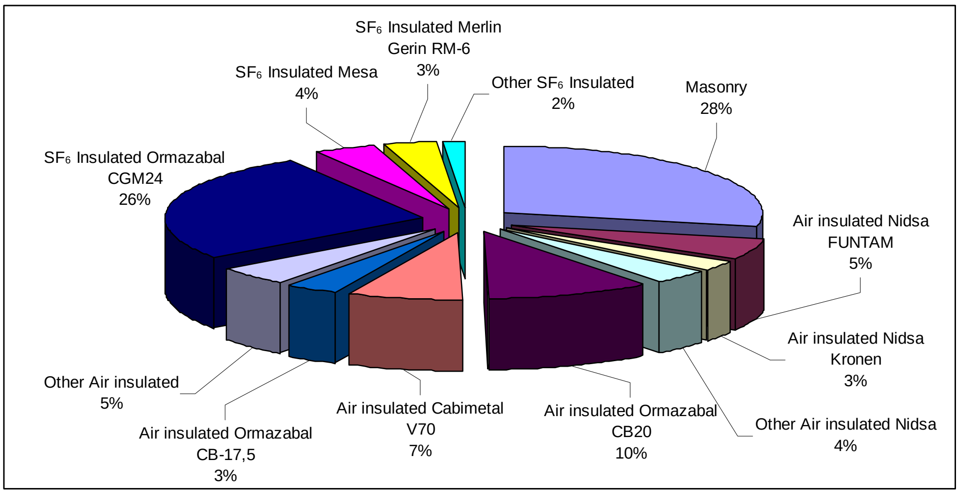


Figure 5-10 Switchgear types - percentage

Following figures show the distribution of MV line-lengths (between two transformers) over three sample cities in Spain.

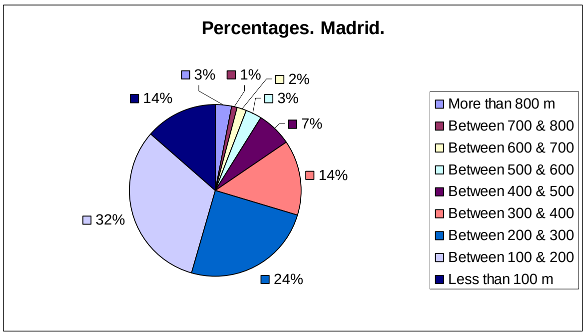


Figure 5-11 MV Link lengths Madrid (%)

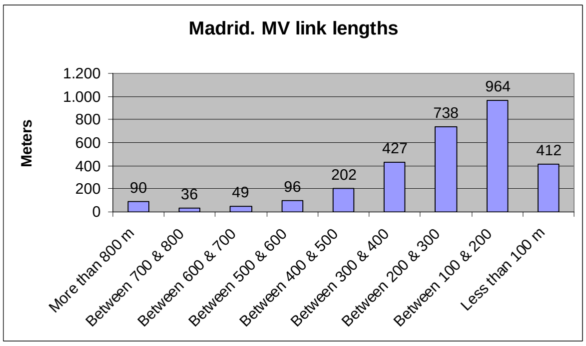


Figure 5-12 MV Link lengths Madrid (abs)

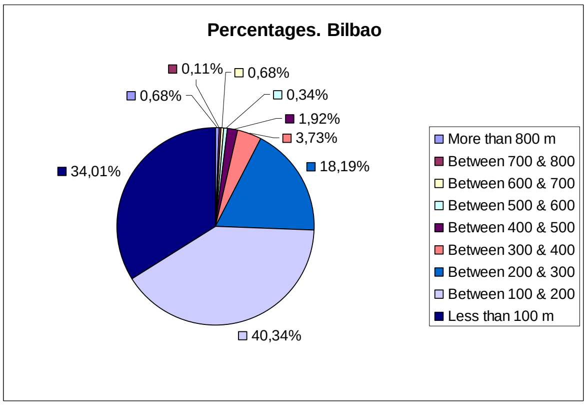


Figure 5-13 MV Link lengths Bilbao (%)

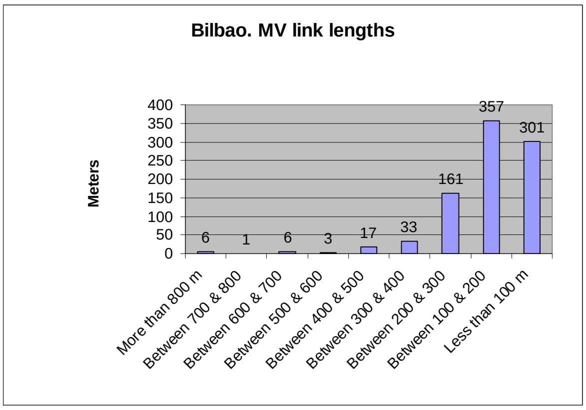
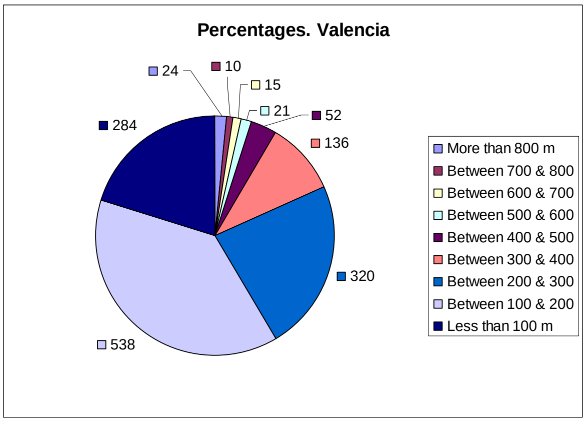


Figure 5-14 MV Link lengths Bilbao (abs)



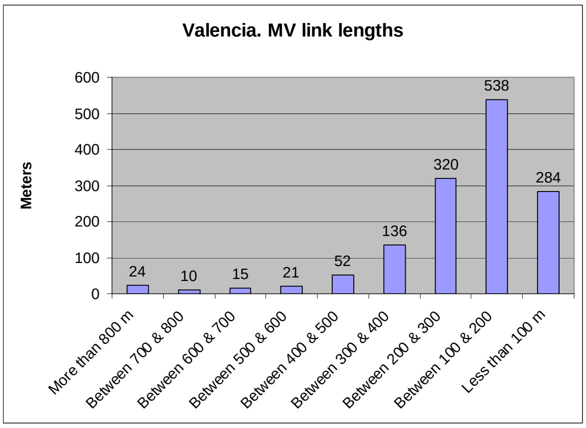


Figure 5-15 MV Link lengths Valencia (%)

Figure 5-16 MV Link lengths Valencia (abs)

These data prove that it is currently possible to deploy MV PLC on a large scale, given the range of coupling units available in the market and using the flexibility that each technology is able to offer (in the case of Iberdrola, using DS2 technology, this means designing frequency plans for each specific cluster).

5.6.2.3 Iberdrola commercial deployment. Examples

Iberdrola's deployment is based on the concept of 'clusters'. For Iberdrola a cluster usually means a number of transformer stations (TS's) linked all-together through MV PLC, and then to Internet via traditional means of digital transmission (fiber optics mainly, but also LMDS/MMDS, Satellite, microwave digital radio-link, xDSL over traditional copper or even PLC communications via telephone wire). Usually the link to traditional transmission is found inside one of the TS's itself, this is called the 'source point'. It is very usual also that source points feed a total of two to four MV PLC branches, which will not necessarily close together in the end (forming 'rings'). A visual example will illustrate this more clearly; using the cluster called ALCOBENDAS1 as on following example:

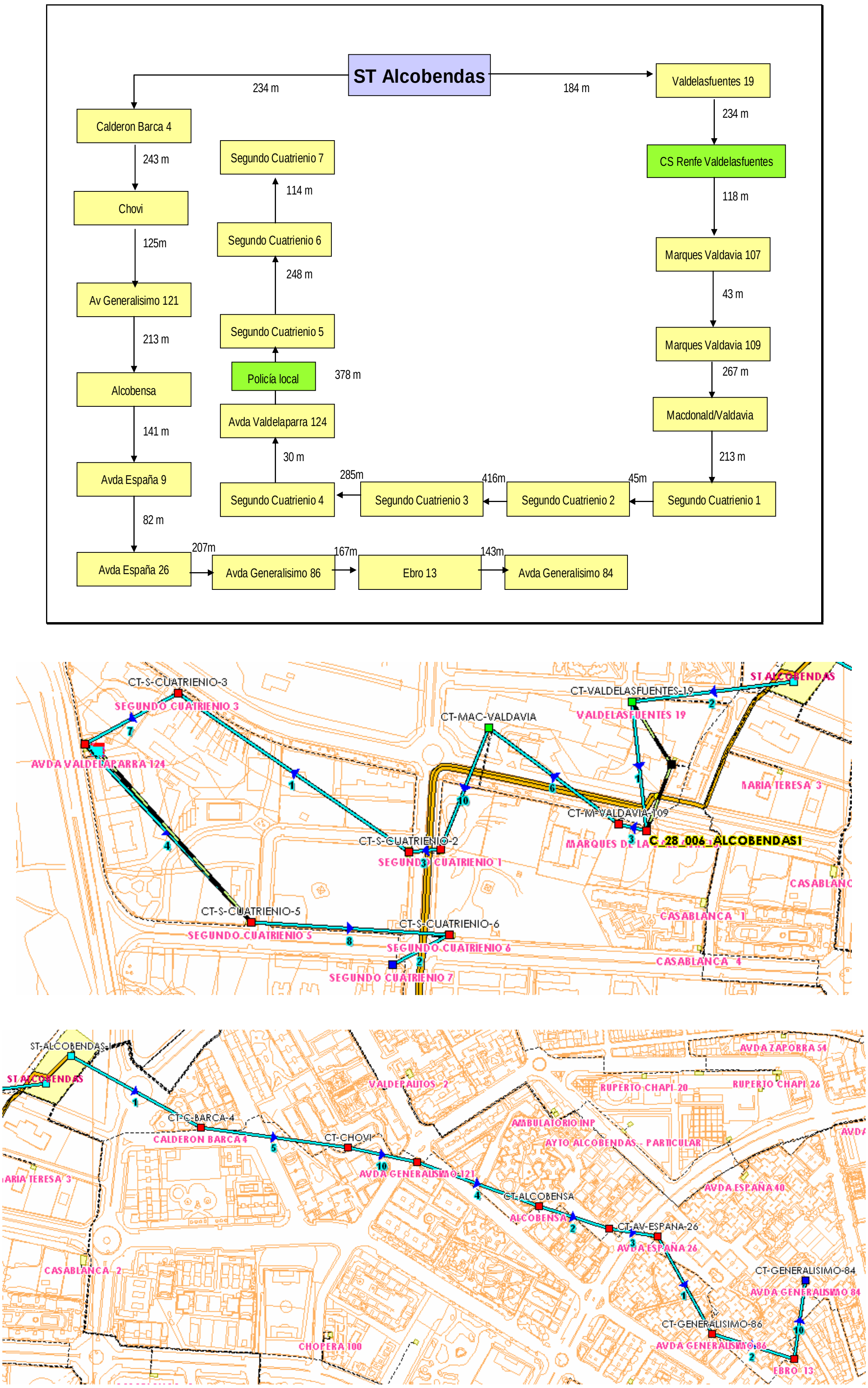


Figure 5-17 Alcobendas1 Cluster

The source point is the Secondary Substation (HV-MV) Alcobendas, from which two MV 'branches' start, one of them serves 9 TS's and the other one a total of 14 TS's. The two TS's marked in green are called 'bridge TS', because no PLC MV equipment is installed inside: only 'bridged' couplers so that PLC signal bridges the transformer.

As it can be seen, no redundancy is planned at MV PLC level in the current situation of the cluster, as only one fiber point is available and it would be impossible to close any of the MV rings that start from Alcobendas Substation (some this type of ring have 30 to 40 TS's!). Deployments in Iberdrola are driven by commercial parameters rather than technical ones, so if one specific area deemed as 'commercially attractive' makes it impossible for the current technology to offer maximum redundancies, the deployment will nevertheless start. For a cost-effective solution Iberdrola has found that this is the most common situation, that allows to take maximum advantage from fiber connections, as long as it is granted that the network of PLC MV links is stable enough. This is clearly the case in current Iberdrola's MV PLC network.

ALCOBENDAS1 cluster feeds a total of 5714 electrical costumers distributed in 21 TS's and can be considered a medium-to-big cluster.

Another example of cluster located in Madrid (ALTAMIRA1) includes 22 TS's that feed 7359 electrical customers:

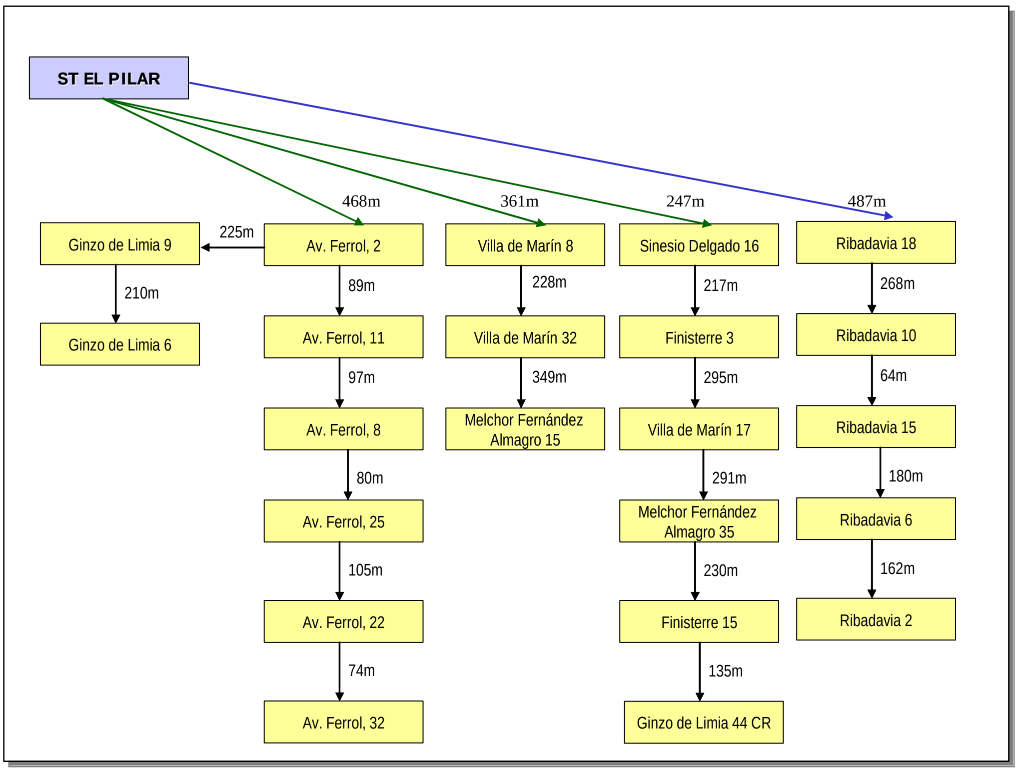


Figure 5-18 Altamira1 Cluster

It has a total of four branches starting from the source point, which requires a careful frequency planning.

Biggest clusters are present in the city of Madrid, in which one of them has 27 TS's. Another one has a total of 9463 electrical customers fed. However the average is lower: the total of 47 clusters deployed up to date feed a total of slightly more than 200.000 electrical customers, mainly in urban areas of Madrid and Valencia.

More than 90% of the TS's in the deployment are connected by MV links. The rest uses mainly fiber optics (all of the fiber used for these purposes is owned by Iberdrola).

Another example of cluster is IBIZA1, which comprises 14 TS's that feed 6966 electrical customers. The source point in this case is a normal TS, not a Secondary Substation.

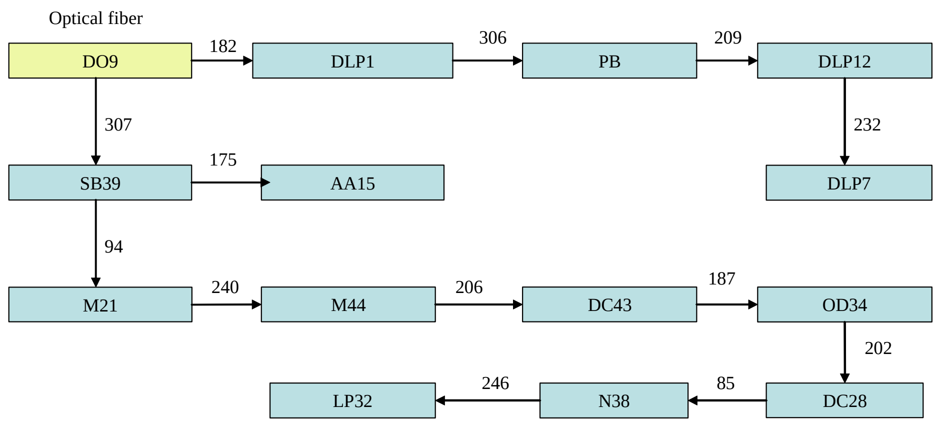


Figure 5-19 Ibiza1 Cluster

In the following picture taken from Iberdrola's GIS, IBIZA1 is represented along with three more clusters in the area: IBIZA2, LAESTRELLA1 and LAESTRELLA2. These four clusters include a total of 17957 electrical customers fed from 42 TS's.

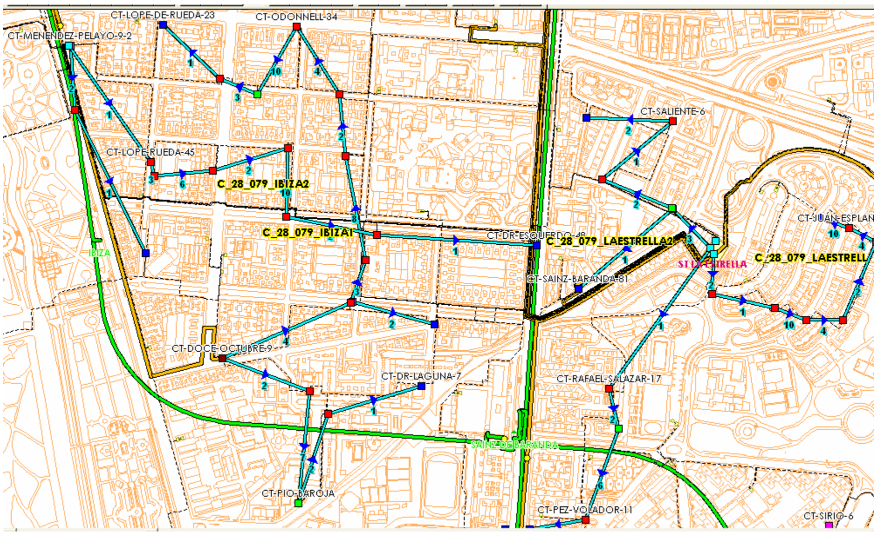


Figure 5-20 Ibiza and La Estrella clusters

A deep study is being developed right now in Iberdrola to extract the maximum amount of possible information from the extensive MV PLC base that is now installed and working day-to-day as part of the commercial deployment. The physical level will be studied first, paying special attention to possible relationships between distances frequencies, types of cables and cells. The initial obtained data points to the obvious fact that lower frequencies find lower attenuations and thus are able to achieve acceptable speeds at higher distances, but the big variance that appears at first glance clearly deserves further analysis. Some underground links close to 600m are known to work quite effectively in the range of 20Mbps (Upstream + Downstream). Noisy lines however will offer lower throughputs even in much lower distances.

5.6.3 Distribution of MV coupling units used by Iberdrola

Depending on the type of switchgear and MV lines, it has been necessary to use different kinds of MV couplers. An updated chart of the percentage distribution of the 1300+ couplers installed in the field last year is shown in the following figure.

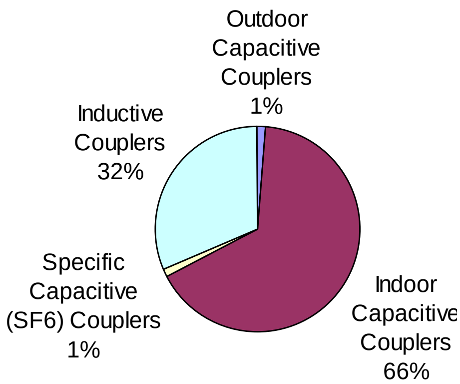


Figure 5-21 Couplers Installed by IBERDROLA

In principle, inductive couplers are favored because of their cheaper price, however in some kind of cells (e.g. masonry) it seems mandatory to install capacitive couplers, and sometimes depending on the characteristics and earthing of cables, it is seen that only capacitive couplers offer good performances.

5.6.4 Conclusions

It is clear, based on the experience of more than one year of extensive MV PLC deployment, that this activity can be performed in a quick and predictable way (much more than LV PLC deployments). Installation costs are still slightly high mainly because of safety requirements in MV that imply specific procedures and specialized staff. Cost of the couplers will drop as more and more utilities start creating a real market. Further investigation on alternative coupling techniques is also being encouraged by Iberdrola.

These MV PLC networks serve as powerful backbones for the services offered (right now, broadband Internet access). Iberdrola has started trials to check the possibility of using this MV PLC infrastructure for internal uses in Distribution, namely telecontrol and remote metering. More applications for Distribution business will be investigated afterwards.

5.6.5 Deployments of Unión Fenosa

Union Fenosa has been testing MV technology since October 2002. Union Fenosa has deployed a field trial in a residential neighbourhood in Madrid. The objectives of this trial are to test the viability of MV technology as a valid solution for backbone interconnection in addition to test LV technology using the previously mentioned MV technology,

The coverage of the pilot comprises thirty end-users in several buildings distributed in three transformer substations. These transformer substations are connected in cascade from a HV/MV substation by three MV links. The interconnection to the service provider is made at the HV/MV substation using one E1 circuit by radiolink.

. The main service provided to end-users is High Speed Internet Access. In addition, other services have been tested, such as Telecontrol of MV transformer stations and Provision of point to point G.703 circuits over PLC.

The PLC technology used is based on DS2 chipset for both MV an LV technology. Madbric and Wisconsin chipset technology have been tested.

The couplers tested in the field trial have been provided by Eichhoff and Arteche (inductive couplers) and Dimat (Capacitive couplers).

The MV topology is shown in the next picture:

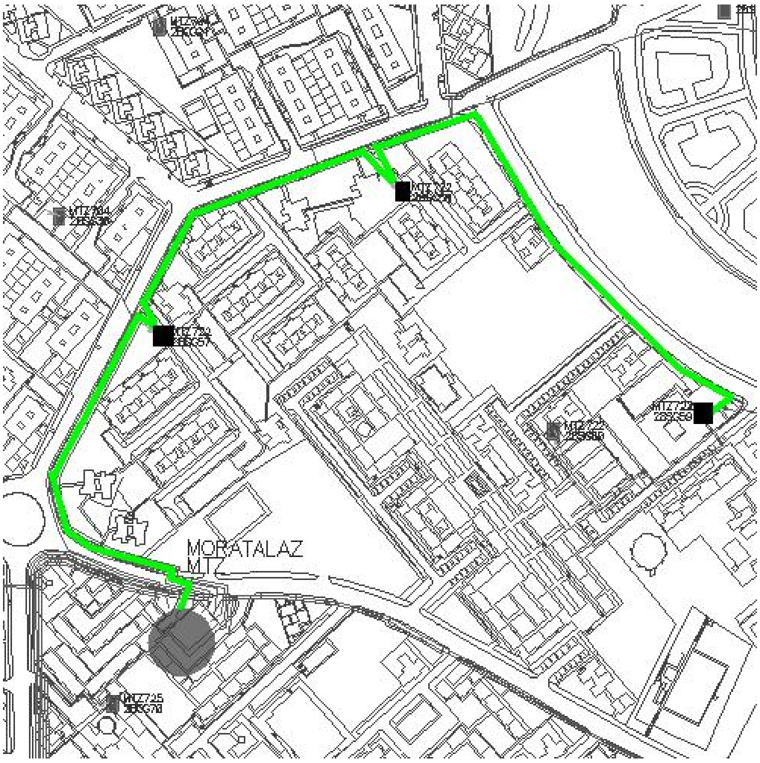


Figure 5-22 PLC architecture network in Union Fenosa´s deployment

The distances for MV links are 355 m, 233 m, 410 m. Mbit/s Aggregate data throughputs (upstream + downstream) obtained over MV range from 6 to 13 Mbit/s using Madbric chipset.

All the cables under test are underground.

6 MEDIUM VOLTAGE COUPLING EQUIPMENTS

6.1 INTRODUCTION

The PLC signal is injected in the MV electricity cables through the MV coupling equipment.

Inductive and capacitive coupling are the two possible physical technologies. The coupling method depends on the characteristics of the power line, impedance and attenuation, and on the characteristics of the MV cells. Apart from technical requirements, the application of each technology will be also influenced by economical requirements. The main difference between inductive coupling with clamp-couplers and capacitive coupling with a capacitor, is the way in which connection is made to the cable.

In case of overhead lines, couplers must not only operate safely at the nominal operating voltage and current, but must also pass a series of stress tests, be user friendly to linemen, and be designed for long term outdoor use.

More information is provided in subsection 4.4.1 and 4.4.2.

Capacitive Couplers:

A capacitor requires a direct connection to the conductor.

This requires a piercing technology for low voltage cables, and makes it impossible to connect directly through the insulation of the medium or high voltage cable. In these cases the capacitor has to be connected directly with the bus bar or a non-insulated piece between cables and switch if possible, even though the location can be bad from the signal's point of view.

The installation must be in accordance with safety regulations concerning insulation and safety distances and must not negatively influence the electrical field in a dangerous way inside the cabinet.

Capacitive coupling is independent of the actual current through the conductor but requires maximum safety for the voltage level of the conductor.

Inductive Couplers:

An inductive clamp-coupler does not need any electrical connection to the conductor.

It allows clamping the inductive clamp-coupler directly on an insulated cable, typical in SF6 cells, with no tooling on the cable out of any area when dangerous voltages are present.

In case of an insulated and shielded medium or high voltage cable, if the shield is accessible, it is possible to inject the signal through the shield without tooling too by using a physical phenomenon.

Inductive coupling is independent of the voltage level of the insulated conductor but depends on the current through the conductor.

The performance of inductive couplers depends on of state the power switch (see chapter 6.2.).

6.2 CAPACITIVE COUPLING

A capacitive coupling system matches the line impedance to the impedance of the communications terminal to maximize the transmission of the PLC signal power to the line, assuring the electrical insulation between the line and the communications terminal.

The basic scheme of a capacitive coupler is shown below:

Capacitive Coupler - Simplified block diagram

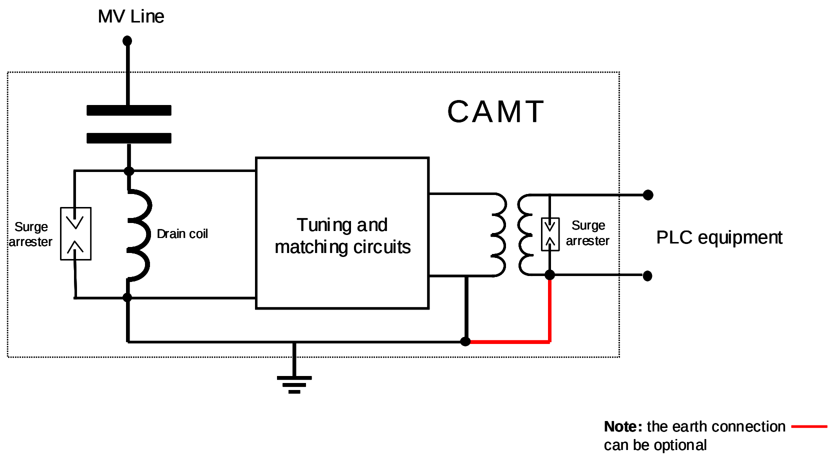


Figure 6-1 Capacitive Coupler

The protection elements are the drain coil and two gas surge arresters, one equipment side and the other line side. The drain coil has an air core to minimize intermodulation. The tuning circuit is designed to use the unit in the specified frequency range and in order to comply with the return and composite loss requirements. The matching unit is made of an insulating transformer which matches the primary impedance (line side) to the secondary impedance (equipment side).

The connection to the line is carried out by means of a capacitor, and a passive circuit is used to tune the system in order to achieve the required bandwidth of 2 to 40 MHz. This circuit also helps the matching transformer to adapt the line impedance to the PLC equipment impedance in the whole frequency range.

Concerning safety, two surge arresters are used, one in the line side and another in the equipment side. Furthermore, a drain coil is used to drain any possible residual current leakage of the capacitor.

Most of the capacitive couplers have been developed for air cells, although there are also models for SF6 cells.

6.2.1 Transmission characteristics of capacitive couplers

- **Line-side impedance**

  Impedance of the line at the PLC frequencies, for which the coupler has been designed. By experience the most common line impedance is around 20 Ω.

- **Equipment-side impedance**

  Impedance of the PLC equipment interface, usually 50 Ω.

- **HF Bandwidth**

  Range of frequencies able to be transmitted through the coupler. Depending on the PLC technology, the frequency range is between 1-2 MHz up to 30-40 MHz.

- **Insertion loss**

  It is the power loss introduced by the coupler. Typically is around 2-4 dB in the whole HF bandwidth.

6.2.2 Safety characteristics of capacitive couplers

- **Line voltage:**

  Maximum phase-to-phase line voltage for which the coupler has been designed

- **Isolation**

  Electrical isolation at industrial frequency between the windings of the matching transformer. A typical value is 5 kVrms during 1 minute.

- **Impulse withstand**

  Voltage impulse that is capable to withstand the matching transformer. For this kind of couplers test waves of 1,2/50 μs and amplitude of 1,6 kV to 2 kV are used.

- **Partial discharges**

Partial discharges are tiny electric arcs which occur whenever a flaw appears inside the insulating equipment, resulting in abrupt variations of the magnetic field. In the long term partial discharges can also degrade the insulating material and eventually destroy it.

6.3 INDUCTIVE COUPLING

The typical connection between the coupling and the power line network is as shown in next figure:

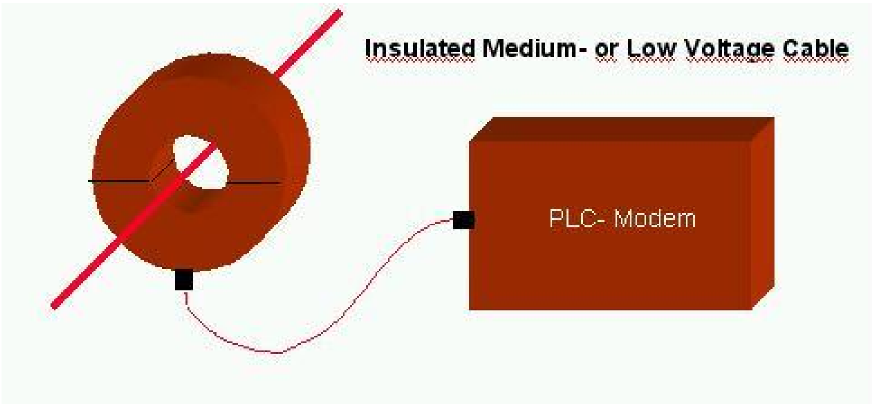


Figure 6-2 Principle of an Inductive Clamp Coupler

To feed PLC Broadband Signals into medium voltage Powerlines without contacting the cables, a magnetic circuit is "clamped" around. Thus signals will be transmitted with low loss for a wide frequency range of 2-40 MHz.

Picture below shows an inductive clamp coupler with inner diameter of 45 mm incl. coupling loop with BNC-Plug (Manufacturer Eichhoff GmbH):

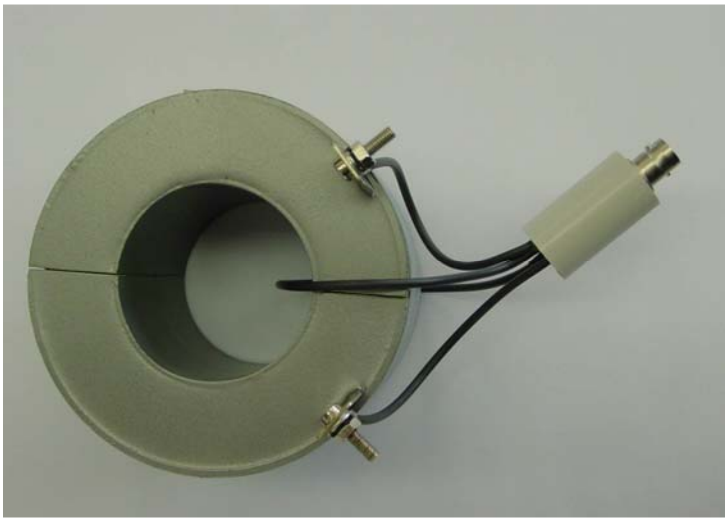


Figure 6-3 Inductive clamp coupler

Inductive couplers can be installed on insulated cables with or without shielding and on non insulated cables. Insulated and shielded cables are mostly installed as underground cables whereas non insulated cables are used in overhead installations. In the later case the couplers itself must to have sufficient insulation to fulfill safety requirements.

For high frequency signals (RF), the cable presents impedance Z0 towards one side of the coupling, and Z1 towards the other.

If this type of coupling is done at a place where the impedance of the cable in one of the sides is low, the coupling will behave as a 1:1 transformer. These places of “low” impedance can be identified easily in a power line network without the need to perform any measurements; these are the points where an abrupt change is produced (abrupt change of impedance or strongly uneven impedance).

This inductive coupling is illustrated in the following figure:

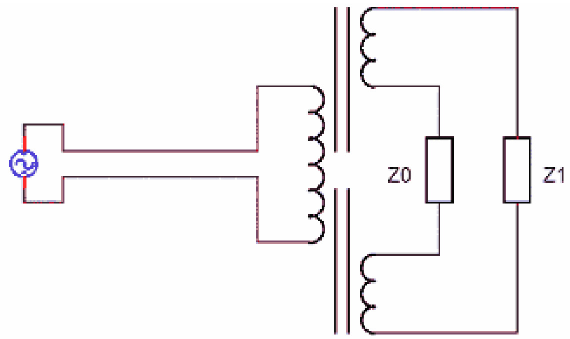


Figure 6-4 Inductive coupling principle

Where the impedances (complex) Z0 and Z1 of the power line are seen from one side of the coupling as well as from the other side.

Inductive couplers are not exposed to the full fault energy of underground lines, such as the energy of the charge due to the cable’s considerable capacitance. Thus, they are inherently safer for placement at pad-mounted distribution transformers covered with thin steel covers and placed in residential lawns and gardens.

Inductive couplers are typically placed on energized MV cables adjacent to an elbow connector by a lineman wearing gloves.

6.3.1 Inductive Coupling into insulated cables

In case of insulated cables, inductive clamp-couplers do not need inherent insulation. Therefore the coupler itself can be relatively compact and inexpensive. Inductive clamp-couplers can be placed on energized insulated phase conductors without interrupting power where the installation environment and local safety regulations allow. Because of this, the coupler itself does not have to be heavily insulated and can be relatively compact and inexpensive.

The clamp-Coupler does have the advantage of extremely low costs for mounting because this type of coupling does not require any connection to the phase: it can simply be applied on insulated cables with no tooling on the cable.

The low impedance of underground MV cables, typically in the 20 to 40 ohm range, also facilitates efficient inductive coupling and a low value of low frequency roll-off. Distances on XLPE may exceed one kilometre without excessive path loss.

6.3.2 Inductive Coupling into shielded cables

The situation becomes different if the cable is shielded. In this case, the coupling has to pass the shield before coupling into the phase. Coupling into both shield and phase has the disadvantage of high EMI and losses because of bad conductivity of ground-resistance and magnetic losses underground.

Using a simple physical trick allows having all the benefits of magnetic coupling with the Clamp-Coupler and preventing all EMI problems and any losses caused by the ground-resistance:

By leading the ground-connection of the cable shield through the coupler again, it is possible to reduce all ground losses of the PLC-signal to zero.

By preventing all magnetic fields from the shielded cable, EMI will be reduced down to the shielding factor of the cable shield: an extremely small value.

The explanation of this solution is shown in next figure:

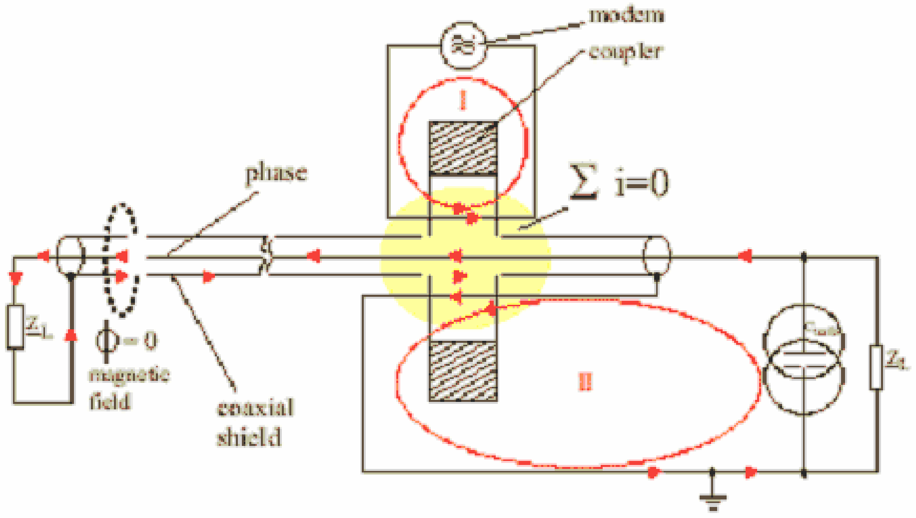


Figure 6-5 Inductive coupling into shielded cables

Any inductor tries to keep the current constant and, consequently, the coupler tries to keep the resulting high frequency current inside the yellow area at zero.

The modem is sending a current through this yellow area inside the coupler, and this will cause the same resulting current with the opposite direction in all other lines together.

The ground-connection of the shield has to be connected to ground in exactly the way shown in the drawing. If connected as recommended, the current inside the ground-connection may be exactly the same as the current from the modem with opposite direction.

In that case, the current through the shield and the phase must be exactly the same currents with opposite directions summating to zero. This will cause a magnetic field ϕ around the cable of exactly zero, so there will not be losses caused by ground-conductivity.

In the previous figure we can see that the current through the connection of the shield to ground is exactly like this.

On the cable side is only one current circuit (II), and every current has to have the same value inside this circuit.

Because of the turn-ratio of the coupler, the current on the modem side (I) has exactly the same value than the one on cable side (II).

6.3.3 Inductive Coupling into insulated and shielded cables

If the cable is shielded, the coupling has to pass the shield into the phases. This can be achieved by installation as shown in next drawing:

Shield ground connection

led through the coupler

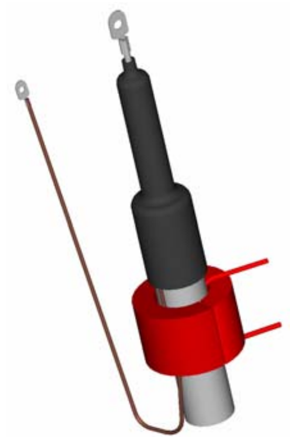


Figure 6-6 Coupling loop

By leading ground-connection of the cable shield through the coupler, it is possible to reduce all ground losses of the PLC-signal almost to zero. By preventing all magnetic fields leaving the shielded cable, EMI will be reduced down to the shielding factor of the cable shield: an extremely small value.

6.3.4 Inducting Coupling in non-insulated cables

Although there are insulated inductive couplers are available for installation on non insulated overhead cables there is a need for further development of solutions with low attenuation and easy installation.

6.3.5 Installation requirements

State-of-the-art PLC coupling equipment comply with all safety requirements and installation regulations. There are no specific requirements for the installation of PLC coupling equipment apart from the usual requirements applicable to works in MV lines.

7 REGULATION AND STANDARDIZATION

7.1 INTRODUCTION

In Europe, PLC network components, as well as any product, must comply with the essential requirements of the Directives that are related to them.

From that point of view, passive and active components must be regarded separately. MV-PLC couplers are passive devices and PLC modems are active devices.

For MV PLC the safety aspects are essential.

7.2 COUPLING DEVICES

Because MV coupling devices are passive, no EMC-certification is needed for them.

7.2.1 Capacitive couplers

Capacitive couplers for use in MV cabinets must be tested according to IEC 61334-3-22 "Mains signalling requirements – MV phase-to-earth and screen-to-earth intrusive coupling".

The standard establishes definitions, requirements, and methods of testing and rated values for phase-to-earth capacitive and screen-to-earth intrusive inductive coupling devices to be used in MV-PLC systems.

7.2.2 Inductive couplers

MV PLC inductive couplers work in the same principle as current transformers. Although the safety requirements for MV PLC inductive couplers are not defined in a specific standard, the standard for current transformers is applicable.

Inductive couplers are working in principal as current transformers. Current transformers have been used since the beginning of the MV-technology decades ago. Ordinary current transformers are designed to connect directly to a connection point on the MV cable.

The inductive couplers for PLC are constructed that the MV-cable must be stuck through the coupler itself. In this case the high voltage network will not be disconnected and the insulation of the MV cable will not be damaged as well.

An inductive coupler does not need any physical connection to the conductor.

7.3 MODEMS

For the electronic components of PLC equipment Safety and EMC-Tests are required.

The installation location for medium voltage PLC-modems is normally in substations. Thus the environment for the electrical installation of PLC-electronics is similar to industrial locations.

So the PLC-modems must match industrial environment specification. The standards to apply are EN 50178 “Electronic equipment for use in power installations” and/or EN 60950 “Safety of information technology equipment”. These standards are giving requirements for safety, protection and isolation for the installation location mentioned above.

Medium Voltage PLC modems work as standard modems with two different interfaces for power supply and data communication.

In any case, EMC behaviour is different in the MV PLC from the LV PLC.

7.4 MEDIUM VOLTAGE NETWORK

For the consideration of Medium Voltage PLC networks the network operators are responsible for the safety aspects of the network.

The safety requirements for the MV network can be different for different countries and also for each power utility. The installation of PLC-coupling devices must be in accordance with safety regulations concerning insulation and safety distances for MV-cabinets. The EMC part of the MV network in case of PLC will be covered by the Mandate M/313 in Europe and FCC Part 15 in the United States.

EMC is expected to be more critical in case of overhead MV lines, more typical in the United States, than with underground ones.

Short explanation to M 313: The European Commission mandated ETSI/CENELEC/CEN with document 313/2001 to define a standard for telecommunication networks. Mandate 313/2001 aims to create a European harmonized standard.

The standard shall apply for all types of telecommunication networks (e.g. DSL, PLC, LAN). The discussion takes currently place in an ETSI/CENELEC Joint Working Group. The delivery of the European harmonized standard is open.

8 GLOSSARY AND ACRONYMS

Aerial (insulated) cable	An insulated table designed to be suspended overhead and out-doors.
BIL	Basic Impulse Level
BPL	Broadband over Powerline
Busbar	A low impedance conductor to which several electric circuits can be separately connected.
Circuit-breaker	A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit
Conductor (of a table)	A part of a table which has the specific function of carrying current.
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DSSS	Direct Sequence Spread Spectrum
Earthing switch	A mechanical switching device for earthing parts of a circuit, capable of withstanding for a specific time currents under abnormal conditions such as those of short circuit, but not required to carry current under normal conditions of the circuit.
Electric line	An arrangement of conductors, insulating materials and accessories for transferring electricity between two points of a system.
EPR	Ethylene Propylene Rubber
FDD	Frequency Division Duplexing
Feeder	An electric line originating at a main substation and supplying one or more secondary substations.
FO	Fibre Optic
FTP	File Transfer Protocol
Fuse	A device that by the fusing of one or more of its specially designed and proportioned components opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete device.
Gas-insulated metal-enclosed switchgear	Metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas other than air at atmospheric pressure.
HDSL	High bit-rate Digital Subscriber Line
HV	High Voltage
Indoor substation	A substation sheltered from external weather conditions by being installed within a building.
Indoor switchgear and controlgear	Switchgear and controlgear designed solely for installation within a building or other housing, where the switchgear and controlgear is protected against wind, rain, snow, abnormal dirt deposits, abnormal condensation, ice and hoar frost.
Insulation (of a table)	Insulating materials incorporated in a table with the specific function of withstanding voltage.

Insulator	A device intended for electrical insulation and mechanical fixing of equipment or conductors which are subject to potential differences.
IP	Internet Protocol
Kiosk substation	A compact substation, often prefabricated and used only for distribution purposes.
LAN	Local Area Network
LDAP	Lightweight Directory Access Protocol
LV	Low Voltage
MAC	Medium Access Control
Mesh (of a system)	An arrangement of electric lines forming a closed loop and supplied from several supply sources.
MV	Medium Voltage
MVEDN	Medium Voltage European Distribution Network
OFDM	Orthogonal Frequency Division Multiplexing
Outdoor substation	A substation which is designed and installed to withstand extreme weather conditions
Outdoor switchgear and controlgear	Switchgear and controlgear suitable for installation in the open air, i.e. Capable of withstanding wind, rain, snow, dirt deposits, condensation, ice and hoar frost.
Partial discharge	A discharge which only partially bridges the insulation between conductors. It may occur inside the insulation or adjacent to a conductor.
PLC	Power Line Communication
PoP	Point of Presence
Power transformer	A static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.
PPPoE	Point-to-Point Protocol over Ethernet
PUA	Powerline Utilities Alliance
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Service
Reference earth	Part of the Earth considered as conductive, the electric potential of which is conventionally taken as zero, being outside the zone of influence of any earthing arrangement.
SCADA	Substation Control and Data Acquisition
SF6	Sulfur Hexafluoride
Short-circuit	Accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal to or close to zero
SNR	Signal to Noise Ratio
Sulphur hexafluoride circuit-breaker	A circuit-breaker in which the contacts open and close in sulphur hexafluoride.
Switch (mechanical)	A mechanical switching device capable of making, carrying and breaking currents under norma1 circuit conditions which may include specified operating overload conditions and also carrying for a specific time currents under specific abnormal circuit conditions such as those of short circuit.

Switchgear	A general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution and conversion of electric energy.
Switchgear and controlgear	A general term covering switching devices and their combination with associated control, measuring, pro-tective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures.
TCP	Transmission Control Protocol
TDD	Time Division Duplexing
Transformer substation	A substation containing power transformers interconnecting two or more networks of different voltages.
TS	Transformer Station
Underground substation	A substation which is built to operate underground.
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
WAN	Wide Area Network
XLPE	Cross-Linked Polyethylene

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[14] EN 60950 "Safety of information technology equipment"

WHITE PAPER ON
MEDIUM VOLTAGE
POWERLINE COMMUNICATION
(PLC) NETWORKS

Annexes

CIGRE SC D2 WG 14

“Broadband PLC”

December 2005

TABLE OF CONTENTS

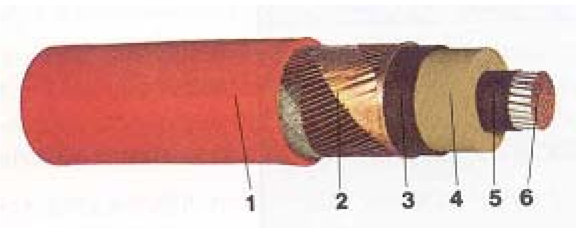
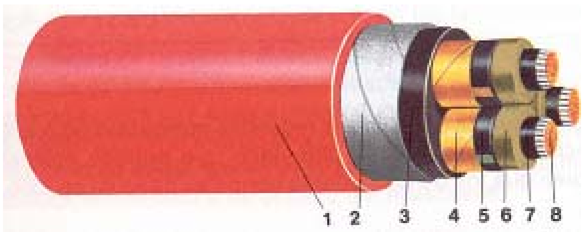
ANNEX A: DESCRIPTION OF THE MV ELECTRICITY NETWORK

9.1 A1 DESCRIPTION OF MV CABLES

The classification according to the type of insulation is shown next.

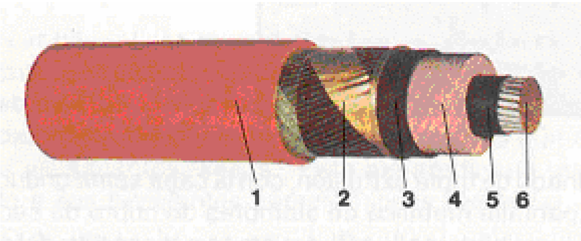
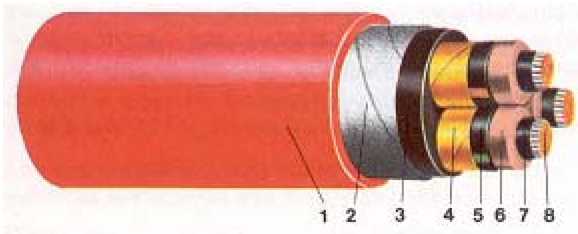
A1.1 XLPE insulated cables (eXtruded cross-Linked PolyEthlene)

XLPE insulation shows an excellent thermal stability that makes it suitable for operation at a conductor temperature of 90ºC and withstand overloads and short circuit rates corresponding to a thermo stable material. Its weakness is a relative to low resistance to ionization in the presence of moisture, water treeing, that forces to take special precautions in this kind of cables.

Unipolar cable	**Tripolar cable**
	
1. Oversheath 2. Metallic Sheath 3. Semi conducting tape 4. XLPE Insulation 5. Semi conducting tape 6. Conductor	1. Oversheath 2. Armouring 3. Sheath and Filler 4. Metallic screen 5. Semi conducting tape 6. XLPE Insulation 7. Semi conducting tape 8. Conductor

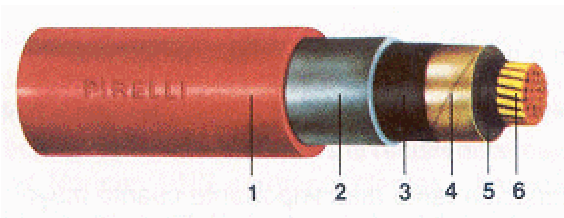
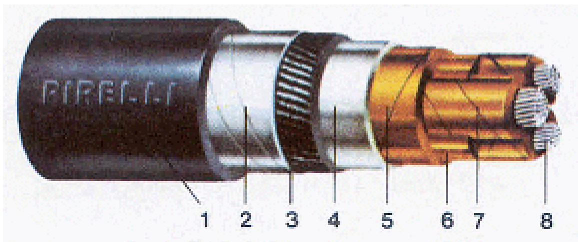
A1.2 EPR insulated cables (Ethylene Propylene Rubber)

This material has the advantages of the cross-linked polyethylene relating thermo stability, improving the resistance to moisture and the resistance to the Corona effect. Therefore, the EPR is the best dry insulation for the time being. Its weakness is the slightly higher dielectric losses factor than XLPE in the dielectric and, overall, a higher thermal resistance that decreases the maximum current that the cable can withstand in permanent conditions (5% compared to the XLPE).

<table>
<tr><th>Unipolar cable</th><th>Tripolar cable</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>1. Oversheath
2. Metal Sheath
3. Semi conducting tape
4. EPR Insulation
5. Semi conducting tape
6. Conductor</td><td>1. Oversheath
2. Armouring
3. Sheath and Filler
4. Metallic screen
5. Semi conducting tape
6. EPR Insulation
7. Semi conducting tape
8. Conductor</td></tr>
</table>

A1.3 Oil paper insulated cables

This type of insulation has been used since many years ago. Paper has little insulation value alone. However, when impregnated with a high grade of mineral oil, it serves as a satisfactory insulation for extremely high-voltage cables. The oil has a high dielectric strength, and tends to prevent breakdown of the paper insulation. The paper must be thoroughly saturated with the oil.

<table>
<tr><th>Unipolar cable</th><th>Tripolar cable</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>1. PVC
2. Lead tube
3. Conductor paper
4. Oil paper insulation
5. Conductor paper
6. Cu/Al conductor</td><td>1. PVC
2. Armouring
3. Sheath (bitumen fibres)
4. Lead tube
5. Insulation tape
6. Filler
7. Oil paper insulation
8. Conductor</td></tr>
</table>

Since 10 years ago, the trend is to use XLPE insulated cables instead of Oil paper cables that were used in the past, with the oversheath made of polyolefin. Nevertheless, many cables that can be found in existing installations are different. The older installations usually have oil paper insulated tripolar cables, which conductor is made of Copper more frequently than Aluminum, although both types are used. In newer installations, cables are XLPE insulated cables, with Aluminum conductor and oversheath made of PVC. In any case, the situation is different not only for each country but also for each utility in the same country.

The size of the cable can vary depending on the section of the grid where the cable is installed and it is directly related to the current that the cable has to withstand. Although it is possible to find many other values in old existing installations, nowadays the cross-sectional area of the conductor in the cables usually used in MV (12/24 kV) are 240 mm^2 (for the main branches), 150 mm^2 (for 1^{st} order branches) and 95 mm^2 (for 2^{nd} order branches) The external diameter of the cable depends on each particular manufacturer, and it is different depending on the composition of the cables.

9.2 A2 DESCRIPTION OF LV/MV TRANSFORMER SUBSTATIONS

The classification according to the size of the infrastructure is shown next.

A2.1 Masonry Transformer Substations

In the past, substations usually were conventional masonry substations, where all medium voltage elements were installed into compartments separated by walls and enclosed by a protective fence. This type of spacious substations can still be found nowadays. They are usually associated to tripolar cables because of the antiquity. Nevertheless, and due to the changes and works made on the electrical grid, it is possible to find unipolar cables inside masonry cubicles.

Masonry compartment with XPLE unipolar cables

Masonry compartments with tripolar cables

A2.2 Modular Transformer Substations

Metal-enclosed modular cubicles are the evolution of masonry compartments. Their compact dimensions allow for easy installation in small rooms or prefabricated substations. Depending on the size of connection compartment, it is possible whether install a capacitive coupling unit inside the cubicle or not. Installation must ensure a safety distance between coupler connection and any other element connected to ground (1 cm per kV). But not all utilities allow this kind of installation.

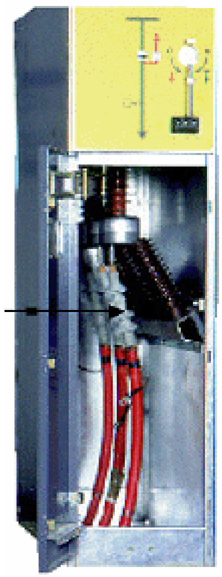
Considering air insulated switchgears cubicles, it is possible to find either tripolar or unipolar cables coming inside the modular cubicles. It depends on the year of installation and on the further changes made on the electrical grid.

On the other hand, SF6 cubicles are made to support unipolar cables connections. SF6 cubicles are being used for new installations. There are SF6 isolating and breaking cubicles, which all active parts and bus bars are situated inside a SF6 filled sealed for life module, and air isolating and SF6 breaking cubicles that integrates in a little module filled with SF6 gas the necessary switchgear for each one of the operation and protection functions.

In addition, Ormazabal, a Spanish manufacturer, has developed a new model for SF6 cubicles that integrates the capacitive coupling unit in the design.

Modular cubicle with tripolar cable

Modular cubicle with unipolar cables



SF6 isolated cubicle

A2.3 Compact Transformer Substations

In order to reduce the room allocated to transformer substations, compact transformer substations are being installed in newest installations. This kind of substations integrates all the elements in the same block. The space to install any external element (such as coupling units) is really small. Even the operation in many cases has to be done outside the substations, opening the doors. There are different models depend on placement: underground, semi-underground, outdoor, etc.

Compact Transformer Substation

ANNEX B. CHARACTERISTICS OF MV PLC COUPLING EQUIPMENT

9.3 B1 INDUCTIVE COUPLERS

The magnetic base material is a pure metal with superior magnetic characteristics. In opposite to ferrites, this material is a good conductor for electric current and this allows guaranteeing a safe ground potential by grounding the coupler:

- Safe ground potential guaranteed for connection and disconnection of PLC-equipment at the coupler.
- No static electricity discharge possible.
- No influence to electrical field inside the cabinet.

Because any inductive coupler is independent from the voltage level of an insulated cable, it depends on the current in this conductor.

This requires a magnetic material with no saturation up to the highest currents through the cable. Otherwise we will get an amplitude modulation of PLC signals and also intermodulation and harmonics of noise and signals.

Only pure metal cores allow meeting all requirements in saturation resistance, low intermodulation and broadband characteristics.

The advantages of pure metal cores instead of ferrites are:

- No saturation at high currents.
- No intermodulation.
- No change of magnetic characteristics from –40 to +130°C.
- No change of magnetic characteristics in case of high current peaks (20 kA).
- Smallest possible sizes.
- No aging of the magnetic core.

Typical technical data of inductive clamp-couplers are showed in the following table.

B1.1 Characteristics of Inductive Couplers

Rated voltage	Only dependent in the insulation of the cable: 0.4 up to 110 kV in combination with a insulated and shielded high voltage cable possible
Overall dimensions	Dependent in the usable inner diameter, e.g. Low voltage “in home” cables: approx. 30 x 30 x 60 mm Medium- and low-voltage “access” cables / bottles From a usable inner diameter of 43 mm: h= 85 mm x ∅ 80 mm Up to a usable inner diameter of 200 mm: h= 40 mm x ∅ 300 mm
Weight	Dependent in the size, from 120 g to app. 4 kg
Saturation resistance	300 Amps AC 50/60 Hz @ < 1 dB peak Hum-Modulation
Rated AC withstand voltage	Only depends on the insulation level of cable
Rated lightning withstand voltage (1,2/50 μs)	Only depends on the insulation level of cable
Insulation resistance	Only depends on the insulation level of cable
Partial discharge level at 1,2 Um	Non discharges possible, coupler is completely at ground potential
Coupling inductivity	Automatically physical adapting to frequency requirements: From 4 to 0,2 μH
Transmission frequency range typical values	2 to 40 MHz @ -4 ± 2 dB attenuation
Efficiency of coupling caused by energy distribution	Typically better η > 50%, reduced losses of PLC-signal in transformer
Insulation voltage data cable	500 V AC
Wave impedance ratios	1:1 by using matched feeding loop 1:1 to 1:0.4 by using universal feeding loop

Nominal impedance coupling side	20 to 50 Ohms with universal feeding loop 20 to 40 / 30 to 60 Ohms with matched feeding loop
Nominal impedance equipment side	50 Ohms / 60 Ohms (US)
Average power in permanence	> +40 dB mW
Gas arrester	If located at coupler: increasing in band signal energy in case of transient currents Connection cable with integrated or external gas arrester and transient filter at modem side is possible
Harmonic distortion and intermodulation	< - 60 dB
Typical installation time	10 minutes
MTBF	Cable (equipment side): ≥ 20 years Clamp-coupler: at least 40 years (Climatic category: 25/100/21 – C acc. to IEC 60068-1)

B1.2 Improvement of broadband PLC systems on shielded MV lines

Broadband PLC systems on shielded MV-line differ very much from LV-networks because of the cables used and the exactly known topology of the network. For using MV-lines instead or in combination with fiber type lines, it becomes important to get maximum performance and reliability. This point is a technical analysis of possible lines of improvement for inductive couplers.

For PLC operation, a Signal to Noise Ratio (S/N) of at least + 6 dB may be required. Apart from the attenuation of the coupling device, the attenuation of the line and the noise level, the S/N decreases when the level of man made noise grows or the hum modulation occurs:

$S/N[dB] = (Ps[dB_{mW}]) – (Ai[dB] + As[dB] + Ah[dB] + Pn[dB_{mW}])$

Ps[dBmW] = send level, relative 1 mW = 10 log (Ps / 1mW)

Ai[dB] = attenuation of the coupling device and energy distribution

As[dB] = attenuation of the line

Ah[dB] = hum modulation

Pn[dBmW] = noise level, relative 1 mW = 10 log (Pn / 1 mW)

a) Hum modulation: the biggest problem of inductive couplers

Hum modulation is the intermodulation of the PLC signal and the mains current. For intermodulation a non linear device is required, for example a saturated ferrite coupler.

Saturation happens if the mains current amplitude causes a too large magnetic density in the inductive coupler. Inductive ferrite couplers allow a B-field of 300-400 mT, inductive high saturation steel couplers of 1.200 – 1.600 mT.

Hum modulation causes a signal of this style.

However, even if every letter is correct and without additional noise, the signal is only as readable as the smallest letter will allow. In this "example" the hum modulation is 20 log (6 letter grade /12 letter grade) = -6 dB.

If we want to have compact couplers for easy installation, we have to allow a hum modulation of up to 3 dB per coupler at maximum current, even if they are made of pure high saturation resistant nanocristalline steel instead of ferrite.

A hum modulation of each 3 dB per coupler will cause a signal loss of 3 dB + 3 dB = 6 dB.

b) Man made noise

If a high current flows through the line, this current is caused by the operation of many devices. Unfortunately, with many devices there will be many sources of interference too.

The effect of man made noise is this style

A personal "reading" S/N is surely better than + 6 dB, because every letter is readable. But the types become less easy readable by interference, in this case by adding some "man made art". Reading is possible but will take additional time, slowing down the personal reading "system" performance.

Experience shows that the noise level will increase by 6 dB under these conditions, which means that the signal is half as good readable than without man made noise:

The signal wilλ be this style

Still readable but not good enough for stable operation.

c) Looking for solutions

c1) Using a pre-amplifier to increase the sensitivity of the modem

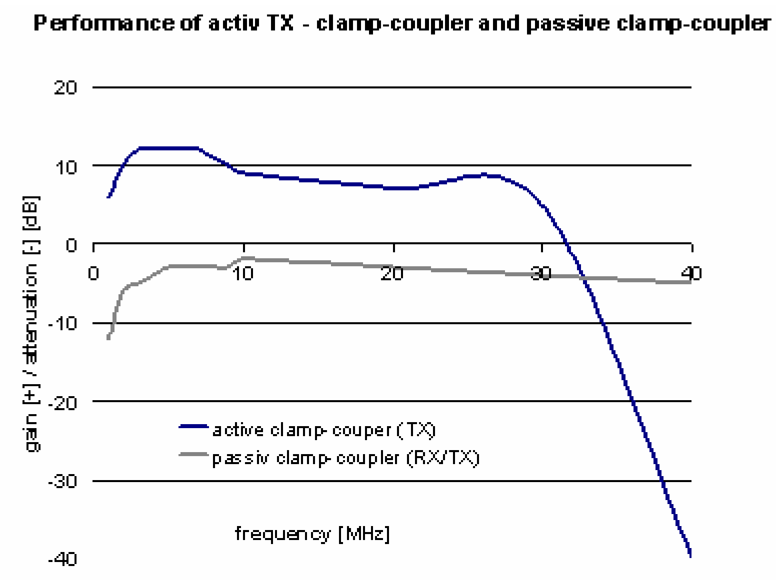
In MV networks with very low noise level, it is possible to increase the sensitivity of the modem by using a pre-amplifier.

This will help if the external man made noise on the line is lower than the noise level of the modem. The problem is that, in practice, this will only happen in some MV networks with star-structure. In any other cases, a pre-amplifier causes more problems than it solves. This is the signal without pre amplifier:

This is the signal With pre amplifier

c2) Using a boost-amplifier to increase the signal strength and the S/N

Some special inductive couplers with integrated power amplifier that feed an effective input of up to + 33 dBmW (2 watts), and offer an effective gain of +12 dB at the lower frequencies and + 6 dB at the higher frequencies, more critical concerning radiation.



As we can see, signals above the PLC band will be actively attenuated in order to supress harmonics. By releasing all interference and noise problems by its amplification, the problems will be reduced. In our example:

This is the signal without booster

This is the signal with booster

As shown above, the grade of hum modulation will not be reduced, but readability is improved and the grade of man made noise is decreased, which is simulated by changing another letter style with less “art”.

Of course, a modem with powerful output stage and automatic power setting is always the first choice. Although, as long as this improvement is only necessary in critical cases, is more convenient to use simple modems with an additional active coupler.

These couplers with integrated power amplifier can be used in combination with special reception-couplers, which improve the S/N and the effective blocking sensitivity KP of the modem.

9.4 B2 CAPACITIVE COUPLERS

Typical technical data example of capacitive couplers are shown in the following table.

B2.1 Characteristics of Capacitive Couplers

General	
Coupling type	Phase-to-earth by means of capacitor of 1 nF or 2 nF
MV power-line nominal voltage	24 or 36 kV (between phases)
Frequency range	2 - 38 MHz
Harmonic Distortion and Intermodulation	≥ 60 dB
Discharge current (ISN)	20 kA (8/20 μs)
Dielectric strength (50 Hz/1 min)	50 kV according to IEC 60358 (24 kV coupler) 70 kV according to IEC 60358 (36 kV coupler)
Impulse voltage (1.2/50 μs)	125 kV according to IEC 60358 (24 kV coupler) 170 kV according to IEC 60358 (36 kV coupler)
Isolation resistance	>10 GΩ
Transformer insulation	5 kVrms /50 Hz/1 min (according to IEC 61334-3-22)
Partial discharges	<10 pC at 15 kV according to IEC 60358 (24 kV coupler) <10 pC at 22.8 kV according to IEC 60358 (36 kV coupler)
Nominal impedance	
Equipment side	50 Ω
Type	Unbalanced or Balanced
Line side	20 Ω
Permanent average power	500 mW
Composite loss	≤ 3 – 4 dB (24 kV coupler) ≤ 5 – 7 dB (36 kV coupler)
Return loss (equipment side for 50 Ω and line side for 20 Ω)	≥ 6 - 10 dB
Drain coil	
Impedance at 50/60 Hz	< 20 Ω
Current carried at 50/60 Hz	1 Arms permanently 50 Arms for 0.2 s (according to IEC 61334-3-22)
Gas surge arrester (line side)	230 V (Nominal Voltage)

Operating and storage conditions	
Temperature and humidity	From –25 to +55ºC and humidity relative from 10 to 100% in accordance with EN 60870-2-2 class C2 (climatogram 3K6)
Storage conditions	From –40 to +70ºC and humidity relative from 10 to 100% In accordance with EN 60870-2-2 class C3 (climatogram 1K5)
Behavior against ageing	In accordance with IEC 60932
Mechanical characteristics	
Connection to line	By means of M10 rod or M10 screw base of approx. 20 mm in depth
Connection to the communication terminal	By means of TNC or BNC connector
Connection to earth and fixing	By means of M8 rods