



BSI Standards Publication

Power line communication systems for power utility applications

Part 1: Planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids

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This British Standard is the UK implementation of EN 62488-1:2013. It is identical to IEC 62488-1:2012. It supersedes BS EN 60495:1994 which is withdrawn.

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**Power line communication systems for power utility applications -
Part 1: Planning of analogue and digital power line carrier systems
operating over EHV/HV/MV electricity grids
(IEC 62488-1:2012)**

Systèmes de communication sur lignes
d'énergie pour les applications des
compagnies d'électricité -
Partie 1: Conception des systèmes à
courants porteurs de lignes d'énergie
analogiques et numériques fonctionnant
sur des réseaux d'électricité EHT/HT/MT
(CEI 62488-1:2012)

Systeme zur Kommunikation über
Hochspannungsleitungen für
Anwendungen der elektrischen
Energieversorgung -
Teil 1: Planung von Systemen zur
analogen und digitalen
Nachrichtenübertragung über
Hochspannungsleitungen
(IEC 62488-1:2012)

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Foreword

The text of document 57/1279/FDIS, future edition 1 of IEC 62488-1, prepared by IEC/TC 57 "Power systems management and associated information exchange" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62488-1:2013.

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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

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IEC 61000-4-4	NOTE Harmonised as EN 61000-4-4.
IEC 61000-4-5	NOTE Harmonised as EN 61000-4-5.

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INTRODUCTION

The complexity and extensive size of present-day electricity generation, transmission and distribution systems are such that it is possible to control them only by means of an associated and often equally large and complex telecommunication system having a high order of reliability.

The control of electrical networks and transmission and reception of data are through a combination of analogue and digital communication systems controlling devices and systems distributed throughout the electrical network.

The emergence of digital communication systems for controlling the devices of the electrical distribution network enables faster data transmission. The ability to represent the various electrical parameters as an analogue signal and or digital signal ensures the quality and quantitative aspects of seamless communication to be maintained throughout the electrical power network.

Therefore, by using either analogue power line communication (APLC) or digital power line communication (DPLC) or a combination of both types of system, seamless efficient communication may be maintained throughout the power network.

The development of digital techniques for communications in the electrical distribution networks is now very widespread along with other applications in electronics. This is especially relevant for the electrical distribution network where many of the devices have built into them analogue to digital converters, together with digital signal processing enabling them to perform many functions and offer fast seamless communication. The conversion of the analogue signal into a binary signal requires the binary digits to be formed into a code for the transmission of the information. These codes take different forms to represent the information to be transmitted. However, the main advantage for this is that digital signals compared with analogue signals provide for virtually error free transmission and the minimum errors that do arise may be detected and corrected by using suitable data encoding techniques. Further, digital transmission circuits generally are compatible with the digital devices in the communications circuit. The most commonly used multiplex systems are frequency division multiplex (FDM) and time division multiplex (TDM).

The development of the technical report “Planning of power line carrier systems” was first produced by the International Electrotechnical Commission through publication IEC 60663 in 1980 entitled Planning of (single sideband) power line carrier systems. In 1993, the International Electrotechnical Commission produced IEC 60495 “Single sideband power-line carrier terminals”. In the intervening years, electronic systems and the associated communications systems for electronic devices evolved and developed considerably. The introduction of digital transmission and reception techniques improved the quality of transmission and reception within electronic devices, enabling them to provide more detailed quality analysis and control of the data being communicated throughout the electricity distribution network, from control centre to service provider.

Both of these standards, IEC 60663 and IEC 60495, are being updated and replaced by the following: IEC 60663 is replaced by IEC 62488-1 and IEC 60495 is replaced by IEC 62488-2, IEC 62488-3, IEC 62488-4, covering respectively analogue, digital power line carrier and broadband power line terminals.

The first part of this series is IEC 62488-1. Following this standard, parts IEC 62488-2, IEC 62488-3, IEC 62488-4 will follow. During the development of the above mentioned standards, the existing standards IEC 60663 and IEC 60495 will be maintained in use. They will be subsequently phased out at a date to be agreed by the International Electrotechnical Commission in conjunction with IEC technical committee 57.

These international standards apply to power line carrier (PLC) terminals used to transmit information over power networks including extra high, high and medium voltage (EHV/HV/MV) power lines. Both analogue and digital modulation systems will be included.

IEC 62488 series consists of the following parts under the general title: Power line communication systems for power utility applications:

- Part 1: Planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids;
- Part 2: Analogue power line terminals or APLC;
- Part 3: Digital power line carrier terminals or DPLC;
- Part 4: Broadband power line systems or BPL.

POWER LINE COMMUNICATION SYSTEMS FOR POWER UTILITY APPLICATIONS –

Part 1: Planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids

1 Scope

This part of IEC 62488 applies to the planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids. The object of this standard is to establish the planning of the services and performance parameters for the operational requirements to transmit and receive data efficiently over Power Networks.

The transmission media used by the different electricity supply industries will include analogue and digital systems together with more common communication services including national telecommunications authorities, radio links and fibre optic networks and satellite networks. With the developments in communication infrastructures over the last two decades and the ability of devices connected in the electricity communications network to internally and externally communicate, there is a variety of architectures to use in the electricity distribution network to provide efficient seamless communications.

These series of standards for the planning of power line carrier systems will also be an integral part of the development of the overall architecture, standard IEC 61850 developed within IEC TC57 which provides the fundamental architecture for the formation of the smart grid.

2 Terms, definitions and abbreviations

2.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Other terms used in this standard and not defined in this clause have the meaning attributed to them according to the International Electrotechnical Vocabulary (IEV).

2.1.1 amplitude modulation

AM

modulation technique in which information is transmitted through amplitude variation of a carrier wave

2.1.2 analogue interface

interface dedicated to the processing of voiceband analogue signals

2.1.3 anomaly

small discrepancy between the actually received and the desired data

Note 1 to entry: The occurrence of a single anomaly does not cause interruptions of the applications using the transmitted data.

2.1.4**attenuation**

power reduction along a transmission line for the mode or modes under consideration, quantitatively expressed either by the ratio or the logarithm of the ratio of an input power at the initial point to the corresponding output power at the final point

2.1.5**availability**

time or fraction of time a system is operational over a given time interval

2.1.6**background noise**

noise present over all real high voltage power-line channels due mainly to corona and, partial discharges and electromagnetic interference with other PLC equipments operated over the same electricity grid and other interferences due to radio stations working in the same radio frequency spectrum

2.1.7**bit error ratio****BER**

ratio of the number of bits errors received divided by the total number of bits sent

2.1.8**bit error ratio test****BERT**

set of instruments and measurement methodology to be adopted to evaluate the BER of a transmission system

2.1.9**broadband over power line****BPL**

technology that allows data to be transmitted over utility power lines using bandwidths of several MHz

Note 1 to entry: These systems typically run over a frequency spectrum in a range from 1 MHz to 30 MHz allowing the transmission of broadband communications. These systems can be found on all the range of power lines from LV to MV. The BPL systems are means to deliver broadband communications to homes and business facilities. Among the BPL systems, we can distinguish the systems used outside the homes or offices (to-the-home-internet access also called access BPL or smart-grid applications operated by the electricity companies) and the "in-home" or "in-house" applications used for home networking (Generally using an Ethernet network technology) and automation. These applications are generally called Home Plug applications.

2.1.10**carrier-frequency range**

bandwidth available for a specific power line carrier communication technology

Note 1 to entry: In Europe, the typical carrier-frequency range for narrowband HV PLC is 3 kHz to 148,5 kHz or for broadband PLC is 1,6 MHz to 30 MHz. For the USA IEEE PLC standard the frequency range is 45 kHz to 450 kHz. Parts of the range may be barred by national regulations.

2.1.11**channelling**

elementary subdivision of the carrier frequency range or part thereof allocated to a single PLC transmits and receive channel (bidirectional)

2.1.12**code division multiple access****CDMA**

multiple access technique in which a number of transmitters modulate their data on pseudo random signals which are orthogonal to each other, which prevents the demodulators from seeing signals other than their own

2.1.13

coloured noise

non-white noise or any wideband noise whose spectrum has a non-flat shape

Note 1 to entry: Also called non-white noise; examples are pink noise, brown noise and autoregressive noise.

2.1.14

corona noise

noise caused by partial discharges on insulators and in air surrounding electrical conductors of overhead power lines

Note 1 to entry: Discharges occur on the three different phase conductors at different times. The corona noise level is considerably dependent on weather conditions. The effect of the corona noise is particularly strong under foul weather conditions.

2.1.15

coupling capacitor

capacitor used for the coupling of the carrier signal to the power line in a PLC system

2.1.16

coupling system

group of devices used to couple the PLC high frequency signals to the power line

2.1.17

defect

large discrepancy between the actually received and the desired data

Note 1 to entry: Defects cause interruptions of the applications using the transmitted data and are used as input for performance monitoring, the control of consequent actions, and the determination of fault causes. Examples are: loss of signal, sync loss, alarm indication signal, slip, loss of frame alignment.

2.1.18

distribution line carrier

DLC

system for communication over the distribution power lines

Note 1 to entry: They DLC systems can be narrow band high speed communication systems on the medium voltage distribution network, or broadband/narrow band communication systems on the low voltage distribution network.

2.1.19

effectively transmitted signal-frequency band

that part of the frequency band used for the transmission of the baseband signal

2.1.20

environment

external conditions in which a system operates

Note 1 to entry: Different classes of constraints and limits for EMC/EMI are defined for environment classes such as industrial, commercial, domestic.

2.1.21

error free second

EFS

a one second period without bit error

2.1.22

errored second

ES

a one-second period in which one or more bits are in error

2.1.23

errored second ratio

ESR

ratio of errored seconds ES to total seconds in available time during a fixed measurement interval

2.1.24

Ethernet interface

interface dedicated to the processing of data signals in accordance with the recommendation IEEE 802.3 (2000)

2.1.25

forward error correction

technique used for correcting errors in data transmission over unreliable or noisy communication channels by encoding the message at the sender in a redundant way by using an error-correcting code so as to enable the receiver to correct a limited number of bit errors

2.1.26

frame check sequence

FCS

extra bits or characters added to a data frame for error detection

2.1.27

frame loss rate

the number of frames that never reached the destination divided by the number of frames transmitted successfully by the source

Note 1 to entry: It is usually expressed as a percentage.

2.1.28

frequency division multiplexing

FDM

multiplexing technique in which several transmitters are allotted separate frequency bands for transmission over a common channel

2.1.29

frequency shift keying modulation

FSK

a frequency modulation technique in which coded information is transmitted through discrete frequency changes of a carrier wave

2.1.30

gross data rate

number of bits per unit of time exchanged between the terminals of a PLC link

2.1.31

group delay

propagation time of a narrowband signal from input to output of a linear system

Note 1 to entry: Mathematically, group delay equals the negative derivative of the phase shift in radians between input and output of a linear system versus angular frequency.

2.1.32

impulsive noise

noise consisting of short-duration pulses of random amplitude and random duration

2.1.33

jitter

short-term variations of the significant instants of a timing signal from their ideal positions in time (where short-term implies that these variations are of frequency greater than or equal to 10 Hz)

2.1.34

latency

time from the source sending a packet into a packet switched network to the destination receiving it

Note 1 to entry: One-way latency is distinguished from round trip latency, which is the one-way latency from source to destination plus the one-way latency from the destination back to the source. Round-trip latency is more often quoted, because it can be measured from a single point. Note that round trip latency excludes the amount of time that a destination system spends processing the packet.

2.1.35

line matching unit

LMU

unit which interfaces the EHV/HV side of power line with the PLC equipment

Note 1 to entry: It usually consists of a box mounted near the coupling capacitor. Its characteristics are normalized by IEC 60481.

2.1.36

line trap

a device presenting high impedance at the carrier frequency band while introducing negligible impedance at the power frequency

Note 1 to entry: The high impedance limits the power of the carrier signal within the power system. Line traps are connected in series with transmission lines. In most cases the Line trap is mounted directly on top of the coupling capacitor. Its characteristics are normalized by IEC 60353.

2.1.37

modulation scheme

technique used to convert a baseband signal into a high frequency carrier signal suitable for transmission over power line

Note 1 to entry: Examples are: AM-SSB, Spread Spectrum, QAM, OFDM.

2.1.38

multiplexing techniques

method by which multiple analog message signals or digital data streams are combined into one signal over a shared medium

2.1.39

narrowband noise

noise process with a narrow bandwidth such as a 50/60 Hz 'hum' from the electricity supply

2.1.40

nominal high frequency band

frequency band in which a particular PLC transmitter or receiver is operating within the carrier-frequency range

2.1.41

nominal impedance

value of impedance for which an input or output circuit has been designed and for which the prescribed requirements apply

2.1.42**operating conditions**

set of conditions (e.g., voltage, temperature, humidity, and the like) over which the specified parameters maintain their stated performance rating

2.1.43**orthogonal frequency division multiplexing****OFDM**

modulation scheme that distributes the data over a large number of sub-carriers with frequencies such that the sub-carriers are orthogonal, which prevents the demodulators from seeing sub-carriers other than their own

Note 1 to entry: Each sub-carrier is modulated with a conventional modulation scheme (such as QAM or PSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

2.1.44**peak envelope power****PEP**

average power of a carrier signal present during one cycle of the carrier-frequency at the highest crest of the modulation

Note 1 to entry: It is recommended that in order to determine the peak envelope power, the transmitter should be modulated by two sinusoidal voice-frequency signals of equal amplitude, located within the effectively transmitted frequency band. The transmitter is terminated by a resistive load equal to its nominal impedance and the limiter is not in operation. The amplitude of the modulation signals must be chosen as to satisfy the requirements for spurious emissions. The peak envelope power is then considered to be four times the power of one of these signals, selectively measured (CCIR Recommendation 326-1, point 3.1.3.1).

2.1.45**peak to average power ratio****PAPR**

peak power of a signal divided by its average power

2.1.46**phase shift keying****PSK**

modulation scheme that conveys data by changing, or modulating, the phase carrier signal

2.1.47**PLC mean output power**

output power of a PLC terminal averaged over a time sufficiently long compared with the cycle time of the lowest modulating frequency and during which this average power assumes the highest value for which the equipment has been designed

2.1.48**PLC nominal output power**

output power of a PLC terminal expressed as the peak envelope power (PEP) for which the equipment has been designed, compatible with the requirements for spurious emissions, available at the carrier frequency output across a resistive load equal to the nominal impedance

2.1.49**PLC terminal equipment**

equipment able to manage a telecommunication link over a high voltage power line, mainly used to reliably transmit speech, data and power system protection signals

2.1.50**power line**

installation used to transfer electric energy from one point to another in an electric power system

2.1.51
quadrature amplitude modulation
QAM

analog or digital modulation scheme conveying two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves with 90° phase difference, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme

2.1.52
quality objective

specified level of quality that shall be met by a system to be deemed acceptable

Note 1 to entry: In speech communication, quality objectives can be subjective when listeners judge transmission quality by qualifiers such as excellent, good, fair, poor or unsatisfactory.

2.1.53
quality of service
QoS

defined measure of performance in a data communications system

2.1.54
reliability

degree of the ability of a system to consistently perform according to its specifications

2.1.55
return loss

loss of signal power resulting from the reflection caused by impedance mismatch

Note 1 to entry: The return loss is usually expressed as a ratio in decibels (dB).

2.1.56
sensitivity level

minimum power level of an HF signal to be applied at the receiver input in order to sustain the maximum specified data throughput affected by a predefined BER

Note 1 to entry: Example: sensitivity level = –60 dBm at 64 kb/s and BER=10^{–6}.

2.1.57
serial interface

interface dedicated to the processing of serial type data signals

2.1.58
severely errored second
SES

a one-second period which has a bit error ratio $\geq 10^{-3}$ or during which loss of signal (LOS) or alarm indication signal (AIS) is detected

2.1.59
severely errored second ratio
SESR

ratio of severely errored seconds SES to total seconds in available time during a fixed measurement interval

2.1.60
single side band modulation
AM-SSB

refinement of amplitude modulation that more efficiently uses electrical power and bandwidth

2.1.61**signal to noise ratio****SNR**

ratio between the signal power and the noise power

2.1.62**smart grid**

application of computer intelligence and networking abilities to the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements, from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices

2.1.63**spurious emissions**

emissions at one or more frequencies, which are located outside the nominal carrier-frequency band

Note 1 to entry: Spurious emissions comprise harmonics, parasitic signals and intermodulation products.

2.1.64**tapping loss**

measure of the loss of power sustained by a carrier frequency signal when connected to the carrier output of a PLC equipment

2.1.65**telecommunication management network****TMN**

architecture for management, including planning, provisioning, installation, maintenance, operation and administration of telecommunications equipment, networks and services

Note 1 to entry: TMN uses the OSI management standards as its framework and applies to all telecommunication technologies: wired, wireless as well as to private and public networks.

2.1.66**throughput**

number of bits per unit of time available at the user data interface of a PLC link

2.1.67**time division multiple access****TDMA**

multiple access technique using TDM

2.1.68**time division multiplexing****TDM**

multiplexing technique in which several transmitters are allocated separate periodic time intervals for transmission over a common channel

2.1.69**transient noise**

noise consisting of relatively long duration noise pulses

2.1.70**wander**

long-term variations of the significant instants of a digital signal from their ideal position in time (where long-term implies that these variations are of frequency less than 10 Hz)

2.1.71

white noise

purely random noise that has a flat power spectrum

Note 1 to entry: Band limited white noise refers to noise with a flat spectrum and a limited bandwidth.

2.2 Abbreviations

ADSL	asymmetrical digital subscriber line
AGC	automatic gain control
AIS	alarm indication signal
AM	amplitude modulation
APLC	analogue power line carrier
AWGN	additive white Gaussian noise
BER	bit error rate
BERT	bit error rate test
BPL	broadband over power line
CC	coupling capacitor
CDMA	code division multiple access
CENELEC	comité européen de normalisation électrotechnique
CF	carrier frequency
CISPR	comité international spécial des perturbations radioélectrotechniques
CSMA/CD	carrier sense multiple access with collision detection
CVT	capacitor voltage transformer
DLC	distribution line carrier
DPLC	digital power line carrier
E&M	ear and mouth (telephone signalling wires)
EFS	error free second
EHV	extra high voltage
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPS	electricity power system
ES	errored second
ESR	errored second ratio
ETH	Ethernet
ETSI	European telecommunications standards institute
FCS	frame check sequence
FDM	frequency division multiplexing
FIR	finite impulse response
FSK	frequency shift keying
FXO	foreign exchange office
FXS	foreign exchange subscriber
GMR	geometric mean radius
HF	high frequency
HTTP	hypertext transfer protocol
HV	high voltage

ICAO	international civil aviation organization
IEEE	institute of electrical and electronics engineers
IETF	internet engineering task force
IEV	International Electrotechnical Vocabulary
IP	internet protocol
ISO	international organisation for standardisation
ITU	international telecommunications union
LAN	local area network
LMS	least mean squares
LMU	line matching unit
LOS	loss of signal
LV	low voltage
MAC	media access control
MOS	mean opinion score
MV	medium voltage
NAT	network address translation
NIC	network information center
OFDM	orthogonal frequency-division multiplexing
OPGW	optical ground wire
OSI	open system interconnection
OSPF	open shortest path first
PABX	private automatic branch exchange
PAM	pulse amplitude modulation
PAPR	peak to average power ratio
PEP	peak envelope power
PESQ	perceptual evaluation of speech quality
PLC	power line carrier
PLCS	power line communication system
PLT	power line telecommunications
PSK	phase shift keying
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase shift keying
REN	renewable energy
RIP	routing information protocol
RMS	root mean square
RTU	remote terminal unit
Rx	receive(r)
SCADA	supervisory control and data acquisition
SDA	synchronous digital hierarchy
SES	severely errored second
SESR	severely errored second ratio
SNMP	simple network management protocol

SNR	signal to noise ratio
SSB	single side band
TCP	transmission control protocol
TDM	time division multiplexing
TDMA	time division multiple access
Tx	transmit(ter)
UDP	user datagram protocol
VDSL	very-high-bit-rate digital subscriber line
VoIP	voice over IP
WAN	wide area network
Wi-Fi	Wireless Fidelity

3 Power line communication systems

3.1 Introduction to PLC

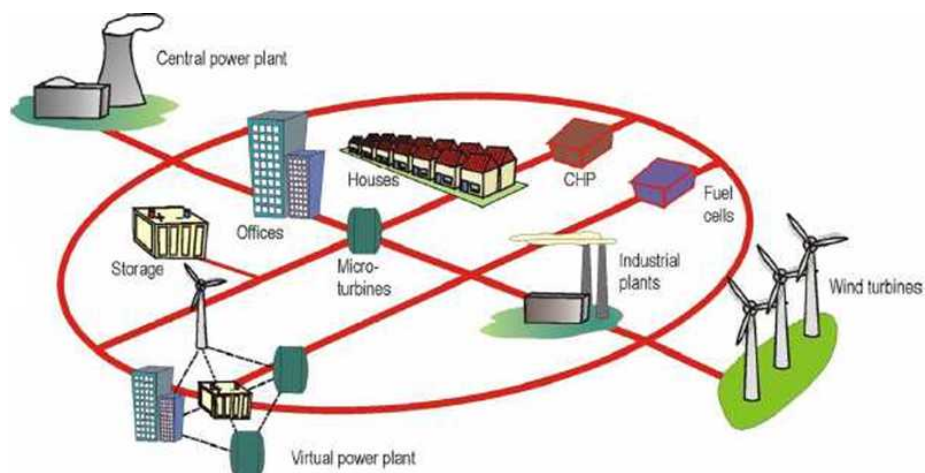
3.2 PLC usage

The electrical grids have been relatively steady from the middle of the 20th century until the 1980's when the digital processing techniques began to be of common use.

Since that time, the constant evolution in the telecom electronic and the need for more reliable power network have brought the PLC from single point to point link equipment used mainly for supporting teleprotection service and simple PABX interconnection to extend telephony service to modern networking equipment that can be used in service oriented telecom architectures.

The modern power line carrier system can be integrated into IP communication network interconnecting nodes at data link level as point to point links (on HV and EHV networks) or as part of the network itself (multipoint broadband applications on the MV and LV networks).

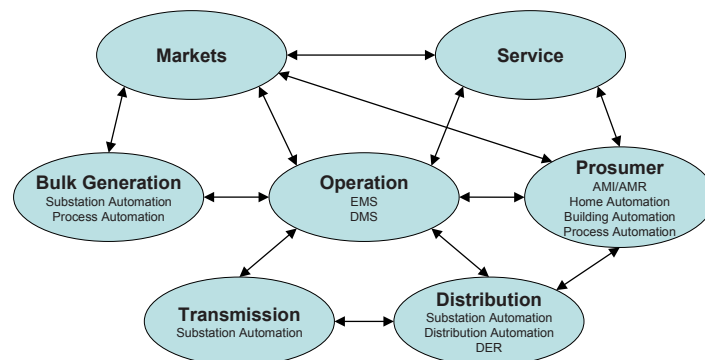
In addition, this new architecture provides solutions for management, control and monitoring of the equipment (SNMP capabilities mainly) that reduce the cost of commissioning and maintenance.



(Source: COM/2006/0105 final GREEN PAPER – A European Strategy for Sustainable, Competitive and Secure Energy)

Figure 1 – Smart grid vision

Current electricity grids are developing into smart grids, increasing the number of electricity business players' demand for an improvement in terms of communication resources. PLC will play a key role on this arena. An example of the smart grid is shown in Figure 1.



(Source: IEC SMB/SG3 SMART GRID Survey – 2009)

Figure 2 – Smart grid players

They are ubiquitous and represent a well proven technology since long time exploited in any segment of the electricity grids from EHV/HV/MV to LV providing for very successful applications. An example is shown in Figure 2.

3.3 PLC telecommunication system

A PLC telecommunication system consists of one or more PLC links together with other telecommunications such as SDH communications. They can form a network of PLC or part of it. An example is shown in Figure 3.

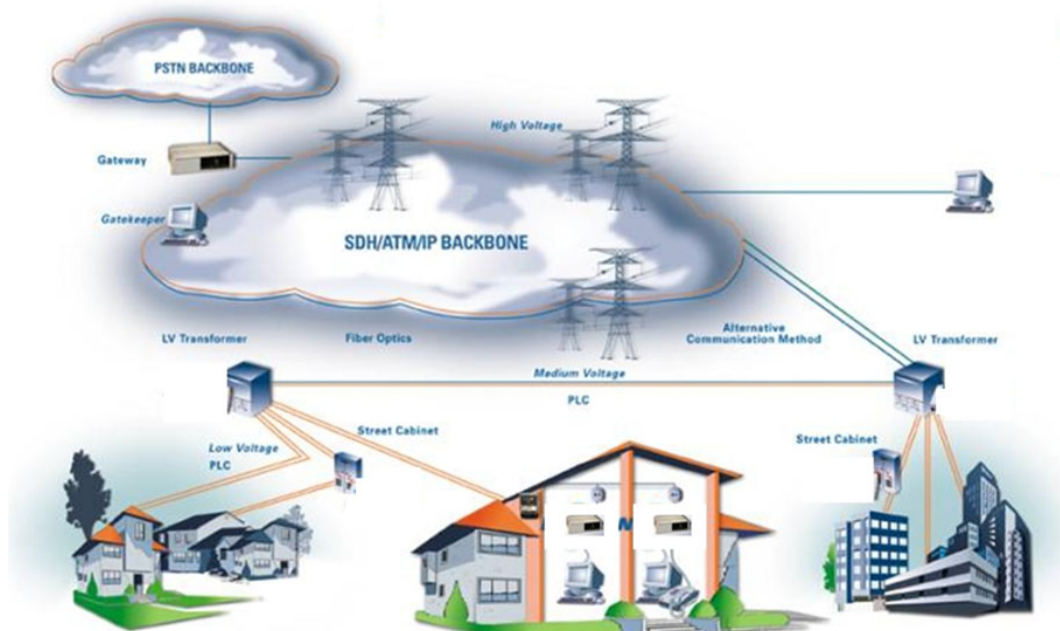


Figure 3 – Complex PLC telecommunication system

According to the definition each PLC telecommunication link consists of:

- two PLC terminals,
- two coupling systems,

- an electricity power line (EHV/HV/MV).

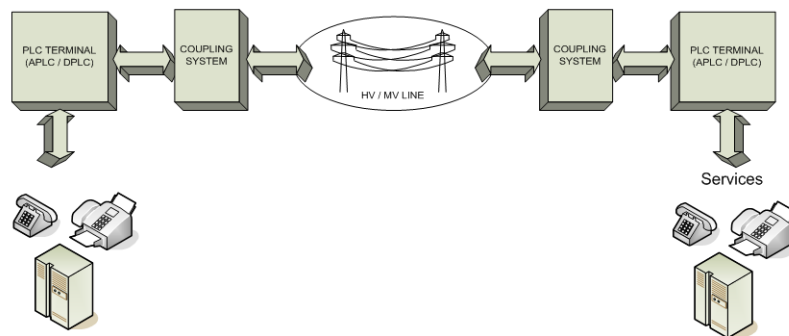


Figure 4 – PLC telecommunication link

Terminal equipments can be divided in two categories: Analogue PLC equipments and Digital PLC equipments respectively named APLC and DPLC systems. A general description of such equipments focusing on their main technical features is provided in the followings paragraphs. An example of this type of link is shown in Figure 4.

Detailed aspects concerning the power line transmission media and coupling systems are described in Clause 5.

Refer to Annex A regarding environmental conditions and Annex B regarding EMC for PLC equipment.

3.4 Analogue and digital PLC systems (APLC & DPLC)

3.4.1 APLC systems

APLC systems, as shown in Figure 5 have been in use from the 1930s and are commonly used by the electricity utilities for their communication (teleprotection, telephone and data, fax) mainly on the EHV and HV electricity transmission grid.

The modulation scheme generally used for these systems is the single sideband (SSB) amplitude modulation to carry one or several basic telephone channels in the carrier range from 20 kHz to 500 kHz (sometimes extended to 1 MHz).

When more than one service is required, the services are mixed using frequency-division multiplexing. The main limitation of APLC systems is the data rate which is limited to some hundred bps per service because of the limited bandwidth and the nature of the modulation.

In the following, some of the most used technologies within APLC systems are listed:

- Frequency-division multiplexing;
- Single sideband modulation;
- Channel equalisation;
- FSK modem (rates $\leq 2\,400$ bit/s);
- PSK or QPSK modem (rates > 600 bit/s).

A typical APLC terminal equipment structure is given in Figure 5.

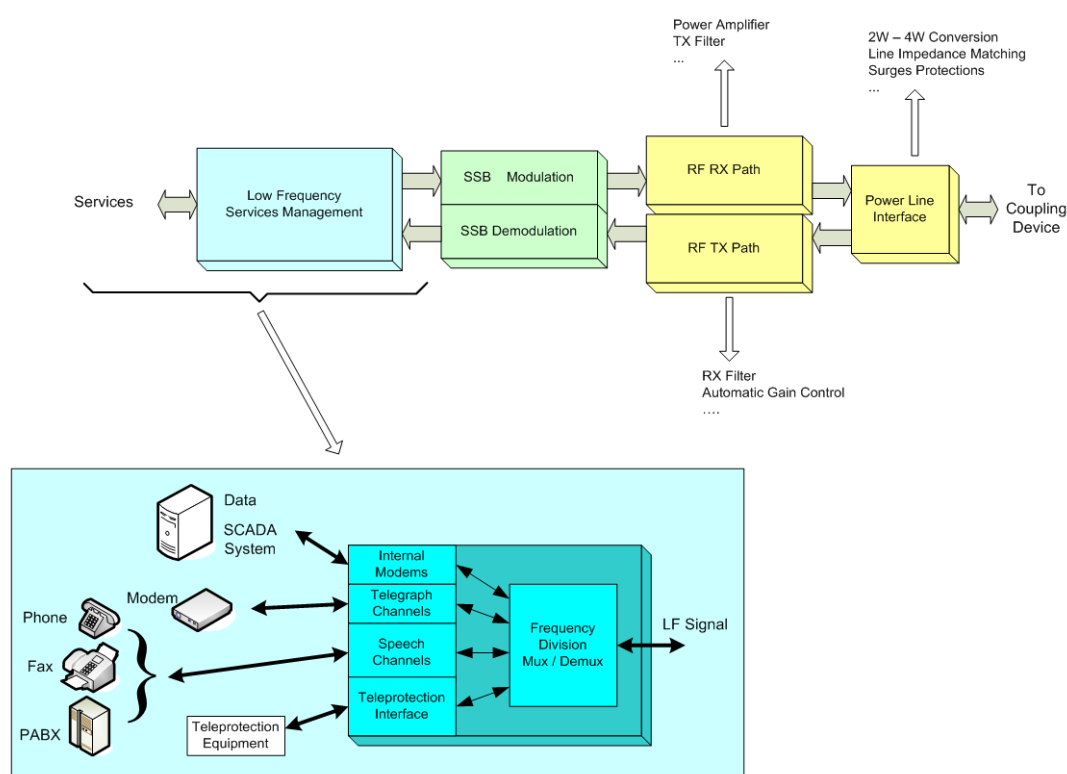


Figure 5 – Typical structure of an APLC terminal equipment

3.4.2 DPLC systems

From the early 1980s, there has been a wide interest in developing PLC systems based on digital modulation schemes. The original information can be either data in its original format or digitised signals, such as speech, fax or others.

When more than one service is to be transmitted, digital PLC makes use of time division multiplexing to arrange the different services into a single stream.

The main advantage of digital PLC links as compared to analogue PLC links are the following:

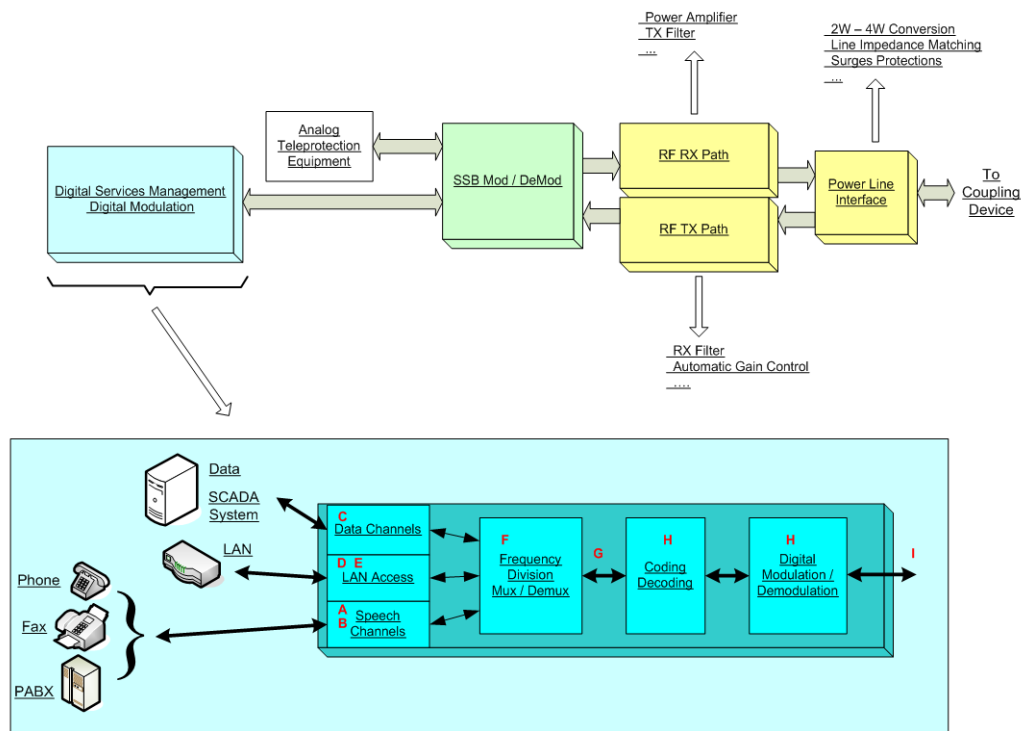
- a) Enhancing the transmission capacity compared with traditional analogue PLC links for the same channel bandwidth:
 - more data channels (or data channels running at higher rates);
 - more speech channels using vocoding techniques.
- b) Easy integration of the PLC network into a larger digital network (digital PLC as an embedded component of a digital telecommunications network):
 - $n \times 64$ kbps channel as a tributary channel of a digital telecom network;
 - Digital data interfaces for lower speed data avoiding intermediate modems;
 - Data rate of DPLC allow their use for LAN to LAN connection (typically through an Ethernet access);
 - A native network access provide an easy way to integrate the DPLC links in a network management system.
- c) The use of time-division multiplexing provides greater degrees of flexibility as compared to frequency-division multiplexing.

Digital PLC links can be used in access links or network internal links, for the transmission of speech, data and teleprotection related signals.

In the following, some of the most used technologies within DPLC systems are listed:

- Quadrature-amplitude modulation;
- Multicarrier modulation (OFDM);
- Trellis coding;
- Echo cancellation;
- Adaptive equalisation;
- Time-division Multiplexing;
- Speech compression.

A typical DPLC terminal equipment structure is given in Figure 6.



Key

- A Speech/telephone interfaces: 2 wires or 4 wires with E&M signalling, FXO, and FXS
- B Speech coding and management includes speech compression/decompression, echo cancellation, digital management of signalling and call progress, FAX, etc.
- C Interfaces for data service: V.24/V.28, V.11 (X21, X24), G.703, etc.
- D LAN interface; mainly Ethernet interface
- E TCP or UDP /IP for LAN to LAN communication. Can also be at applicative level (FTP, SNMP.)
- F Digital time division multiplexer; multiplexes a number of channels into an aggregate serial bit stream.
- G Digital interface, aggregate multiplexed serial data running at a given gross bit rate. The specific value of this gross bit rate depends on the implementation. For a given implementation it may have different possible values.
- H Signal converter; converts the digital data into a signal which is suitable for transmission over band limited PLC channels, using a given modulation format. The two main modulation schemes currently used are QAM and OFDM.
- I Band limited signal carrying the digital information of G.

Figure 6 – Typical structure of a DPLC terminal equipment

It is important to note that the teleprotection functionality currently is still managed as analogue service.

Depending from the design, it can be an access for an external analogue teleprotection, as well as a teleprotection device integrated into the PLC system.

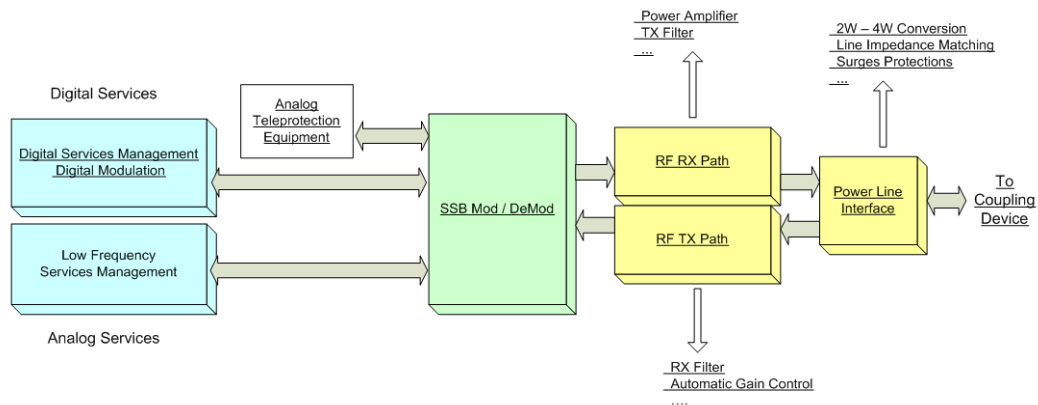


Figure 7 – APLC/DPLC terminal equipment structure

PLC systems can also be composed by a mix of APLC/DPLC terminals. Figure 7 gives an example of such a PLC System.

A typical APLC/DPLC link carrying telecontrol, teleprotection and telephony services is shown in Figure 8.

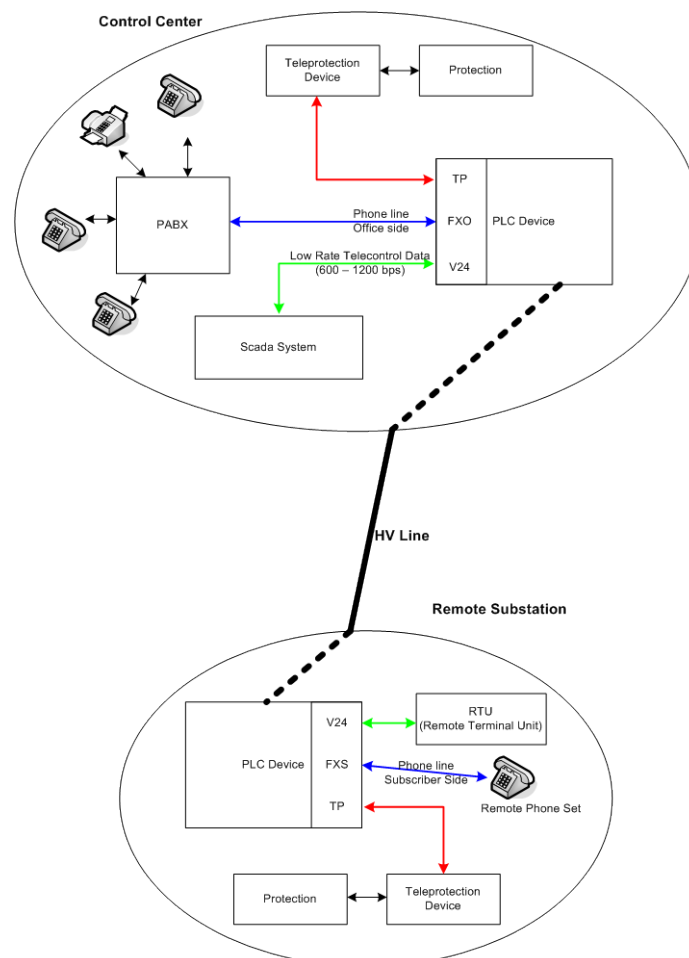


Figure 8 – APLC/DPLC link carrying telecontrol, teleprotection and telephony services

3.5 PLC modulation schemes

3.5.1 General

The modulation technique to be adopted for PLC equipment is a design issue depending on several factors. In the following are summarized the key features and parameters to be considered to perform an evaluation and comparison of the most commonly used modulation techniques in the PLC field.

3.5.2 AM-SSB (Refer to Table 1)

AM-SSB stands for amplitude modulation with single sideband. It is used as the modulation method in the analogue PLC terminal equipments (IEC 60495:1993). It can also be used as the final high frequency modulation in a digital PLC terminal. The conventional amplitude modulation scheme (with both sidebands and full carrier transmission) was used in the early years of analogue PLC, but has been replaced by the SSB modulation to provide a better efficiency of the transmission. Actually, the suppression of one of the sidebands and the suppression of the carrier (or the transmission of a reduced amplitude carrier) allows a significant reduction of the transmitted power to achieve the same quality of service with the same signal to noise ratio.

3.5.3 QAM (Refer to Table 1)

Quadrature Amplitude Modulations are in fact combinations of ASK and PSK modulations. Often a geometric representation of these amplitude factors is used. This geometric representation is called signal space, and each waveform is represented by a dot in the signal space. The spectral efficiency, i.e. the number of bits/sec that can be transmitted for each Hz of bandwidth, is high; this leads to high transmission rates (bits/s) in a narrow bandwidth (Hz).

In a practical implementation the input binary stream to be transmitted is grouped into symbols of n bits. A symbol of n bits is used to address one out of the 2^n points in the signal space, in a process called “symbol mapping”. A simple example for $n = 4$ (16-QAM) is shown in Figure 9.

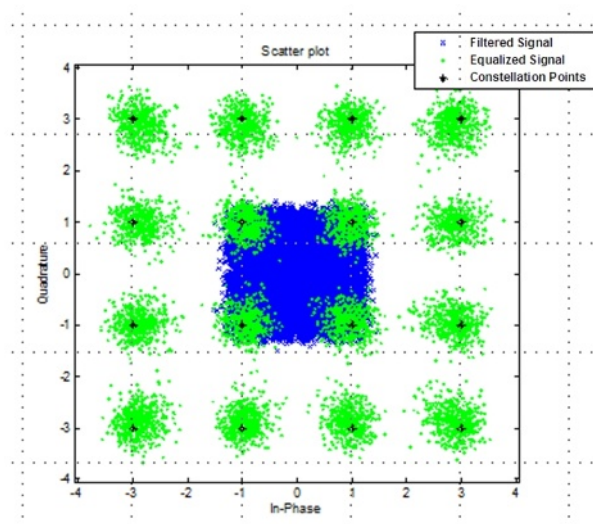


Figure 9 – Signal space for a 16-QAM constellation

It can be shown that the performance of a QAM modem depends basically on the geometry of the signal space. Robustness against noise, for instance, depends on the euclidean distance between points. The goal of the receiver is to detect the received points and decode the corresponding bits, but the received signal will be corrupted by channel noise and other impairments. The effect of noise on the signal space is that the points will not be clearly

defined but will be scattered over areas within which the received signal may lie. The receiver then defines a decision area around every theoretical point; if the received signal lies within the decision area the corresponding theoretical point will be decoded as valid. If, because of the noise, the received signal crosses the decision threshold, the wrong point will be decoded and subsequently the wrong information bits will be delivered to the user.

As with most digital transmission systems, there is a trade-off between bandwidth, probability of error and system complexity. For a given transmission rate, the higher the number of points in the signal space (2^n), the narrower the channel bandwidth but the greater the receiver complexity and the higher the probability of error for the same SNR.

3.5.4 OFDM (Refer to Table 1)

Known also as multicarrier modulation, it transmits the information by using many carriers, which are located in a limited frequency band.

In a conventional frequency division multiplex system, each of the modulated carriers are separated by filtering, so that there is no spectral overlap of the carriers. This means there is no interference between the carriers, and each carrier can be demodulated individually.

The multicarrier modulation, however, uses spacing between the carriers following special rules, so that the information of each carrier can be detected at the receiver, even if there is a spectral overlap of the carriers.

Data to be transmitted are grouped into blocks of K bits. This number of bits is distributed to the carriers and each carrier is modulated with a group of bits. A 2^m -QAM (quadrature amplitude modulation) is used to encode the data into the phase and magnitude of the carrier, where m is the number of the bits assigned to the carrier.

In a simple implementation, every carrier is modulated with the same number of bits. This is a sufficient method, if the transmission characteristics are the same for each carrier. Transmitting via the power line, however, means having complex channel characteristics where the amplitude response is not flat and/or the group delay is not constant. By measuring the channel characteristics it is possible to determine the transmission characteristics for each carrier. The distribution of the bits to the carriers is done according to the results of this measurement such that a carrier with good conditions for the transmission gets more bits to transmit than a carrier with bad conditions. Using this method, a good adaptation to the characteristics of the transmission channel is possible.

The advantages of the multicarrier modulation are good protection against impulsive noise (such as that produced by switching in the power network) and the efficient use of the bandwidth. By splitting the channel into many narrowband subchannels, the multicarrier modulation is resistant against frequency response distortion and does not rely on sophisticated equalisation techniques.

The simultaneous processing of many QAM-signals increases the complexity of the implementation and may be considered as a disadvantage of the multicarrier modulation.

3.5.5 Other modulation schemes

The other class of modulation scheme that can be used for digital power lines communication are spread spectrum modulation techniques. They are characterized by the use of a bandwidth much greater than the one required by the original signal to transmit. This is generally done by using a long pseudo-random code to spread the data into a large coded stream using a wide bandwidth (direct sequence spread spectrum). The inherent advantages of these techniques are:

- a) The resulting signal is a wide band “noise like” signal generally with a low level. This characteristic makes it difficult to be detected and therefore decoded.

- b) The messages privacy is ensured as long as the pseudo random code is long enough. The spreading of the signal on a wide bandwidth makes it robust to narrow band noise and to multipath interference.
- c) Different signals, each one with its own pseudo-random code can be superposed on the channel allowing many users to access simultaneously to the communication channel (code division multiple access CDMA).

The spread spectrum modulation, because of its wide bandwidth, is not used on HV power line carrier equipment; it is used in broadband power line communication over the distribution network in competition with OFDM modulation.

Table 1 – Characteristics of DPLC modulation schemes

Modulation schemes	Characteristics
Single carrier Typical QAM	• Good spectral efficiency • Good peak to average ratio • Low complexity • Susceptible to multipath interferences → Needs equalization • Needs specific techniques to reduce impact of impulse noise and narrow band interference
Multi carrier Typical OFDM	• Robustness to multi path interference → No equalization required • Good spectral efficiency • Robustness to narrow band interference by deactivation of sub-channels • High complexity • Susceptible to frequency offset • Susceptible to phase noise • High peak to average ratio
Spread spectrum	• High immunity to noise and interferences • Large bandwidth → Not applicable for HV PLC

The modulation technique used for PLC equipments is not the only element to take into account to evaluate the performance of the system. A number of techniques have been developed to take advantage of the pros and to avoid the theoretical disadvantages of the cons. This is shown in Table 2, where the pros and cons are indicated with “+” and “–”, respectively.

Table 2 – QAM and OFDM DPLC modulation scheme characteristics

DPLC modulation scheme	Single carrier modulations e.g. QAM	Multi carrier modulations e.g. OFDM
Peak to average ratio	+	–
Complexity of basic modem	+	–
Data delay	+	–
Sensitivity to frequency jitter	+	–
Sensitivity to phase noise	+	–
Complexity of echo cancellation	+	–
Spectral efficiency	–	+
Channel equalization	–	+
Data rate adaptation in small steps	–	+

DPLC modulation scheme	Single carrier modulations e.g. QAM	Multi carrier modulations e.g. OFDM
Susceptibility to multipath interference	–	+
Susceptibility to narrowband interference	–	+
Susceptibility to impulsive noise	–	+

3.5.6 Echo cancellation

In order to reduce the bandwidth needed for a PLC link, it is possible to superimpose the transmission and reception bandwidth allocated to a DPLC communication using echo cancellation techniques. In fact, echo cancellation enables transmission in two directions simultaneously using the same frequency band, thereby reducing the bandwidth requirements in half relative to systems without echo cancellation. Therefore, both directions of transmission share the same bandwidth with echo cancellation used to separate the two directions.

When we transmit full-duplex data over the same PLC bandwidth, the main problem is undesired feed-through of the transmitted signal into the receiver due to the impedance mismatch between the two-wires cable and the hybrid, which is used to provide a virtual four-wires connection between the transmitter on each end and the receiver on the opposite end. This reflection of the transmitted signal is called echo and so an echo canceller is necessary to detect the received data.

The main functionalities of echo cancellation are the following:

- to recognize the originally transmitted signal that re-appears with some delay in the received signal; to synthesize an estimate of the echo of the transmitted signal;
- to remove the echo by subtracting that synthesis from the received signal.

As shown in Figure 10, the near-end transmitted signal can be used to eliminate its own echo at each receiver of the full-duplex link. The echo canceller takes advantage of its knowledge of the local transmitter signal in order to generate a replica of the echo. This replica is subtracted from the echo plus far transmitter signal to yield an echo-free signal which ideally contains the far transmitter signal alone.

Typically, the core of an echo canceller is a discrete-time FIR (Finite Impulse Response) filter. This filter is adapted to match the impulse response of the environment being cancelled and it shall be long enough to adequately cover the duration of that impulse response. This technique requires adaptive signal processing to generate a signal accurate enough to effectively cancel the echo, where the echo can differ from the original due to various kinds of degradation along the way. The FIR filter can be adapted using the LMS (least mean squares) algorithm.

When adapted, the typical performance of an echo canceller is 50 dB of echo attenuation. So, with a good approximation, we can say the DPLC link performances with overlapped bandwidth and echo cancellation are the same of a link with transmission and reception in different bands.

In conclusion, echo cancellation technique allows a great data-rate increase with the same bandwidth requirements because it doubles the system spectral efficiency.

Teleprotection transmission shall not rely on adaptive echo cancellers, because of their poor performance during line faults changing the channel impulse response temporarily.

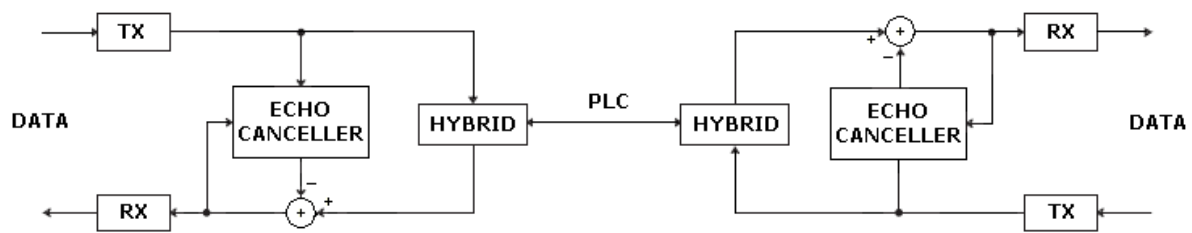


Figure 10 – Echo cancellation method for a DPLC link

4 Frequency bands for PLC systems

4.1 Introduction to the characteristics of PLC systems for EHV, HV and MV networks

There is a growing demand for data transmission networks throughout the World. The initiative for these demands in data services comes from an increase in internet services, which need to be available throughout the day and available to companies and residential homes.

This demand in data communication services is supported by an increase in traditional communications networks of fibre optic communications, adoption of the abundant telephone services through asymmetrical digital subscriber line (ADSL) and higher speed variants such as VDSL. These services are also supported by cable local area network technologies and satellite networks. In more recent years, Wireless networks and Wi-Fi have shown considerable prominence in networking. All these types of networks are dedicated and designed to a particular architecture and topology. They also require cables to be installed and configured to specific equipment. Consequently, any further increase in such networks requires further installation of the different types of cables and this can be a prohibitive cost.

Although these traditional communications networks are in abundance, the most ubiquitous wire network available throughout the world is the electricity distribution network. Although designed to supply power at a range of voltages, normally 110 V or 240 V at either 60 Hz or 50 Hz, respectively, there is the potential of simultaneously transmitting and receiving data traffic over these power distribution lines. The data traffic may be either for home or business services or for internal telecommunication services within the electricity supply industry.

The simultaneous use of the power distribution network for both energy transmission and data communication is unique and reduces the costs of installing two services over one transmission path. Consequently this allows the control of devices in all aspects of the infrastructure of the world from businesses to homes without the inherent costs of installing cables in the ground. For these fundamental reasons a new transmission network of data communications technology has evolved called generically power line communications technology.

The first application of power communications was the form of ripple control technology within a Swiss electricity distribution system in 1893. The aim was the application of a control signal to switch a remote circuit breaker. The voltage of the signal was the order of millivolts and frequency of the signal in the kilohertz range. From this initial trial and application, the frequency ranges have increased, allowing high data rates of the order Megabytes per second. The developments of this form of communication over the last 100 years have been significant mainly because of the structure of power cables used in the low, medium and high voltage systems of our buildings and homes. Further, the developments in communications technology from analogue to digital systems, signal processing, modulation systems and data processing have enhanced the transmission services available to customers both industrial, residential but also the internal communications network of an electricity distribution network.

The power distribution network is very diverse ranging from high voltage operating at the order of 100 kV, medium voltage at below 100 kV and low voltage below 1 kV. For power line communications, the focus is on the low voltage distribution network which is the widest geographically spread in the majority of countries. Further, it has the convenient connection point to the range of buildings and homes and their different infrastructures.

Signalling over the low voltage in the early years concentrated on low speed data rates and consequently low frequency applications with the classical application of meter reading for electricity, gas, water and heat meters. Other applications included load monitoring and shedding together with connection and disconnection services. In the 1990s there was the demand for more services which involved higher data rates of the order of 1 Megabytes and higher and consequently higher bandwidths and frequencies in the 1 MHz to 30 MHz range. It is this latter development that evolved into the new term of “Broadband Power Line communications” technology.

This broadband power line communications allows high speed data transmission services such as data and voice over the internet protocol known as “VoIP”. These services are distributed through normal electrical power lines that are incorporated into every house hold socket. Further this data is shared among simultaneous users. For this reason, the concept of data services to every plug in the home or building gives the concept of “Internet to and from the socket”. The consequence of this is the transmission and reception for any socket in the home or building without additional wiring. Therefore the power line is feeding a high speed data signal into a local mains power supply network to every socket in that electrical network. Therefore the transmission capacity is shared between the users.

However, although there is considerable potential for power line carrier communications at both low frequency and high frequency for the range of different services, there are potential problems with the power line that shall be taken into consideration and investigated on every type of electrical distribution network within any country and area within a country. Therefore the performance of a power communications service may experience different communications conditions for the same type of network but in different geographical environments and countries.

There are a number of particular conditions that affect the power communications network. The impedance of the power distribution network varies considerably according to the type of power cable and network topology, according to the configuration being a single phase, ring main or a three phase tree and branch network. Also the frequency of transmission will determine the impedance values of the circuit. This leads to the cable attenuation which may be very high according to the frequency of operation. This can also lead to standing waves on long cables and may lead to frequency nulls in the frequency response. In addition the interfacing of the equipment to the power line will introduce attenuation and noise to the circuit which is affected by the impedance of the line which varies according to the frequency of operation. Further as devices are switched in and out of the circuit the noise of the line will vary and the attenuation will vary in an unpredictable manner. Although only as a figure of merit operating power line systems in the low frequency range provides more stable conditions and therefore a more seamless communications throughout the system. Further, due to these electrical and communication impairments of the system a potentially more serious problem arises and that is due to potential electromagnetic emission from the power lines when operated in the high frequency range 1,6 MHz to 30 MHz and higher. These frequencies that emanate from the power line have the ability to cause interference to established radio frequency services. Although this does raise cause for concern there are a number of devices and methods available to potentially compensate and overcome these electrical problems. These include using repeaters, amplifiers, isolators, line traps, and couplers. The particular line shall be analysed to decide the type of device to be used and where it is placed in the circuit. These techniques work, however the control of the energy injected into the power line from the modem will establish the potentially radiated emission from the power line and the amount of interference caused to other established radio services.

The radio spectrum is a unique resource that has considerable demands made on it by companies and users. Further, the frequency range from 1,6 MHz to 30 MHz has special propagation conditions allowing long range communications services around the world. Further it is utilised very efficiently by low frequency power communications. Therefore this part of the spectrum requires special protection by choosing an appropriate emission limit for interference. To provide total protection of radio services is not possible principally because it would require a very low radiating limit which consequently would limit high data rate communication services. In addition, it should be recognised that electronic equipment of any kind is a potential source of interference once placed in the power line which again would make any decision in favour of very tightly radiated limits completely uneconomic. There are other safety-of-life services with respect to human life and property that shall also be protected. Also manufacturers should develop procedures enabling reduction of emissions in cases of interference through reduced power levels for specific frequencies. The risk of potential interference to radio services depends not only on the different users of the power line agreeing a strategy but also on the different network structures and technologies and the frequency ranges used. For power line communication systems compared to DSL systems or cable TV systems, the risk of interference for the same radiated emission level is considerably higher. Therefore considering the higher densities of deployment for power line networks there is a potential risk of a rise in the noise floor level for that locality. Due to the wide geographical coverage of power line networks throughout each country standards bodies have introduced and formulated specifications to restrict the bandwidth and power levels of communication systems for one main reason and that is of avoiding or reducing the interference with respect to other radio users who use the same part of the spectrum. This is essentially the aim of the different national and international standards bodies.

4.2 Frequency bands for power line systems

Signalling over the power line has existed for many years. The early transmission systems from the 1900s used extremely low data rates and consequently low transmission frequencies of the order of Kilohertz. However, as more applications demand higher data rates, the frequency of transmission increased.

Therefore according to the data services available to customers on the network determines the frequencies and bandwidth of the transmission system. The frequency used is directly related to the application and local environment. Table 3 provides the typical power communication technique and representative frequency band for the particular system.

Table 3 – Early power communications techniques and frequencies

PLT technique	Frequency range
Ultra narrow band(UNB)	10 Hz
Power frequency	60 Hz
Ripple control	100 Hz to 1 000 Hz
Distribution PLT	3 kHz to 148,5 kHz
Transmission PLT	30 kHz to 500 kHz
Local PLT	40 kHz to 30 MHz

The early techniques of ultra narrow band operating at extremely low frequency of 10 Hz through to ripple control operating in the frequency band from 100 Hz to 1000 Hz are used for basic switching of equipment in the electricity distribution network. However, as applications of remote meter reading and data transmission developed, higher frequencies came into use including distribution PLT, transmission PLT and local PLT.

In the late 1990s there was a considerable development in providing high data rate transmission systems for internet services to residential and industrial customers. These new services introduced data and voice over the internet protocol “VoIP” which provided a common communication service to all residential and industrial customers. These services

demand the higher data rates and hence bandwidth. The characteristics of such services ranging from security of service through to signal error are shown in Table 4.

Table 4 – Parameters of power communications systems

Parameter	Ultra narrow band	Distribution PLT	Broadband PLT
Range	Excellent	Very good	Very good
Data Rate	Low	High	Excellent
Security	Good	Good	Good
Line Conditioning	Minimal	Excellent	Excellent
Latency(time delay)	Good	Medium	Low
Error rate	Low	Excellent	Good

Table 4 demonstrates that there is no ideal PLT communication system. Good quality parameters include the range the system will operate over, however for the broadband PLT system the data rate is excellent and current systems operate at 250 Mbyte and higher speeds are becoming available. In comparison for the low data rate system a longer range is achievable. Therefore it is important to determine the exact services that will be transmitted over the power line network.

Table 5 details the early power line carrier frequencies, many of which are still operational today. However, manufacturers and utility companies have combined to develop power line systems for greater range and higher speed and consequently services such as video on demand. Also the national and international standards bodies have become involved to provide neutrality to the vast range of services being developed throughout the World and potentially coexistence between the operations of such systems.

Today, the operational frequency bands used throughout the world have specific frequency ranges for data signals being transmitted between the backbone network and the home or building, known as the “Access network” and the data network inside the home or building known as the “In-house network.” Further, the networks are classified as low frequency and high frequency systems.

Table 5 – Frequency bands in power line communication systems

Architecture	Underground	Underground	Underground/Overhead
Low frequency systems standards organisation			
	IEEE	CENELEC/ETSI	IEC CISPR 22
Frequency range	45 kHz to 450 kHz	3 kHz to 148,5 kHz	1,6 MHz to 30 MHz
Access band	45 kHz to 450 kHz	3 kHz to 90 kHz	1,6 MHz to 10 MHz
In-house band	45 kHz to 450 kHz	95 kHz to 140 kHz	10 MHz to 30 MHz
Architecture	Overhead/underground	Underground	Underground
High frequency systems			
Frequency range	1,6 MHz to 80 MHz	1,6 MHz to 30 MHz	1,6 MHz to 30 MHz
Access band	10 MHz to 80 MHz	1,6 MHz to 10 MHz	1,6 MHz to 10 MHz
In-house band	1,6 MHz to 10 MHz	10 MHz to 30 MHz	0 MHz to 30 MHz

4.3 Channel plans

4.3.1 General

There are different channel plans for PLC communication systems depending on the level of voltage of the electrical power line used, international standards and local regulation, and type of transmission i.e. narrowband or broadband.

4.3.2 EHV/HV/MV narrowband PLC channel plan

Most of the multi-purpose APLC systems require a bandwidth of 4 kHz for each direction of transmission; therefore, the available range of frequencies (24 kHz to 1 MHz) is divided into a number of channels each 4 kHz wide. Two of these will be required for each two-way carrier circuit but they need not necessarily be adjacent.

In order to assure compatibility and coexistence with other systems in operation new DPLC systems will use basically the same channelling approach. Depending on the technology used it is common to have adjacent, non-contiguous and superimposed bidirectional transmission channel grouping a number of 4 kHz channels.

Other channel widths have also been adopted in some countries to suit their special needs.

The frequency ranges and standards applied in Europe, USA and other countries are shown in Table 6. Further, Figure 11 shows the APLC narrowband channel plan.

Table 6 – HF spectrum allocated for PLC systems

	Europe	USA	Other Countries
Reference standard	IEC 62488	IEEE 643	-
Frequency range	40 kHz to 500 kHz	24 kHz to 1 MHz	24 kHz to 1 MHz

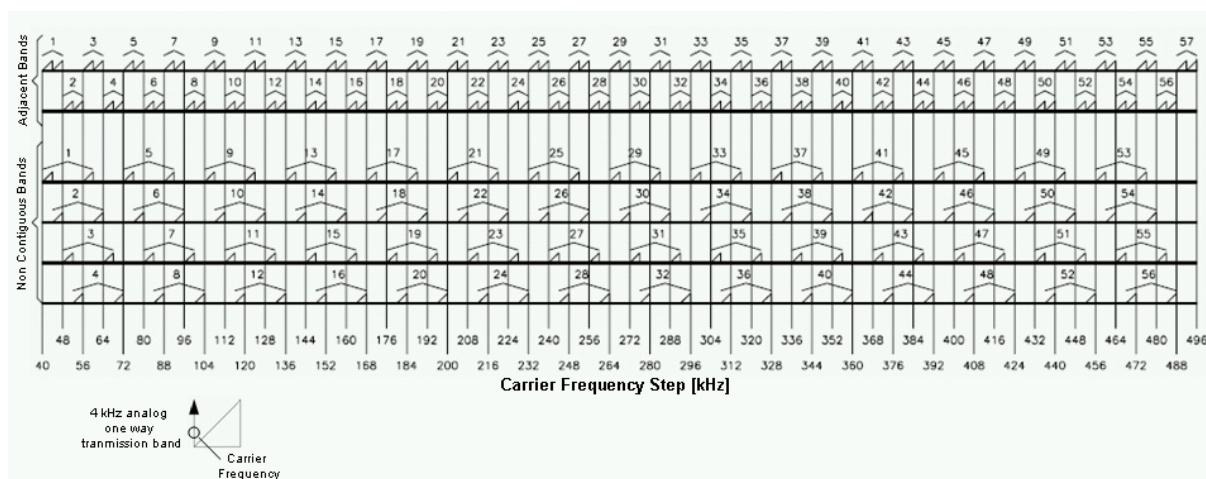


Figure 11 – APLC narrowband channel plan

4.3.3 MV/LV narrowband DLC channel plan

DLC is mostly used over MV/LV underground cables as shown in Table 7. Also, Figure 12 shows the situation in Europe and the USA.

Table 7 – HF spectrum allocation for narrowband PLC

	CENELEC (EUROPE)			USA	Other countries
Reference standard	EN 50065-1			IEE 643	-
Frequency range	3 kHz to 148,5 kHz	A band (3 kHz to 95 kHz)	Utilities access	50 kHz to 450 kHz	-
		B band (95 kHz to 125 kHz)	Consumer in-house		
		C band (125 kHz to 140 kHz)			
		D band (140 kHz to 148,5 kHz)			

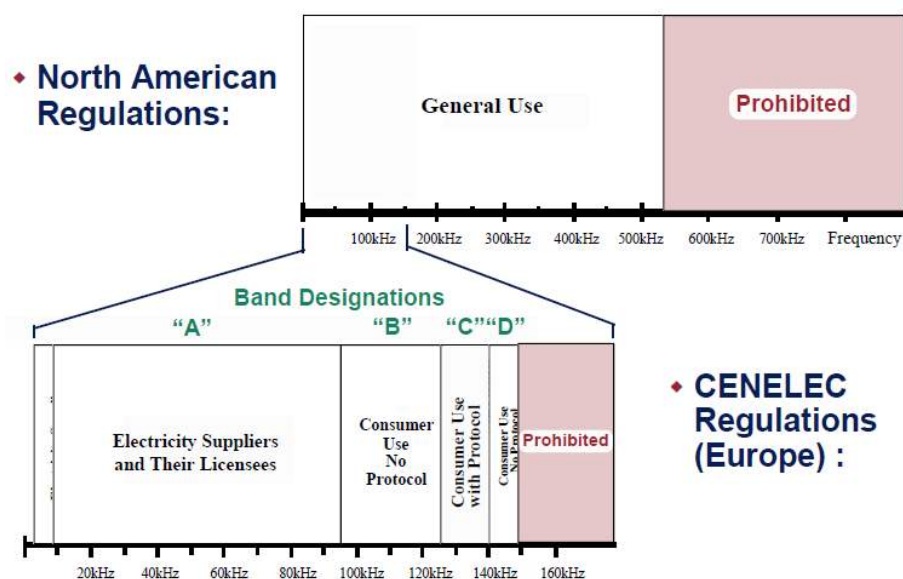


Figure 12 – DLC narrowband channel plans Europe vs. North America

4.4 High frequency spectral characteristics

APLC systems generate discrete frequencies (pilots, maintenance signals, guard signals for teleprotection), speech signals and narrowband spectra from modems using typically Frequency Shift Keying (FSK) as the modulation method.

DPLC systems generate a modulated signal with a continuous spectrum $p(f)$ and possibly additional tones with discrete frequencies f_i used for auxiliary functions (pilots, maintenance signals, guard signals for teleprotection). Generally during synchronisation of a DPLC link, the characteristics of the signal spectrum changes until synchronisation is achieved and data is transmitted, and therefore the spectral characteristics are stable.

The signal spectrum of combined APPLC/DPLC systems can be split into sub-bands allocated either to the APPLC or the DPLC sub-system of the combined APPLC/DPLC system. The spectral characteristics of the signals in the sub-bands are those of pure APPLC or DPLC systems, respectively.

4.5 Regulation and emission limits for PLC

4.5.1 Extra high voltage, high voltage for narrowband systems

The regulation and emission limits for narrowband communications are determined and limited by local national regulations for conducted and radiated electromagnetic fields.

4.5.2 Medium voltage and low voltage narrowband systems

Refer to 4.3.2 for operating frequency bands for Cenelec standard, EN 50065-1.

4.5.3 Medium voltage and low voltage broadband systems

These systems are limited by the conducted and radiated electromagnetic field as designated in CISPR 22. This standard is currently under review.

4.6 Selection of the frequency bands for HV PLC systems

4.6.1 General

This subclause gives considerations and advices taking into account signal power of the HF modulated signal in order to meet the constraints and requirements for channelling, frequency allocation and paralleling of APLC/DPLC systems.

4.6.2 Maximum power of PLC signal

The relevant power quantities to be distinguished are:

$P_{Peak} [W_{Peak}] =$ Peak power of the PLC signal. It is usually limited by the power amplifier of the PLC terminal.

$P_{PEP} [W_{PEP}] =$ Peak envelope power $[W_{PEP}]$ corresponds to the power of a sinusoidal signal with peak power P_{Peak} . The relation to P_{Peak} is

$$P_{PEP} = \frac{P_{Peak}}{2}. \quad (1)$$

$p_{RMS}(f) [W_{RHz}] =$ P_{PEP} is usually limited by the power amplifier of the PLC terminal.
Power density of the continuous signal spectrum. It may be limited by national regulations.

$P_i(f_i) [W_{RMS}] =$ Power of discrete tones at frequencies f_i . National regulations may specify the maximum power of individual discrete frequencies $P_{cont max} [W_{RMS}]$ that are continuously present within the nominal frequency band:

$$P_{cont max} \geq P_i(f_i). \quad (2)$$

For individual discrete frequencies only appearing for a given period of time – as is the case for short duration teleprotection signals – a higher limit $P_{temp max} \geq P_{cont max}$ might be allowed.

$P_{RMS} [W_{RMS}] =$ RMS Power of the PLC signal. It may be limited by thermal constraints of the PLC power amplifier. P_{RMS} is the sum of the powers of individual discrete frequencies and the power of the continuous part of the spectrum in the nominal frequency band:

$$P_{RMS} = \sum_i P_i(f_i) + \int_{Bn} p_{RMS}(f) df, \quad (3)$$

where Bn [Hz] is the used PLC band.

A further important quantity is the ratio between the peak power and the RMS power,