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DIGITAL POWER LINE CARRIER EQUIPMENT

PRESENT USE AND FUTURE APPLICATIONS

Task Force D2.08

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Members:
F. Castro (Spain), J. Gajica (Yugoslavia), G. Kling (Germany), T. Olsen (Secretary) (Norway), I. Perak (Croatia), **J. Piotrowski (Convener)** (Poland), M. Sobolewski (Poland), H. Spiess (Switzerland), G. Stevenot (France), M. Zapušek (Slovenia).

Corresponding members:
P. Cristaudo (Australia), C. Huibin (China), J. Hernandez (Mexico), R. Pellizzoni (Argentina), B. Rudnicki (Poland), S.Tanterdtid (Thailand).

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1 INTRODUCTION

Cigré Study Committee D2 (former Study Committee 35) previously issued the document "Report on digital PLC" [1] dealing with general aspects of this new technology. This new Technical Brochure deals mainly with the planning and applications.

Study Committee 35 approved in 2001 the creation of a Task Force with the title "Field experiences and measurements methods for Digital Power Line Carrier Systems". Based on the main advantage of Digital PLC (DPLC), namely the greater transmission capacity when compared with Analogue PLC (APLC) occupying the same frequency band, it was of interest to collect experience, establish a status for the applications and add some aspects to the present international standards regarding testing.

With basis in the scope given by the Study Committee, the SCTF D2.08 presents this report under the title "Digital Power Line Carrier Equipment – Present Use and Future Applications".

2 EXPERIENCE

To collect experiences from the users, a questionnaire was distributed through the members of TF D2.08, and also through National Committees of Cigré. Answers were received from 45 utilities where 22 had Digital PLC in operation. A summary of the answers is given in Annex A.

From Annex A we can make the following observations:

Applications: The DPLC-links are basically used as multipurpose links, in the same way as the APLC-links. They are used at the same voltage levels, on the same range of distances and have the same coupling circuitry to the line.

Both the transmission of speech and data (for SCADA) is considered to be important.

Performance: The performance of the DPLC-links is considered to be "good". The same conclusion was reached for the critical parameter speech quality.

Co-existence of DPLC and APLC

Nearly half of the utilities that use DPLC terminals in parallel with APLC terminals on the same power line have experienced problems.[1]

Future plans: Most of the utilities that answered the question will include DPLC in their future plans.

[1] Problems of co-existence of APLC & DPLC coupled on the same line can be reduced by the use of symmetrical hybrids to decouple the two types of equipment.

3 PLANNING

3.1 Link Planning

3.1.1 General

Only quality planning of PLC links assures rational usage of the frequency range dedicated to PLC communications, reliable operation of each PLC channel and consecutively high quality of services (QoS).

Planning of a PLC link is based on knowledge of four groups of input data:

- ***characteristics of the PLC equipment***, with which the PLC link is to be set up
- ***telecommunication characteristics of the HV power line***, on which the planned PLC link will be operating; frequency response (attenuation and group delay distortion) and corona noise power level in the frequency band of the planned PLC link
- ***frequency plan of the existing PLC system***; availability of free frequency space within frequency plan of the entire PLC system
- ***application requirements*** having in mind minimal required transmission capacity of a DPLC channel $\boldsymbol{C_d}$ and maximal allowed Bit-Error-Rate, $\boldsymbol{BER_{max}}$**,** and available time.

Knowledge of above-mentioned data allows successful realisation of the ***PLC link planning procedure***.

The PLC link planning procedure is fully described in International Standards IEC 60663 [2] and IEC 60495 [3] and other standards like ANSI/IEEE Std 643-1980 [4]. Also Cigré Technical Brochure 15 “Guide on Power Line Carrier (1979)” may serve as useful assistance.

The documents, mentioned above, present procedures for determining the telecommunication characteristics of a HV line (attenuation and corona noise power level) and principles for evaluation of reliability and quality of ***APLC links***. The publications do not deal with planning aspects of DPLC links because at the time of publication DPLC links did not yet exist. Evaluation procedures related to power line telecommunications characteristics like attenuation and corona noise power level, as described in above-mentioned publications, are usable for DPLC links planning as well.

3.1.2 Characteristics of a DPLC channel

The priority goal of DPLC link planning is to assure adequately high Signal-to-Noise Ratio, SNR, at a DPLC channel receiver input in adverse operational conditions. A drop of SNR below critical value causes loss of the DPLC channel and by that loss of all telecommunication services, realised in it. Due to this reason the “C/SNR” characteristic of a DPLC channel is essential input data for DPLC link planning. In addition to SNR, the type of noise (impulse, narrowband) and channel distortion are important and have to be specified.

The DPLC link planning procedure should include necessary steps to check or to assure (in connection with adequate power of transmit signal and mode of connection to transmission medium) that attenuation of a planned DPLC link is lower than maximal allowed attenuation according to technical data of the DPLC equipment used (***sensitivity of a DPLC channel receiver)***.

3.1.2.1 Efficiency of a DPLC channel (Eff)

The primary task of a DPLC channel is transmission of a digital signal which may be a uniform digital (data) signal or is composed from digital data signal(s) and/or digitised and compressed analogue speech signal(s), merged into uniform digital signal using e.g. time division multiplexing technique. The bandwidth of a DPLC channel is limited and therefore the transmission of a digital signal through a DPLC channel is possible if the digital input signal is transformed into a band limited analogue signal, suitable for transmission through a band limited DPLC channel. Such transformation is called ***digital modulation*** and usually includes coding of the digital signal as well.

There are various types of digital modulation and coding methods. The DPLC channel resistibility to noise and interference is strongly dependent on the type of implemented digital modulation and implemented coding method.

Essential characteristics of a DPLC channel are ***net*** transmission capacity, $\mathbf{C_d}$, given in bits-per-second (bit/s) and ***gross*** bandwidth of the DPLC channel for one side of transmission, $\mathbf{BW_d}$, given in Hz. Usually these two characteristics are programmable; it is possible to choose different combinations of values for transmission capacity and bandwidth of DPLC channel. ***DPLC channel efficiency*** is defined by transmission capacity and bandwidth; equation 1:

$$\textit{Eff [bit/s/Hz]} = C_d / BW_d \qquad \text{(Eq. 1)}$$

Net transmission capacity, $\mathbf{C_d}$, is (predominant) part of a DPLC channel transmission capacity, available for user applications. Gross bandwidth, $\mathbf{BW_d}$, equals the spectral bandwidth of the DPLC channel signal including spectral overhead and auxiliary signals. It is normally an integer multiple of 4 kHz.

It is very important to consider the following property of a DPLC channel in the DPLC link planning procedure:

The higher the efficiency of a DPLC channel, the higher the sensitivity to noise and interference.

Consequently, when planning a DPLC link, it is necessary to strive for the lowest possible efficiency of the DPLC channel: As low transmission capacity C_d as possible and as wide bandwidth BW_d as possible. At first sight, such recommendation is irrational, but essentially contributes to higher availability of the DPLC channel in adverse transmission conditions. Of course, there are limitations to values of transmission capacity and bandwidth of a DPLC channel.

Lowest possible transmission capacity is defined by requirements of each application while widest possible bandwidth of PLC channel is limited by the frequency plan (availability of free frequency space), and of course by design constraints of the DPLC equipment used.

3.1.2.2 “C/SNR” characteristic of a DPLC channel

The ***“C/SNR”*** characteristic of a DPLC channel is essential input data for DPLC link planning. Example of a ***“C/SNR”*** characteristic is shown in Figure 3.1. The ***“C/SNR”*** characteristic in Figure 3.1 is fictional and is for illustration only. The disturbing noise signal is assumed to be AWGN (Additive White Gaussian Noise).

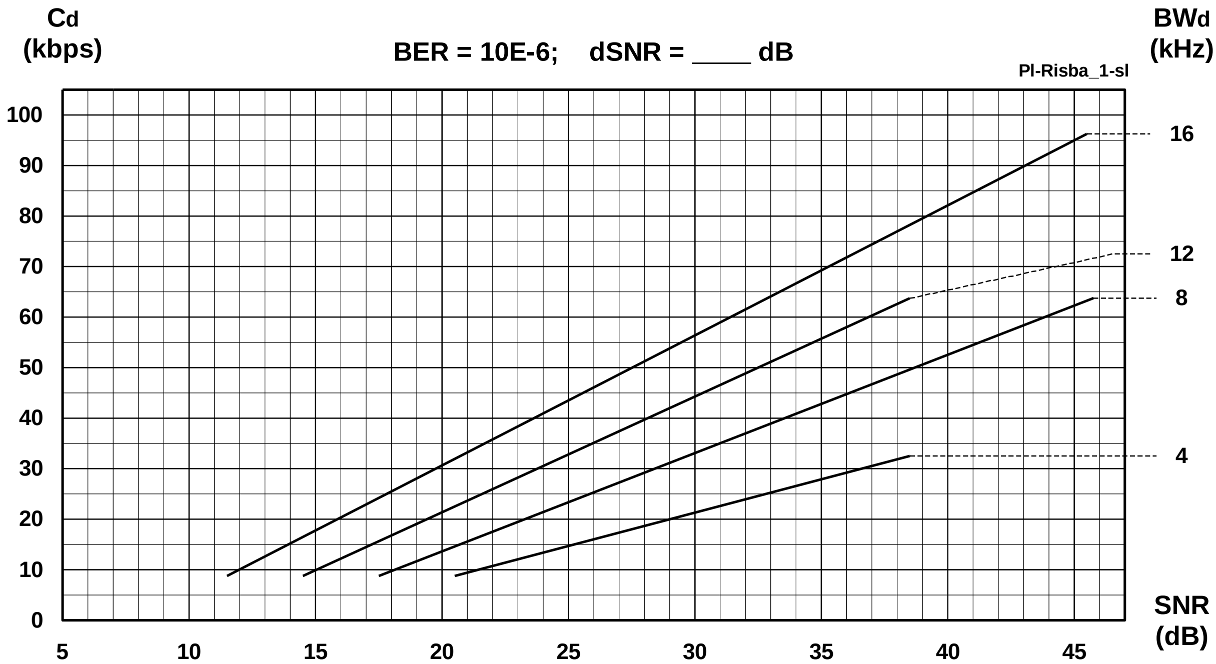

Figure 3.1: “C/SNR” characteristic of a DPLC channel (illustration)

The “C/SNR” characteristic is always given for a certain value of bit-error-rate, ***BER***; usually for the value 10^{-6}. If the construction of a PLC terminal enables different values of DPLC channel bandwidth, the ***“C/SNR”*** characteristic should be given for every possible value. In such case, the “C/SNR” characteristic of a DPLC channel contains a family of curves (Figure 3.1). A curve is given for each value of a DPLC channel bandwidth within the whole range of possible DPLC channel transmission capacity values for a relevant value of the DPLC channel bandwidth. The DPLC channel transmission capacity may occupy only some discrete values (cannot be set at any value in a continuous range). Therefore, it is not necessary that a “C/SNR” characteristic is given as a continuous curve, but only for possible values of DPLC channel transmission capacity.

Some data applications are relatively tolerant to bit errors. An example of such application is (some) algorithms for speech compression, which allows a BER $\leq 10^{-3}$. Applications with implemented FEC (Forward Error Correction) function should also be tolerant to such bit-error-rate.

Consequently, the application(s) bit errors tolerance level is an important parameter in planning of DPLC links. For this reason it is desired that the “C/SNR” characteristic of DPLC channel be also given for bit error rate of BER = 10^{-3}. It is not necessary to give an entire characteristic, but just stating the difference between SNR values for both values of bit-error-rate, expressed in dB, is satisfactory; equation 2:

$$dSNR\ [dB] = SNR(BER = 10^{-6})\ [dB] - SNR(BER = 10^{-3})\ [dB] \quad \text{(Eq. 2)}$$

Measurement of a DPLC channel “C/SNR” characteristic (measurement of BER) is carried out by means of pseudo-random bit sequence: e.g. $2^n - 1$; n = 6, 9, 11, 12 or 15, while Additive White Gaussian Noise (AWGN) is used as a disturbing signal, and the channel frequency response is assumed to be free of amplitude- and group delay distortion.

For the time being there is no standard that defines design and characteristics of a PLC terminal with DPLC channel. Manufacturers offer PLC terminals with DPLC channels of different design and characteristics. Several parameters are included in the “C/SNR” characteristic of a DPLC channel. It is logical and necessary to define a uniform method of “C/SNR” characteristic measurement and presentation. Two important goals are achieved in this way:

- a uniform way of using “C/SNR” characteristic as a source of input data for DPLC link planning, regardless of who the manufacturer of the PLC equipment is
- a simplified DPLC channel “C/SNR” characteristic comparison of different PLC equipment manufacturers.

It is also important to have a uniform method for evaluation or understanding parameters that appear in the “C/SNR” characteristic. A form of stating a “C/SNR” characteristic is shown in Figure 3.1 and equation 1.

3.1.2.3 Signal-to-Noise Ratio (SNR)

The parameter ***SNR*** is the ratio between the power level of useful signal of the DPLC channel and the power level of the disturbing signals (noise, interference, impulse disturbances) at the input of a DPLC channel receiver. Laboratory measurement of a DPLC channel “C/SNR” characteristic is carried out by means of Additive White Gaussian Noise as disturbing signal. Other types of disturbing signals that are present in real operating conditions on HV power lines (interference and impulse disturbances) are very difficult or even impossible to be authentically simulated in the laboratory.

3.1.2.4 Power level of the DPLC channel signal at the receiver input

Typical technical data of a PLC equipment is Peak-Envelope-Power of the PLC terminal, PEP, and Peak-Envelope-Power of the DPLC channel, PEP_d, respectively. The ratio between average and peak-envelope-power of DPLC channel transmit signal (**P**eak-to-**A**verage-**P**ower-**R**atio; PAPR) depends on the type of implemented digital modulation. Peak envelope power of the DPLC channel signal, which is proportional to the square of the maximum instantaneous voltage of all signals in the frequency band of the DPLC channel, of course should not exceed specified peak envelope power of the DPLC channel. Actually, the Peak Envelope Power of a DPLC channel transmit signal rarely reaches the value of specified Peak Envelope Power of a DPLC channel.

Specified Peak Envelope Power of a DPLC channel, PEP_d, may be the same as specified PEP of a PLC terminal (in the case of single-channel PLC terminal), or only a proportional part of PEP (in the case of a multi-channel PLC terminal).

If a PLC link contains only a DPLC channel then the following applies: $PEP_d = PEP$

Distribution of a PLC terminal PEP to individual channels of a multi-channel PLC link is performed in accordance with the following rule: The part of a PLC terminal PEP, which is dedicated to an individual channel, is proportional to the square of that channel bandwidth (the same peak voltage to each unit part of transmit nominal RF band, B_N). The following equations are valid:

$$PEP_d\ (W) = PEP\ (W) \times (BW_d / B_N)^2$$
$$PEP_d\ (dBm) = PEP\ (dBm) + 20 \log (BW_d / B_N)$$

$B_N = n_a \times BW_a + BW_d$, where:

B_N	is nominal RF bandwidth of a PLC link for one direction of transmission
BW_d	is ***gross*** bandwidth of a DPLC channel for one direction of transmission
BW_a	is ***gross*** bandwidth of each APLC channel for one direction of transmission (bandwidth of all APLC channels is the same)
n_a	is a number of APLC channels.

Due to the fact that the most standard bandwidth of an APLC channel is 4 kHz it is logical that the above equations are developed for unit part of transmit nominal RF band B_N of 4 kHz width. In this situation, the following equations are valid:

$$PEP_d\ (W) = PEP\ (W) \times (n_d / (n_a + n_d))^2$$
$$PEP_d\ (dBm) = PEP\ (dBm) + 20 \log (n_d / (n_a + n_d))$$

$$BW_a = 4kHz$$
$$n_d = BW_d / 4kHz$$

where: **n_a** is a number of APLC channels

The suggested principle for power allocation serves as a guideline. In order to achieve equal or target, ranges for the digital and analogue services, other level allocations recommended by the manufacturer, may be more appropriate, in particular for large BW_d/B_N ratios.

The measurement of a DPLC channel “C/SNR” characteristic should be performed under the condition specified in document IEC 60495 [3], clause A.3.1:

$$a_L\ [dB] = PEP_d - 15dB - 20 \log n_d \qquad \text{(Eq. 3)}$$

$n_d = BW_d / 4kHz$, where:

a_L [dB]	is attenuation of an artificial line
PEP_d	is the specified PEP of a DPLC channel
BW_d	is ***gross*** bandwidth of a DPLC channel for one direction of transmission

The power level of a DPLC signal, ***S_d***, at a DPLC channel receiver input is calculated from equation 4. Actual values for various DPLC channel bandwidths are given in Table 3.1 (values are independent from defined PEP_d).

$$S_d\ [dBm] = PEP_d\ [dBm] - a_L\ [dB] \qquad \text{(Eq. 4)}$$

BW_d (kHz)	S_d (dBm)
4	15
8	21
12	24
16	27
20	29

Table 3.1: Power level of the DPLC channel signal at the DPLC channel receiver input

These values should always be used for SNR calculation at the DPLC channel receiver input when performing laboratory measurement of a DPLC channel "C/SNR" characteristic.

Therefore, determination of the DPLC channel signal power level at a DPLC channel receiver input is not subject to measurement, but to calculations based on clearly defined rules; Eq. 4 and Table 3.1 respectively.

The quality of PLC equipment with a DPLC channel depends on usage efficiency of DPLC channel gross bandwidth and of defined PEP_d. Inefficient use of the mentioned resources is directly reflected as a worsening of the DPLC channel "C/SNR" characteristic.

3.1.2.5 Power level of noise at the receiver input

Laboratory measurement of a DPLC channel "C/SNR" characteristics is performed by injecting Additive White Gaussian Noise as disturbing signal. To define the method of SNR calculation uniformly and clearly, the measurement method of noise power level on the DPLC channel receiver input must be clearly specified.

Modern measuring equipment allows measuring of power level of any kind of signal within 1Hz frequency band (spectrum analyser). Knowledge of the White Noise power level within 1Hz frequency band allows simple calculation of White Noise power level within any bandwidth ***BW*** expressed in Hz; equation 5:

$$N_{BW}\,[dBm] = N_{1Hz}\,[dBm] + 10 \log BW \qquad \text{(Eq. 5)}$$

Gross bandwidth of a DPLC channel signal S_d at the DPLC channels receiver input is BW_d. White Noise power level must be known within the whole DPLC channel bandwidth for correct SNR calculation; equation 6:

$$N_d\,[dBm] = N_{1Hz}\,[dBm] + 10 \log BW_d \qquad \text{(Eq. 6)}$$

3.1.2.6 Signal-to-Noise Ratio at the receiver input

Laboratory measurement of the DPLC channel "C/SNR" characteristic is performed for different values of SNR. SNR is calculated based on the following rule (results from equations 4 and 6); equation 7:

$$SNR\,[dB] = S_d\,[dBm] - N_d\,[dBm] \qquad \text{(Eq. 7)}$$

3.1.2.7 Sensitivity of a DPLC channel receiver ($S_{d\,min}$ (BER_{max}))

Another DPLC characteristic, relatively important when planning a DPLC link, is sensitivity of the DPLC channel receiver. In real life, high power level of corona noise and other disturbances on transmission media (HV power line) present much higher limitation for stable operation of a DPLC channel. But in general (in applications with low power level of corona noise and other disturbances on the transmission medium and with high line attenuation) the sensitivity of the DPLC channel receiver may represent a limitation for stable operation of the DPLC channel.

Technical data for sensitivity of a DPLC channel receiver shows the minimum power level at the receiver input where the DPLC channel receiver operates satisfactorily. At a lower power level the DPLC channel receiver is no longer capable of detecting (demodulating) the received signal with ***corresponding quality***. This limitation is caused by noise, generated in the PLC channel receiver, and by irruption of the transmit signal of local DPLC channel transmitter into the DPLC receiver.

What is the meaning of the term ***"corresponding quality"***? It means that the operation of the DPLC channel receiver is stable (especially from the synchronisation point of view) and the bit-error-rate is equal to or lower than the specified value.

The DPLC channel receiver sensitivity $S_{d\,min}(BER_{max})$ is expressed as the minimum power level at the input of the DPLC channel receiver at which a DPLC channel still operates in a stable fashion and BER is smaller or equal to the specified value BER_{max}.

The DPLC channel receiver sensitivity is a typical PLC terminal data which shows DPLC channel operation limitations originating from the design of the PLC terminal. Especially, this technical data show power level of noise, generated within the DPLC channel receiver and irruption of DPLC channel transmit signal into the receiver of the same PLC terminal. Measurement of a DPLC channel receiver sensitivity is performed in laboratory without presence of external noise source.

The DPLC channel receiver sensitivity depends on the DPLC channel efficiency but may depend on PLC terminal operating frequency plan as well. Frequency bands of transmitter (Tx) and receiver (Rx) can be adjacent, non-adjacent or even superimposed. The same value of DPLC channel efficiency, **Eff**, can be achieved at different combinations of DPLC channel bandwidth BW_d values and its transmission capacity C_d. Theoretically, the receiver sensitivity only depends on the value of Eff regardless of BW_d and C_d values. Practically, this is not necessarily so (eventual limitations in PLC equipment design), and therefore sensitivity of the receiver is different for different combinations of BW_d and C_d values although they result in the same value of Eff.

Manufacturer of PLC equipment should be obliged to state DPLC channel sensitivity values for all different cases with the local transmitter switched on and operating under stated modulation conditions.

Value of DPLC channel receiver sensitivity in combination with specified PEP_d makes it possible to calculate maximum allowed attenuation of a PLC link (HV power line and coupling equipment), irrespective of expected power level of corona noise and other disturbances on the transmission medium, so that BER is still lower or equal to specified value; equation 8:

$$a_{L\,max}\,[dB] = PEP_d\,[dBm] - S_{d\,min}(BER_{max})\,[dBm] \qquad \text{(Eq. 8)}$$

Because applications are not equally tolerant to bit errors, the receiver sensitivity shall be given for the following two values of BER:

$BER_{max} = 10^{-6}$
$BER_{max} = 10^{-3}$

3.1.3 Characteristics of HV power lines

Successful PLC link planning requires knowledge (determining, measuring) of three telecommunication characteristics of transmission media (HV power line together with coupling equipment), on which the planned PLC link will operate:

- frequency plan of intended PLC link
- noise power level N_d (dBm) measured (or calculated) in the frequency band of the DPLC channel
- PLC link attenuation.

3.1.3.1 Frequency plan of an intended PLC link

Frequency plan (transmitters and receivers frequency band allocation in the RF range) is to be defined on the basis of general frequency plan of existing PLC system in the way that is described in document IEC 60663 [2].

3.1.3.2 Corona noise power level

It is necessary to define maximum expected power level of corona noise in the entire frequency band of DPLC channel as described in IEC 60663 [2]. Corona noise power level values for adverse weather conditions should be considered.

Data on corona noise power level that is stated in document IEC 60663 [2] and document ANSI/IEEE Std 643-1980 [4], are results of measurements made on real HV power lines. Measurements were done by means of level meter with ***true R.M.S.*** measuring characteristic. The envelope of actual noise signal on AC HV power line is modulated with 150Hz or 180 Hz signal (high local maximums of noise amplitude). This is because of the nature of corona noise. Therefore, harmful influence of actual noise on DPLC channel operation is much stronger than harmful influence of White Noise with the same true RMS level value. For this reason the corona noise power level from above mentioned documents should be corrected by +7dB, unless otherwise specified by the manufacturer; equation 10.

In document IEC 60663 [2] expected corona noise power level on HV power lines is stated in a frequency band of 4kHz (BW = 4kHz) and in document ANSI/IEEE Std 643-1980 [4] in a frequency band of 3kHz (BW = 3kHz). Therefore, for calculating corona noise power level in the entire DPLC channel frequency band, equation 10 has to be used:

$$N_d\,[dBm] = N_{BW}\,[dBm] + 10 \log (BW_d / BW) + 7dB \qquad \text{(Eq. 10)}$$

3.1.3.3 PLC link attenuation (a_L)

Overall PLC link attenuation (HV power line and coupling equipment), a_L, is to be determined according to the procedure described in document IEC 60663 [2]. The adverse operational conditions on the transmission path have to be considered.

3.1.3.4 Comments on chapter 3.1.3

DPLC link planning is much more exacting than planning of a PLC link with APLC channel(s). This is because of the threshold characteristics inherent to digital systems. Either they are very good, or not available.

In addition, it has to be stressed that in the planning procedure only corona noise is considered. Other types of disturbance (interference and impulse disturbances) are not taken into account. Anyway, such method is sufficient, because impulse disturbances interrupt the operation of the DPLC channel only temporarily and for a short period of time. On the other hand too high corona noise power level would disable operation of DPLC channel for a longer period of time (until for example weather conditions improve).

Apart from Corona Noise, one should also consider “Narrowband Interferers”, which are more likely if the bandwidth increases. Different modulation principles behave differently when exposed to narrowband interferers.

3.1.4 DPLC link planning procedure

3.1.4.1 Input data

To perform a PLC link planning procedure, the following input data are necessary:

- PLC equipment data: ***“C/SNR” characteristic*** and ***dSNR***
- transmission path data: BW_d, $N_{d\,max}$ and a_L
- application data: $C_{d\,min}$ and BER_{max}

3.1.4.2 Execution of the planning procedure

A DPLC link planning procedure should be executed in the following four steps:

Step 1: Based on data of required transmission capacity, $C_{d\,min}$**,** and bandwidth, BW_d**,** of the DPLC channel, required SNR_{min} for BER = 10^{-6} has to be read from the “C/SNR” characteristic. If application(s) that will utilise the DPLC channel allows higher BER (BER ≤ 10^{-3}), technical data ***dSNR*** of DPLC channel should be taken into account (see equation 2).

$$\mathbf{BER_{max} = 10^{-6}:}\ SNR_{min} = SNR\ (BER = 10^{-6}, C_d, BW_d)$$
$$\mathbf{BER_{max} = 10^{-3}:}\ SNR_{min} = SNR\ (BER = 10^{-6}, C_d, BW_d) - dSNR$$

Step 2: Based on known values of SNR_{min} and $N_{d\,max}$ calculation of required power level of the DPLC channel receiver input signal S_d is to be performed; equation 13:

$$S_d \geq N_{d\,max} + SNR_{min} \qquad \text{(Eq. 13)}$$

Step 3: Based on known value of S_d and calculated (or measured) PLC link attenuation value, a_L**,** required peak envelope power of DPLC channel, PEP_d**,** is determined; equation 14:

$$PEP_d\ [dBm] \geq S_d + a_L \qquad \text{(Eq. 14)}$$

Required PEP of PLC terminal transmitter is calculated in accordance with a number and types of PLC channels. Universal PLC terminals enable set up of PLC links with analogue (APLC) channels and/or digital (DPLC) channel. If the planned PLC link consists of a DPLC channel only then is the required PEP of PLC terminal transmitter determined by equation 15:

$$PEP \geq PEP_d \qquad \text{(Eq. 15)}$$

If the planned PLC link apart from DPLC channel includes one or more APLC channel(s), then the required PEP of PLC terminal transmitter is determined by equations 16:

$$PEP\ (W) \geq PEP_d\ (W) \times (B_N / BW_d)^2 \qquad \text{(Eq. 16a)}$$
$$PEP\ (dBm) \geq PEP_d\ (dBm) + 20 \log (B_N / BW_d) \qquad \text{(Eq. 16b)}$$

$B_N = n_a \times BW_a + BW_d$, where:

PEP	is required Peak Envelope Power of the PLC terminal
$\mathbf{B_N}$	is nominal RF bandwidth of the PLC link for one direction of transmission
$\mathbf{BW_d}$	is ***gross*** bandwidth of the DPLC channel for one direction of transmission
$\mathbf{BW_a}$	is ***gross*** bandwidth of each APLC channel for one direction of transmission (bandwidth of all APLC channels is the same)
$\mathbf{n_a}$	is a number of APLC channels

Step 4: The obtained value for minimum required PLC terminal transmitter peak envelope power, ***PEP (W)***, should be compared with technical data of the PLC terminal which gives possible values for PEP. A PLC terminal PEP value may not always be continuously settable but can occupy only a value from a set of possible discrete values. Most commonly, the possible values for PEP (W) are 10W, 20W, 40W and 80W. To set up a planned PLC link, PLC terminals whose PEP (W) is the same or higher than minimum required ***PEP (W)*** should be used; calculation by equation 16a.

It may occur that minimum required PEP (W) of the PLC terminal, calculated in accordance with equation 16a, is higher than the highest possible value of the PLC terminal PEP (W). In such a case one of the following three solutions should be chosen:

- reducing the highest expected transmission path attenuation $\mathbf{a_L}$ by choosing a lower frequency band and/or changing the coupling method
- reducing transmission rate of the DPLC terminal, e.g. by reducing the number of serviced or user data rates
- to conclude that implementing a DPLC link is not possible in general, or it is not possible with chosen type of PLC terminal.

If condition (Eq. 16) is not fulfilled, and the value a_L does not include a safety margin, then the only possible way is to increase PLC terminal peak envelope power, or reduce the transmission rate.

3.2 Networking aspects

3.2.1 General

The DPLC link is an element of a complex private telecommunication system. When integrating it into a telecommunication system certain DPLC link properties (positive and negative) should be considered. Special attention should be given to the following items:

- interface compatibility
- jitter

- limitations of telecommunications transmission network compressed sections (hops) usage (delay, multi-compression problem, non-transparency for a majority of different kinds of AF signals)
- adaptability of DPLC channel to conditions changes on the transmission path
- transmission of protection commands.

3.2.2 Interface compatibility

The entire DPLC channel transmission capacity may be used for the transmission of only one digital signal (single-purpose use of a DPLC channel) or for transmission of several time multiplexed digital signals (multi-purpose use of a DPLC channel). In case of single-purpose use the digital signal is connected directly to the DPLC channel digital interface.

In the case of multi-purpose use, data and/or analogue AF signals are connected to appropriate access interfaces on the access side of internal or external access multiplexer (AMUX). An external AMUX is connected to the digital channel interface of the DPLC channel. Generally, it is not realistic to expect all interfaces to be universal (programmable). Therefore, it is necessary to specify the types of all the interfaces of a DPLC link in the project phase. Availability of a wide range of various interface types is an important DPLC link characteristic that ensures adaptability of PLC equipment structure to the requirements of various applications.

3.2.3 Jitter

Jitter becomes an important parameter when DPLC channel is used as an integral part of a digital telecommunication transmission system. The DPLC channel may be used as a spur access link to serve as telecommunication connection between power system site and backbone of digital transmission network or as redundant digital channel in other parts of the digital transmission network.

Jitter, as parameter of a DPLC channel, has to be observed from two points of view:

- DPLC channel as generator of jitter (how much jitter a DPLC channel generates)
- DPLC channel as receiver of jitter-corrupted digital signal (how resistant is a DPLC channel to jitter).

Jitter requirements for digital links are stated in ITU-T recommendation G.823 [8].

3.2.4 Limitations in sections with compressed speech

A simple fact is that transmission capacity of a DPLC channel is low compared to other telecommunication technologies. Another fact is that quality algorithms for digitised speech signal compression exist today. Logical consequence of above-mentioned facts is expectance of extensive use of speech compression technology on DPLC channels. In this way, for establishing one speech connection through a DPLC channel transmission capacity needed is much lower than 64kbit/s.

Speech compression technology unfortunately introduces certain limitations to integration of compressed sections (hops) into a complex telephone system. Compressed telephone link ***is not transparent*** for all types of analogue AF signals (from 300Hz to 3400Hz). Roughly speaking transmission of non-speech analogue AF signals is not possible. Certain limitations should be taken into account when integrating compressed sections into a complex telecommunication transmission system.

3.2.4 1 Speech quality and the multi-compression problem

Speech compression technology enables transmission of speech with low bit rate, much lower than 64kbit/s, but at the same time has a rather strong influence on the transmitted speech quality. Speech quality is one of the important aspects of overall Quality of Service (QoS). While there are many factors that have an effect on speech quality there are some key parameters that characterise it:

- intelligibility (clarity)
- delay
- echo.

More about speech quality and measuring methods are presented in Annex C

Structure of a speech communication system includes a number of telephone exchanges and telephone subscribers (telephone sets, dial-up modems and/or fax terminals), interconnected by many sections (hops) of telecommunication transmission system. In general, an end-to-end link between any two subscribers consists of many hops. Each compressed section inserts delay in from 50 ms to 250 ms range. Delay influences speech communication comfort but does not affect speech intelligibility and speaker recognition.

A much bigger problem is influence of compressed sections on speech intelligibility. As long as only one or two speech compressions/de-compressions is executed in an end-to-end speech connection, adequate quality of the transmitted speech is assured. If there are many compressions/de-compressions executed in an end-to-end speech connection, intelligibility decreases radically and at high delay finally decreases conversation comfort. To achieve adequate speech quality it is necessary to ensure that an end-to-end speech link between any two subscribers does not include many executions of compressions/de-compressions algorithm. This can be achieved by respecting the following rules:

- all speech signal transits from one compressed section to another should be performed on digital level
- all inter-connection sections between telephone exchanges should not be compressed or (if really necessary) compressed at very low compression rate (32kbit/s ADPCM or in extreme case 16kbit/s ADPCM).

3.2.4.2 Transmission of tone "In-band" signalling

Compressed sections are not transparent for tone "in-band" signalling, such as DTMF and MFC. Therefore, telephony interface should be capable of executing detection of such a signalling type and transmit it through compressed section in another format (e.g. as data).

3.2.4.3 Transmission of modem analogue AF signals

Algorithms for compression of digitised speech signal are based on human voice tract characteristics. Therefore, compressed sections of telecommunication transmission network are appropriate only for speech transmission. Through telephone network other types of analogue AF signals are transmitted too, such as signals of standard data modems, signals of narrow band data modems and signals of fax modems. Speech compression algorithm degrades characteristics of analogue AF signal so severely that modem receivers are no longer capable of demodulating correctly data from the received AF signal. Therefore, compressed sections are not suitable for transmission of analogue AF modem signals. The problem should be solved in the ways described in the following chapters.

Transmission of data modem analogue AF signal

Before connection of analogue AF modem signal to a DPLC channel, a modem should be inserted. The modem converts the analogue AF modem signal to a digital data signal. The modems data interface is connected to one of AMUX access data interfaces (in the case of multi-purpose use of the DPLC channel) or directly to a digital interface of the DPLC channel (in the case of single-purpose use of DPLC channel).

Transmission of fax modem analogue AF signal

Telecommunication element of fax terminal is called “fax modem”, which is an integral part of fax terminal. From the point of view of coupling to the transmission path, fax terminal is completely equal to a telephone set. It is always connected in 2-wire mode and by its nature operates in dial-up mode. A fax terminal usually allows establishment of speech connection too (integrated or independent telephone apparatus, connected to fax terminal).

From statements in the former paragraph it follows, that for transmission of fax modem analogue AF signal solution from paragraph 3.2.4.3 is not applicable. The only way to transmit fax messages through compressed sections is use of telephony interface module that allows detection of fax modem signal.

When the input signal to telephony interface module is analogue speech AF signal interface module it executes digitisation and compression of speech signal. Bit rate, to which speech signal is compressed, is an important parameter.

If a telephony interface detects a fax modem signal on its input, it demodulates the fax modem analogue AF signal into a digital data signal. This signal is then transmitted through the DPLC channel. The same part of the DPLC channel transmission capacity is used for transmission of the compressed speech signal. Fax modems only operate with some discrete values of a bit rate. Therefore, for transmission of compressed speech signal a bit rate supported by fax modem must be chosen.

3.2.5 Adaptivity of the DPLC channel

An HV power line as telecommunication transmission media is relatively unprotected from environmental influences. On one side, this property is reflected as sensitivity to interference and other disturbing signals irrupting from surroundings, but above all the weather conditions may have a strong influence on the telecommunication characteristics of the HV power line. Attenuation and corona noise power levels heavily depend on the weather conditions. In adverse weather conditions (high relative humidity, rainfall, ice forming on wires, snow, ...) transmission path attenuation and corona noise power levels increase. Both factors have a strong influence on the reduction of SNR at the receiver input. Minimum required SNR, which still assures a stable and quality operation of DPLC channel is dependant on DPLC channel efficiency $\boldsymbol{Eff}$ (see equation 1).

The lower the DPLC channel efficiency is, the lower the minimum required SNR.
It is desirable, that the DPLC channel be capable of adapting to adverse transmission conditions of transmission media. Adaptation is possible only by reducing the efficiency of the DPLC channel. During the operation, the DPLC channels bandwidth $\boldsymbol{BW_d}$, of course, cannot be changed. During the operation, the DPLC channel efficiency can be decreased only by decreasing the DPLC channel transmission capacity $\boldsymbol{C_d}$.

A change of the DPLC channel transmission capacity during operation is reasonable only in the case of multi-purpose use of DPLC channel. In this case, the DPLC channel is used for the realisation of many telecommunication services. Some of them are essential for power system operation, while some are less important or at least their permanent availability is not critical. The DPLC channel may offer a so called “fall-back” function. A fall-back function is the possibility of a DPLC channel automatically reducing transmission capacity in adverse transmission conditions, so that only the most important telecommunication services are ensured (fall-back function). When transmission conditions improve, the DPLC channel transmission capacity should automatically be restored to its primary value.

It is important to emphasise that a fall-back function cannot be implemented for a DPLC link between switches in a digital network (circuit-switched or packet switched networks) without serious negative impact on the performance. The fall-back function can be implemented in data-pipe applications in access networks where the only effect will be an increase in the transmission delay (not so important for data).

3.2.6 Transmission of protection commands

One of the most important telecommunication services that PLC links should assure is transmission of protection commands. Protection commands serve to improve the characteristics of command type protection systems (faster and more selective operations of protection system). The DPLC link should enable transmission of protection commands as well. Transmission of protection commands occurs when fault(s) appear on an HV power transmission system. Fault(s) in an HV power transmission system usually cause generation of electromagnetic disturbances (mostly in form of pulses) with high power level and it is very likely that under faulty conditions the operation of a DPLC channel is interrupted. Therefore, a DPLC channel by its nature is not an appropriate telecommunication resource for transmission of protection commands.

Transmission of protection commands may be designed in different ways. For transmission of protection commands the frequency band usually intended for transmission of DPLC signals is also used. Therefore, for the time of protection commands transmission, operation of the DPLC channel is interrupted and the signals from an analogue teleprotection subsystem are transmitted instead. The teleprotection subsystem may be integrated in the DPLC terminal or may be provided as an external unit.

3.3 Migration from APLC to DPLC

The main advantage of DPLC when compared to APLC is that DPLC makes a much more efficient use of the transmission bandwidth. Speech compression techniques, for instance, play an important role in achieving this goal. Also the capability of multiplexing different data channels into one single stream instead of using an analogue modem for each channel means saving of bandwidth because there is no need to keep spectral separation among the different modems.

When migrating from APLC to DPLC, all these advantages should be kept in mind. Indeed it will be to the user’s advantage to replace more than one APLC link with just one DPLC:

- the number of speech and data channels will be the same (or higher)
- bringing old APLC links out of service will free the corresponding frequency slots and the final result will be that the user will save bandwidth (the new DPLC will occupy less bandwidth for the same services). This will also be very helpful if the new DPLC link needs more than a 4 kHz slot
- the fact that the number of services is higher in DPLC links will make it easier to reserve channels for future expansion

- the fact that the services offered by several APLC links are integrated into just one DPLC link will mean less maintenance and less room needed in cabinets
- repetition of carrier frequency bands in a network may be alleviated compared to APLC.

4 MEASUREMENTS

4.1 Quality of the Coupling Equipment

The elements that determine the coupling to the line are:

- Line Trap
- Coupling Capacitor / Capacitive Voltage Transformer
- Coupling Device / Line Matching Unit

The two most critical are the Line Trap and the Coupling Device.

The Line Trap is specified by the IEC 60353 [5]. To minimise the influence of switching actions in the HV-network and to minimise crosstalk between adjacent line sections, the proper working of the Line Trap in the frequency range of the Digital PLC has to be checked. This can be done by earthing the power line in the substation and measuring the line attenuation and the return loss.

The Coupling Device is specified in IEC 60481 [6]. For Digital PLC attention has to be given to the return loss. Especially for short HV-lines a low return loss may result in a bad frequency response and will affect the quality of a Digital PLC-link. A low return loss may also lead to high crosstalk from the DPLC transmitter into the local receiver.

4.2 Output Level / Receive Level

Since it can be difficult to measure the level of the modulated signal (especially at the receiver input), the measurement of a single tone generated by a built-in signal generator can be helpful. The manual should then provide a formula to calculate the level of the modulated signal referred to the level of the reference tone from the signal generator.

4.3 Noise Level

The noise level has to be measured at the carrier frequency input of the PLC-equipment with a certain bandwidth defined by the level meter, e.g. 3.1 kHz. A bandwidth correction has to be made to get the noise level within the transmission channel:

$$K_{correction\ factor} = 10 \log TxBW/3.1\ kHz$$

4.4 Signal-to-Noise Ratio (SNR)

The SNR is given by the difference of the RMS noise level of the modulated receive signal and the noise level within the gross bandwidth of the used transmission channel. The given SNR and the used bandwidth allow a maximum bit rate to be transmitted via the channel. Before setting the bit rate of the Digital PLC equipment it has to be considered, that the SNR may change significantly with time. The bit rate (and if available the fallback bit rate) has to be adjusted to ensure the maximum possible availability of the link.

4.5 Performance of a Digital Transmission Link

The ITU-T G.821 [7] gives a definition of the performance of a digital transmission link. The following parameters are defined:

- Error Free Seconds (EFS): Seconds with no bit error.
- Errored Seconds (ES): One second intervals with any error.
- Severely Errored Seconds (SES): One second intervals with a BER > 10^{-3}.
- Available Time (AT) or equally UnAvailable Time (UAT): A period of unavailable time begins when BER in each second is worse than 10^{-3} for a period of 10 consecutive seconds and terminates when the BER in each second is better than 10^{-3} for 10 consecutive seconds.

This Recommendation specifies error performance events, parameters and objectives of an N x 64 kbit/s circuit-switched digital connection ($1 \leq N \leq 24$ or ≤ 31 respectively) used for voice traffic or as a “Bearer Channel” for data-type services. It is clear that this measurement procedure may not be fully applicable to other transmission rates or packet-switched networks. The subject of quality of transmission in packet-switched networks is much more complicated and depends on the application: BER is important for data, but not so important for voice while delay is important for voice, but not so important for data. Packet loss is important if you are using TCP, but applications for which packet loss is not so important (such as SNMP) use UDP.

In the case where the Digital PLC offers a dynamic adjustment of the bit rate, according to conditions of the transmission path, the measurement of the performance has to be done via a sub-channel of the multiplexer. This sub-channel has to be transmitted with high priority.

One important parameter for a DPLC link is the recovery time: The time it takes from when the link under normal operation is disturbed (noise burst, phase drop etc.) to when the link is back in normal operation. This recovery time influences the availability of the link.

4.6 Commissioning of a DPLC-link

Annex B lists the basic measurements that should be carried out during the commissioning of a DPLC link. Additional tests may be recommended by the manufacturer.

5 FUTURE APPLICATIONS AND REQUIREMENTS

The responses to the questionnaire show clearly that the dominating application to-day is the multi-purpose application, i.e. that each service on a link is terminated at each end of a DPLC link (Annex A, question 7).

We also see, however, that some responses indicate that the DPLC link is used as a data pipe, i.e. the whole digital capacity is allocated to one user data channel. The capacity can then be used directly between devices requiring this capacity, or the DPLC link is a connection between nodes in a network.

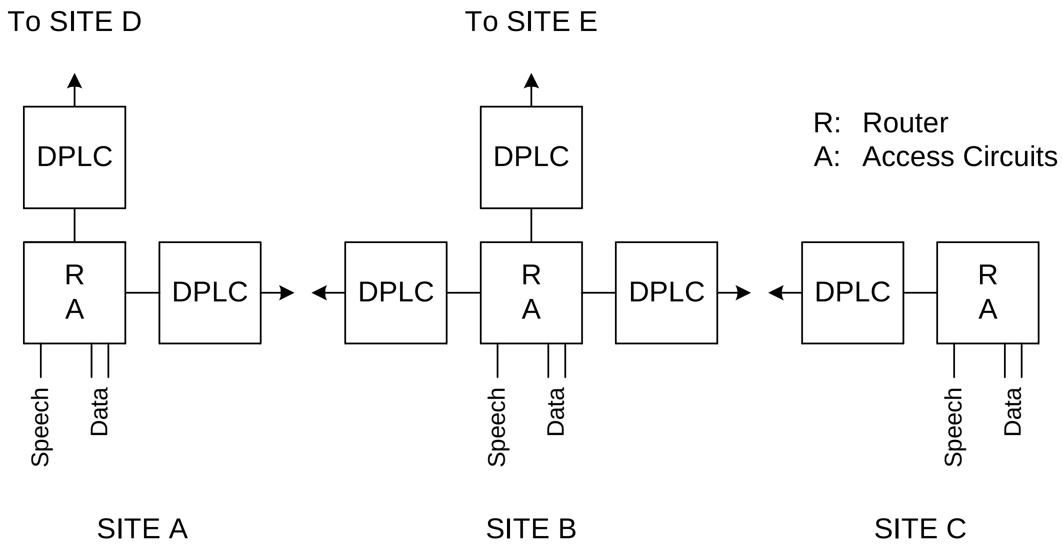

Figure 5.1

Figure 5.1 shows as an example of how this can be done. Nodes are connected by DPLC links to form a network, and in fact this example is also a multi-purpose application on network basis. The responses to the questionnaire (Annex A) showed that speech and data were considered as equally important.

A solution like this has the following advantages:

- an efficient utilisation of the configured capacity of the DPLC links, e.g. by traffic management with service prioritisation facility
- improved availability by network resiliency
- a speech signal is kept in a digital format throughout the network and multi-hop compression with resulting long delays is avoided (reference is made to clause 3.2.4.1).

Other aspects:

- other digital links can be integrated in the same network
- flexible interfacing of the data channels.

What can be expected of future requirements?:

- speech transmission will still be important
- higher transmission rates for RTU-channels
- new interfaces like Ethernet interface
- creation of WANs rather than point-to-point links
- management systems to handle the elements in a network.

In this chapter teleprotection is not mentioned. However, it is expected that most DPLC links will be equipped with teleprotection. This is expected to be an analogue subsystem and with capacity and performance on today’s level (reference is made to [1], clause 6.4).

6 RECOMMENDATIONS TOWARDS STANDARDISATION

Cigré SCTF D2.08 recommends that IEC TC 57 revise the documents:

- IEC 60495 [3] to include DPLC and thus prepare an International Standard for PLC in general. When the document was revised in 1993 the general environmental requirements for documents within TC 57 was not finalised and could not be included. An update of this part in the document is also necessary.

- IEC 60663 [2] to include the DPLC aspects.

7 DEFINITIONS AND ABBREVIATIONS

7.1 Definitions

Available Time	Begins when the BER is better than 10^{-3} for 10 consecutive seconds, and terminates when the BER is worse than 10^{-3} for 10 consecutive seconds
C/SNR (Capacity versus SNR)	Capacity of the DPLC expressed in bits per second for a given Signal-to-Noise ratio.
Errored Seconds	One second intervals with any error.
Error Free Seconds	Seconds with no bit error.
Gross Bandwidth	Bandwidth of the carrier frequency signal including spectral overhead and auxiliary signals. It is normally an integer of 4 kHz.
Gross Transmission Rate	The data rate including overhead for multiplexing, synchronisation etc.
Severely Errored Seconds	One second intervals with a bit error rate > 10^{-3}.
Unavailable Time	Begins when the BER is worse than 10^{-3} for 10 consecutive seconds, and terminates when the BER is better than 10^{-3} for 10 consecutive seconds.

7.2 Abbreviations

a_L	Line attenuation
ADPCM	Adaptive Differential Pulse Code Modulation
AMUX	Access Multiplexer
APLC	Analogue Power Line Carrier
AT	Available Time
AWGN	Additive White Gaussian Noise
B_N	Nominal Carrier-frequency band
BER	Bit-Error-Rate
BW	Band Width
BW_a	Gross Band Width of an APLC channel
BW_d	Gross Band Width of a DPLC channel
C	Capacity
C_d	Net transmission capacity of a DPLC channel
C/SNR	Capacity versus SNR
dSNR	Difference in SNR for a BER of 10^{-6} and 10^{-3}
DTMF	Dual Tone Multi Frequency
DPLC	Digital Power Line Carrier
EC	Echo Cancellation
Eff	DPLC channel efficiency
EFS	Error Free Seconds
ES	Errored Seconds
MFC	Multi Frequency Code
MOS	Mean Opinion Score
N_d	Noise level in the DPLC channel bandwidth
PABX	Private Automatic Branch Exchange

PEP	Peak Envelope Power
PEP_d	Peak Envelope Power of a DPLC channel
PLC	Power Line Carrier
QoS	Quality of Service
RF	Radio Frequency (i.e. carrier frequency)
RMS/true	Correct value of power level independent of waveform
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
S_d	Power level of a DPLC signal
S_{dmin}	Minimum required input power level of a DPLC signal
SES	Severely Errored Seconds
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
TCP	Transmission Control Protocol
UAT	Unavailable Time
UDP	User Datagram Protocol
WAN	Wide Area Network

8 REFERENCES

[1] Cigré report 164. *Report on Digital Power Line Carrier*

[2] IEC 60663 (1980-01). *Planning of (single sideband) power line carrier systems.*

[3] IEC 60495 (1993-09). *Single sideband power line carrier terminals.*

[4] ANSI/IEEE Std 643-1980. *IEEE Guide for Power-Line Carrier Applications*.

[5] IEC 60353 (1989). *Line traps for a.c. power systems*.

[6] IEC 60481 (1974). *Coupling devices for power line carrier systems*.

[7] ITU-T Recommendation G.821. *Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an Integrated Service Digital Network.*

[8] ITU-T Recommendation G.823. *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[9] ITU-T Recommendation P.800. *Methods for subjective determination of transmission quality*.

[10] ITU-T Recommendation P.830. *Subjective performance assessment of telephone-band and wideband digital codecs.*

[11] ITU-T Recommendation P.862. *Perceptual evaluation of speech quality (PESQ), and objective method for end-to-end speech quality assessment of narrowband telephone networks and speech codecs.*

ANNEX A

SCTF D2.08

RESPONSES TO THE QUESTIONNAIRE: Summary

Abbreviations: DPLC for Digital PLC, APLC for Analogue PLC

1 *Number of DPLC links in operation* — 225

2 *Total number of PLC links in operation* — > 2700

3 *Voltage level of power lines* — 30kV – 380/400kV

4 *Range of length for power line length with DPLC links* — From 15km to 500km

5 *Predominantly coupling to the power line for DPLC*

Phase-to-phase	14
Phase-to-earth	10

6 *Transmission data*
Gross bit rate / bandwidth for a duplex connection — _ _ _ _ _ kbps / _ _ _ _ _ kHz

7 *Application*

Multipurpose link:	21
Digital link in a network (data pipe):	4
Teleprotection:	

8 *Coexistence*

	Yes		No	
Do you use DPLC terminals in parallel with APLC terminals on the same power line?	Yes	14	No	8
Have you experienced any coexistence problems?	Yes	6	No	8

If yes, please explain:

9 *Services if used as a multipurpose link*

Speech	Used?		Yes	22	No	2
Importance of the speech connections(s)	Low	3	Medium	6	High	9
Speech bit rate	2.4-9.6 kbps					
Speech compression algorithm (if known)	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _					

	Speech delay per hop (if known)	_ _ _ _ _ ms
	Max number of compressions end-to-end	_ _ _ _ _
	Evaluation of speech quality	Poor [2] Good [15] V good [2]
	Comments to the speech quality	
	SCADA:	
	Is capacity allocated for SCADA?	Yes [15] No [6]
	Transmission rate	0.1-1.2/2.4/4.8/9.6/19.2_kbps
	Protocols	ADLP80, RP570, RP571, HPC560, TCP/IP, DNP3
	Data:	
	Is capacity allocated for data transmission?	Yes [14] No [7]
	Transmission rate	2.4/9.6/19.2 kbps
	Interface(s)	RS232
	LAN interconnection:	
	Is capacity allocated for IP traffic?	Yes [3] No [17]
	Interface	Ethernet [ ] Other [ ]
	Protocol	TCP/IP [ ] Other [ ]
10	*If used as a data pipe*	
	Data transmission rate	64 kbps
	Type of interfaces (typical)	RS232 [ ]
		V.35 [ ]
		G.703 [ ]
		X.21 [ ]
		Other: _ _ _ _ _ _ _ _ _ _ _
11	*Performance of the DPLC link*	
	Availability	Poor [2] Good [18] Very good [2]
	Planning compared to APLC	Simple [12] Compl. [7]
	Commissioning compared to APLC	Simple [9] Compl. [9]
	General satisfaction	From 2 to 4. Average: 3.3 (not weighted) (Scale from 1 (useless) to 5 (excellent))
12	*Further plans*	
	Do you include DPLC in your future plans?	Yes [19] No [2]
	If yes:	
	For new links?	Yes [11] No [2]
	For replacement of APLC?	Yes [13] No [14]
	Reason for replacement	_ _
	Do you plan to use the DPLC links according to clause 9 or to clause 10 of this questionnaire?	Clause 9 [16] Clause 10 [3]

ANNEX B

Steps for Commissioning Digital Power Line Carrier Links

Contents

B.1 Tests before connecting the equipment to the line

Description	*Requirement*	*Reason for test*
Measurement of Return loss at the RF connector to the line	≥ 10 dB	A low value signifies a poor match of the impedance of the PLC equipment to the line, which produces distortion and echoes of the DPLC signal generated by the DPLC terminal.
Measurement of the line attenuation	No sharp peaks or notches	Unexpectedly high attenuation or fluctuations of attenuation of several dB within just a few kHz would indicate a defective line trap or extremely unusual characteristics of the line.

B.2 System tests

Description	*Requirement*	*Reason for test*
Connect the DPLC terminals to the line, switch on power to the terminals and perform equipment and line specific tuning steps as for example: - Check of supply voltages	Equipment and line specific. Detailed	

- Check of equipment settings - Check/adjust transmitter level - Adjust transmitter level alarm threshold - Check/adjust receiver level - Tune RF hybrid - Check SNR - Adjust receiver alarm threshold	instructions normally provided by the equipment manufacturer	
Check the equipment status	No alarms, all levels within permissible limits.	To verify the correct operation of the system.

B.3 Tests at the data interfaces

Description	*Requirement*	*Reason for test*
Connect data testers to the data interface on the local and remote DPLC set and measure the BER for both directions individually. Alternatively, the test can be carried out by looping back the data at the remote DPLC terminal and measuring the BER with a data tester locally for both directions together. Repeat the test for all other data interfaces.	$< 10^{-6}$ if no other value is specified.	To verify the correct operation of the data channels.

B.4 Tests at the telephony interfaces

Description	*Requirement*	*Reason for test*
Test of service telephone, if any.	Buzzer works and conversation is possible.	To verify the correct operation of the service telephone.
Test of PABX telephone interface by initiating calls from the PABXs on both sides of the link. Repeat test for all other PABX interfaces.	Calls can be established and conversation is possible.	To verify the correct operation of the PABX telephone interface.
Test of hot line telephone interface by connecting telephone sets to the interface on both sides of the link and initiating calls in both directions by picking up the handsets. Repeat the test for all other hot line telephone interfaces.	Ringer sounds, call can be established and conversation is possible.	To verify the correct operation of the hot line telephone interface.
Test of subscriber telephone interface by connecting telephone sets to the interface and a PABX to the corresponding interface at the opposite side and initiating calls in both directions. Repeat the test for all other subscriber telephone interfaces.	Dialling is possible, ringer sounds, call can be established and conversation is possible.	To verify the correct operation of the subscriber telephone interface.

ANNEX C

Speech Quality

C.1 Speech Quality

Speech quality is one of the important aspects of overall Quality of Service (QoS) for voice telecommunications. While there are many factors that affect voice quality, there are three key parameters that characterise it:

- intelligibility (clarity)
- delay
- echo

The relationship between clarity, delay, and echo can be quite complex as shown in the three-dimensional Figure C.1.

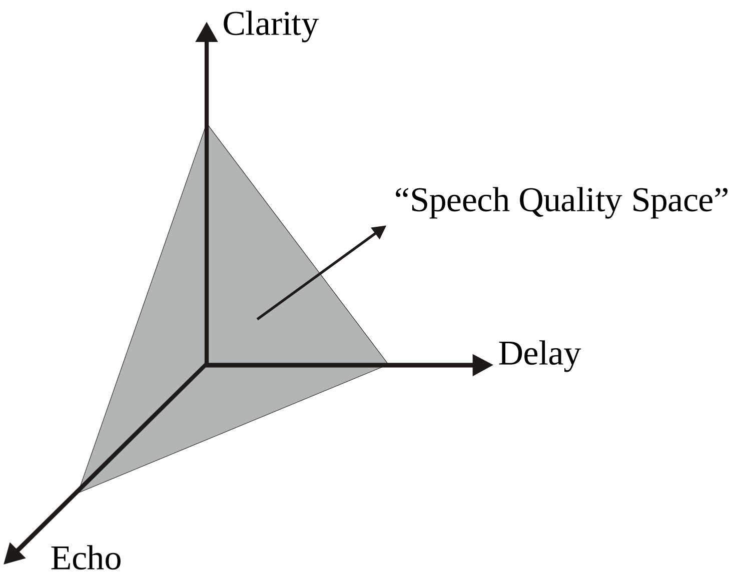

Figure C.1: Relationship among Clarity, Delay, and Echo with regards to Speech Quality

Intelligibility (Clarity) refers to the clearness or fidelity of voice as it is reproduced by a network and perceived by a listener. Clarity is independent of delay. Clarity is also independent of echo since echo is perceived by the speaker and clarity is perceived by the listener.

Delay is the time it takes a voice signal to travel end-to-end between talker and listener and often manifests itself as an apparent time lag between when the talker speaks and when the listener responds. When a perceptible delay is present, conversations can seem uncomfortable. When too much delay is present, voice conversation can become impossible.

Echo in a telephony environment is usually caused by hybrid wire junctions in a network in which a portion of the energy from a person's speech signal is reflected back to the same line.

C.2 Measuring Clarity

The first significant technique used to measure speech clarity was to actually use large numbers of human listeners to produce statistically valid subjective clarity scores. This technique is known as Mean Opinion Scoring (MOS) where value of large numbers of human *opinion score* is calculated. The technique for performing MOS testing on networks is generally described in ITU-T P.800 [9], while ITU-T P.830 [10] provides more specific methods for subjective testing on speech codecs. Both of these ITU-T recommendations describe methods for testing, method for subjective scoring, value of scores, characteristics of speech samples to be used, and other conditions under which testing is to be performed.

MOS testing can be based on two-way conversational tests or on one-way listening tests. In MOS subjective testing of the quality value of speech is from 1 to 5.

Obviously, MOS testing has several drawbacks:

- it is subjective because results depend on many uncontrollable attributes of the test subjects including mood, attitude, and culture. Practically speaking, MOS testing is not a repeatable or consistent method for testing.

- it is expensive because it requires a large number of people and elaborate testing setups.

- it is inefficient and impractical to use to perform frequent testing such as that needed for network design and configuration changes and for routine network monitoring.

MOS testing drawbacks suggest that objective, automated, and repeatable testing methods are needed for measuring subjective speech clarity.

To answer the need for an objective, automated, and repeatable speech clarity testing method that takes into account the subjective nature and perception of clarity, one technique was developed and standardised by ITU-T:

- PESQ (Perceptual Evaluation of Speech Quality) method standardised by ITU-T P.862 [11].

There are developed instruments that perform measurements in accordance with ITU-T P.862, and measurements of delay and echo.