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Distribution automation using distribution line carrier systems - Part 1: General considerations - Section 4: Identification of data transmission parameters concerning medium and low-voltage distribution mains

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Automatisation de la distribution à l'aide de systèmes de communication à courants porteurs - Partie 1: Considérations générales - Section 4: Identification des paramètres de transmission de données des réseaux de distribution moyenne et basse tension

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Section 4: Identification des paramètres de transmission de données des réseaux de distribution moyenne et basse tension

Distribution automation using distribution line carrier systems –

Part 1:

General considerations –
Section 4: Identification of data transmission parameters concerning medium and low-voltage distribution mains

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FOREWORD

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- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 1334-1-4, which is a technical report of type 3, has been prepared by IEC technical committee 57: Power system control and associated communications.

The text of this technical report is based on the following documents:

Committee draft	Report on voting
57(SEC)197	57/241/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This report is a Technical Report of type 3 and is of a purely informative nature. It is not to be regarded as an International Standard.

DISTRIBUTION AUTOMATION USING DISTRIBUTION LINE CARRIER SYSTEMS –

Part 1: General considerations –

Section 4: Identification of data transmission parameters concerning medium and low-voltage distribution mains

1 Scope

This Technical report (type 3) summarizes the results obtained through an intense activity of research carried out in some European countries, in order to assess the ability of MV (medium voltage) and LV (low voltage) distribution power networks to be used as a data transmission medium suitable to support applications related to distribution automation systems.

Taking into account that the research has been focused on a reduced number of typical situations, the results, shown in this report, will be considered representative of all the situations similar to those that have been investigated.

The results are expressed with reference to certain transmission parameters, described in clause 2, which are of great importance for the design of a distribution line carrier communication system.

2 Transmission parameters

Medium and low voltage power lines, conceived to carry high power at a 50 Hz or 60 Hz frequency, provide a difficult channel for data communication.

Signal attenuation and noise level influenced by the electrical loads and by changes in the network topology lead to a great variation in transmission quality as a function of frequency, time and location.

Moreover, a distribution power line cannot be assumed as a homogeneous medium for communication purposes because of the serious impedance mismatch occurring, for instance, at the transition points between cables and overhead lines and at branch-off points. This causes signal reflection and consequently a supplementary attenuation and phase distortion of the transmission signal.

Nevertheless, even though the channel characteristics are so unpredictable (varying with time and location), the investigatory work carried out on several distribution networks provides sufficient information which is useful for determining cost efficient methods to overcome the basic difficulties.

First of all, the behaviour of single network components (e.g. power transformers, capacitor banks, cables, overhead lines, voltage and current transformers, etc.) when transmission signals pass through them, is well known.

The resulting characteristics of each component can be identified by:

- its impedance as a function of frequency, $Z(f)$;
- its transfer function as a function of frequency, $H(f)$.

  NOTE – The module is the ratio of received signal amplitude to transmitted signal amplitude and the phase is the difference between the received signal phase and the transmitted signal phase.

Available information refers to transmission characteristics of a section of distribution network between two coupling points, e.g. the points where transmission signals are transmitted/received.

There are two cases to be considered when two coupling points are, from a transmission point of view, either interconnected or disconnected.

The first case happens when there is a galvanic continuity between the two coupling points or if transmission continuity is ensured by means of an appropriate devices such as a by-pass. The second case happens when neither galvanic nor transmission continuity exists.

With reference to two interconnected coupling points, the parameters assumed to identify the characteristics of the corresponding transmission channel are:

- the impedance, as a function of frequency and time, related to each coupling point

$$Z_C\,(f,t)$$

- the transmission transfer function, as a function of frequency and time, between the two considered coupling points,

$$H_C\,(f,t)$$

NOTE – The module is the ratio of received signal amplitude to transmitted signal amplitude and the phase is the difference between the received signal phase and the transmitted signal phase.

- the noise, as a function of frequency and time, related to each coupling point

$$N_C\,(f,t)$$

With reference to two disconnected coupling points, the most important transmission parameter is:

- the cross-talk transfer function, as a function of frequency and time, between the two considered coupling points

$$C_C\,(f,t)$$

NOTE – The module is the ratio of received signal amplitude to transmitted signal amplitude and the phase is the difference between the received signal phase and the transmitted signal phase.

The above mentioned parameters allow the evaluation of the expected channel characteristics by the creation of a mathematical model approximating the real channel.

3 Transmission parameters of the main components of a distribution network

3.1 *Capacitors*

MV capacitor banks, for reactive power compensation, installed in HV/MV or MV/LV substations present (figure 1, curve "a") a very high selective behaviour with a resonance frequency of about 50 kHz and a very low corresponding impedance (about 0,01 Ω). This means that the impedance rapidly increases when the frequency of the transmission signal is far from the resonance point.

Curve "b" shows the typical behaviour of the same MV capacitor banks provided with external electrical connections of longer length (about 1,5 m). It can be noticed that the resonance point falls to about 30 kHz, thus significantly modifying the impedance values as a function of the frequency.

In practice, since the external electrical connections are normally longer than 1,5 m, the corresponding shifting of the resonance point towards frequencies less than 30 kHz allows using frequencies greater than 50 kHz, so that MV capacitor banks do not involve a significant sink of the transmission signals. This means that in the frequency range above 50 kHz, it is not necessary to add line traps to the MV capacitor banks for transmission purposes.

As far as the LV capacitors are concerned, the situation is quite similar and the previous conclusion can be drawn.

The curve "c" shows the typical behaviour of an LV capacitor with very short external electrical connections, whilst the curve "d" refers to the same LV capacitor with external connections of about 1,5 m.

In practice, the length of the external electrical connection is greater than the above value. In any case, the actual length can be easily increased by adding simple ferrite rings in order to obtain a sufficient impedance value (20 Ω to 30 Ω) so as to not affect signal transmission.

3.2 *Transformers*

Transformers present a frequency variable typical impedance to the terminal of the MV line. Figure 2a shows the impedance of a MV/LV transformer as a function of transmission signal frequency in two different cases: no-load and short-circuit secondary winding. In the range from 10 kHz to 200 kHz, the impedance is of a capacitive type and decreases with the frequency. The resonance of a MV/LV transformer falls generally to a frequency below 10 kHz. Although depending on transformer type and class, reported values are an acceptable reference. Impedance values that range from 1 kΩ to 50 kΩ are much higher than characteristic line impedance which ranges from about 30 Ω to 150 Ω. For this reason, transformers do not affect transmission characteristics for frequencies above 20 kHz.

Below about 10 kHz to 20 kHz, a single-phase power transformer does not dramatically attenuate the signal. Thus a signal injected into an MV network passes easily to the LV section.

For three-phase transformers signal transfer depends on the coil configuration. Figures 2b and 2c show an example of transformer transfer function as a function of frequency, transmitting from the MV side and receiving on the LV side. Figure 2c shows the same function with sending from the LV side and receiving on the MV side. Such measures are carried out with a load of 150 Ω which represents the typical impedance of overhead lines.

From this point of view, it would seem possible to cover both medium and low voltage networks with a single frequency signal, injected at the MV busbars level of a HV/MV substation and received from a device (e.g. an electronic metering apparatus) which is connected to an LV network.

Unfortunately, this apparently favourable situation is, in practice, jeopardized because of the following characteristics.

- It is difficult to send from the LV side to the MV side at a reasonable power due to insertion loss of the transformer terminated by the line impedance.
- The noise level in the frequency range below 20 kHz is high.

- Distribution networks usually include capacitor banks (see 3.1) that present low impedance in this frequency range. To avoid the capture of the signal, the installation of appropriate line traps is required.

Above the range of about 10 kHz to 20 kHz the high attenuation of transformers in both transmission directions and the presence of capacitor banks act as a virtual signal block.

It is therefore necessary to install by-pass units to guarantee the information exchange between LV and MV networks.

According to application requirements, by-pass units can be composed of either passive (single communication process for both MV and LV networks) or active devices (able to manage two independent communication processes between MV and LV networks).

3.3 *Cables*

MV cable: extensive measurements were performed on cables from various suppliers, with cross-sections ranging from 35 mm^2 to 240 mm^2 and of different dielectric material and wire metal. As a result, it is possible to conclude that the characteristic line impedance ranges from 20 Ω to 40 Ω and that the attenuation, with the cable loaded on its characteristic impedance, ranges from 1,5 dB/km to 5 dB/km in the frequency range of 20 kHz to 200 kHz.

LV cable: for cables that include both three-phase concentric neutral cable and aerial cable, the characteristic line impedance ranges from 40 Ω to 120 Ω and the attenuation, with the cable loaded on its characteristic impedance, ranges from 2 dB/km to 10 dB/km in the frequency range from 20 kHz to 200 kHz.

4 Section of MV power network

For a homogeneous line terminated by a characteristic impedance, the attenuation is due only to line loss. An MV power network (constituted by cables and overhead lines) cannot be assumed as homogeneous for communication purposes. A serious mismatch will occur at the point of transition between overhead lines and cables and at the branch-off points.

With particular reference to the frequency range of 20 kHz to 200 kHz, the behaviour of an MV network is slightly influenced by consumer loads (due to good decoupling ensured by MV/LV transformers (>30 dB)), so that the loads of an MV power network are only MV/LV transformers and capacitor banks.

The coupling point impedance $Z_C(f)$ essentially depends on the layout of the surrounding types of lines and their characteristic impedances.

Typical values of a phase-to-ground impedance module are shown in figure 3a for a MV/LV substation placed at the midpoint of a long overhead line and in figure 3b for a substation connected to the overhead line through a cable.

Figure 4a shows attenuation of MV underground lines in the range from 20 kHz to 200 kHz. Figure 4b shows attenuation versus distance. Figure 4c shows the attenuation for a phase-to-ground transmission (including coupling device attenuation) detected by transmission in each substation and by measurement in the other substations.

Noise includes both wide-band disturbances (damped transients and pulse signals) and narrow-band disturbances (modulated and unmodulated carriers with their harmonics). Figure 5a shows the noise measured on an MV network versus frequency. Noise measured in a bandwidth of 3 kHz decreases with frequency. In the range of frequencies from 40 kHz to 95 kHz, the average noise is about 2 mV r.m.s. Figure 5b shows the noise measured in different substations. It can be pointed out that at frequencies greater than 30 kHz the noise can be generally considered as within acceptable limits. Typically it is less than 7 mV r.m.s. on 75 Ω at 70 kHz (bandwidth is 4,8 kHz) for 90 % of the time, with the presence of high power random bursts for 2 % of the time.

Cross-talk measured between two sections of a switched-off line ranges between 35 dB and 40 dB. Its influence on the transmission channel can be easily managed without any modification of the power distribution system.

Finally, an MV network behaves as a mismatched medium, characterized by standing wave phenomena, causing attenuation increase up to values exceeding about 10 dB to 20 dB. To reduce mismatched, it is necessary to add resistive loads in some MV/LV substations in order to reach a quasi-adaptative communication medium.

5 Section of an LV power network

With particular reference to the frequency range reserved for electricity suppliers from 3 kHz to 95 kHz, the behaviour of an LV network is dramatically influenced by consumer loads, as they are directly connected to the network without the interposition of any decoupling device. The LV network is not however generally affected by standing wave phenomena. This causes a variability of the coupling point impedance (about 2 Ω to 150 Ω) and a quite high attenuation (5 dB/100 m to 10 dB/100 m).

Figures 6a and 6b show the impedance at the coupling point for a typical underground cable network and for overhead lines as a function of frequency.

Figure 7 shows maximum and minimum values of line attenuation as a function of frequency between substations separated by a distance of up to 500 m for a typical underground line. Figure 8 shows attenuation variation during a 24 h period, for the same network, measured at 100 kHz.

Figure 9 shows line attenuation of an overhead line as a function of the distance from the transmitting point at different frequencies.

Figure 10 shows attenuation in a building as a function of floor distance from the groundfloor of the building.

Noise includes both wide-band disturbances (damped transients and pulse signals) and narrow-band disturbances (modulated and unmodulated carries with their harmonics and TV row frequencies)). Figures 11a and 11b show the noise distribution detected with a 500 Hz bandwidth receiver on an LV noncoated overhead line network. Figure 11a gives a curve of the noise level as a function of frequency. Figure 11b gives a curve of noise level probability distribution at 80 kHz. It can be pointed out that the noise at frequencies greater than 50 kHz can be generally considered as within acceptable limits, with a typical value of less than 1 mV r.m.s. at 70 kHz (bandwidth of 500 Hz) during 90 % of the time.