Presentation of the Results of Measuring Characteristics of Power Line Installations in the Signals Transmission

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Abstract – **The subject of this paper is the presentation of research results of contemporary electrical cables characteristics in the function of signals transmission in the frequency range from 1 to 30 MHz, which is required by standard ETSI TR 102 494 for communications within the residential and business buildings. Results of analysis of the standard power line network topologies in the typical residential and business facilities are presented, also. Specific phenomena that are manifested in the signals propagation through electrical network are pointed out.**

Keywords – **Research results, Power line network, Residential and business facilities.**

I. Introduction

Power line networks are designed and implemented according to the criteria of optimization of basic function enforcement – transfer of electricity to final consumers – a variety of devices in the business and residential facilities. This fact causes that the installations, in the frequency bands for transmission of the information and multimedia signals, have characteristics that are, more or less different from the characteristics of networks specifically built for these signals. The most influential differences are constructive and technological characteristics of the cables, installation topologies in the business and residential facilities, variations of installation parameters caused by the changes in the consumer states, as well as the presence of specific additive interferences and noises.

II. Electrical installation cables

The main elements of the electrical installation cables are copper wires which with insulating layers around them form the structures, hereinafter called core. One or more cores in the same sheath form cable. The standard dimensions of the cables are expressed as part of wire cross sections, given in mm^2. Cables with three or five cores with cross sections of 1.5, 2.5, 4 or 6 mm^2 are applied in most residential and business facilities. In cable forming process cores are led straight and parallel, as opposed to telecommunications cables, where the twisting is done in pairs or quadruplets.

Insulating layers around the core are made of dielectric materials, primarily of extruded polyethylene and polyvinyl – chloride. In general, cables with polyethylene isolation are very superior for the transmission of high frequency signals (up to 30 MHz), because the dielectric losses in this material are approximately two order of magnitude smaller than in the polyvinyl – chloride. However, as the lengths of cables in the system are small, order about 10 meters, cables with polyvinyl – chloride insulation are fully satisfying.

For assessing the functionality of the installation cables as the telecommunications transmission medium it is necessary to determine their characteristic parameters in the specified range of frequencies. The basic parameters are the transfer function, characteristic impedance and propagation velocity of the signal. In further analysis, as well as in experimental verifications, cables are treated as homogeneous two – conductor transmission lines, regardless of the actual number of cores in them. Calculations were made for the cable type 3x2.5mm^2. Cross – section of this cable type is given in Fig. 1.

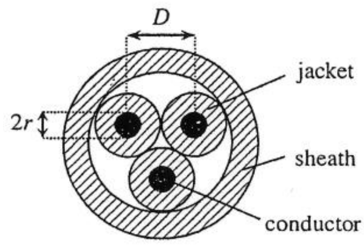

Fig. 1. Cable cross – section [2]

Primary distributed parameters are determined by standard formulas 1 – 6 [2]:

$$R = \sqrt{\frac{2\mu_r\mu_0 f}{\pi\sigma r^2}}\left[\frac{\left(D/2r\right)}{\sqrt{\left(D/2r\right)^2-1}}\right] \quad (1)$$

$$L_{ex} = \frac{\mu_r\mu_0}{\pi}\cosh^{-1}\left(\frac{D}{2r}\right) \quad (2)$$

$$L_{in} = \frac{R}{2\pi f} \quad (3)$$

$$L = L_{in} + L_{ex} \quad (4)$$

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$$c = \frac{\pi \varepsilon_r \pi \varepsilon_0}{\cosh^{-1}\left(\frac{D}{2r}\right)} \qquad (5)$$

$$G = 2\pi f C \tan\delta \qquad (6)$$

On the primary parameters basis the terms for the attenuation constant, propagation velocity and characteristic impedance are delivered and given by formulas 7, 8 and 9 [2]:

$$\alpha = \frac{R}{2Z_0} + \frac{GZ_0}{2} \qquad (7)$$

$$c = \frac{c_0}{\sqrt{\varepsilon_r}} \qquad (8)$$

$$c_0 = \sqrt{\frac{L}{C}} \qquad (9)$$

Eq. (7) can be expressed in the form of:

$$\alpha\left(\frac{dB}{m}\right) = \alpha_1{}^{-5}\sqrt{f} + \alpha_2{}^{-9} f \qquad (10)$$

For standard cable PP-Y 3x2.5 relevant information are:

2r = 1.8mm, D = 43.6mm, ε_r = 3.5, tan δ = 0.08.

For such a cable, equation for path attenuation may be presented:

$$\alpha\left(\frac{dB}{m}\right) = 2{,}3 * 10^{-5}\sqrt{f} + 3{,}3 * 10^{-9} f \qquad (11)$$

In Eqs. (10) and (11) frequency is introduced in Hz. In the same way it is found that value of characteristic impedance is 87Ω and propagation velocity is $0.53c_0$.

With additional calculating it is established that Eq. (11) can be used, with satisfactory accuracy, for cables with cross – sections of 1.5mm^2 and 4mm^2. Values of parameter (D/2r), which has a dominant influence on the results, are changed within range of ±10 % and this makes the variation of coefficients values in Eq. (11) below 5%.

Results shown in [2] can be used in favor of previous attitude. For cables NYM 3x1.5 mm^2 and NYM 3x2.5 mm^2 (standard VDE – 0250) had been carried out calculations and measurements of path attenuations in the frequency band 2.5 – 30 MHz . In the lower frequency band, even up to 10 MHz, values of path attenuations in both cables are identical. With further increase of frequency, a slightly greater increase of attenuation is noticed in cable 3x1.5 mm^2, and on 25 MHz attenuation difference is 0.04 dB/m.

Experimental verification of the calculation according to the Eq. (11) had been done by measurements on the standard installation cables PPY 3x1.5 mm^2 , PPY 5x2.5 mm^2 and PPY 3x4 mm^2. Measurements were carried out in homogeneous segments of cables, 25 meters length.

A fully satisfactory concordance of the calculation and measurement results is determined, as well as data from the cited literature. Values of path attenuation are within the limits of 0.04 dB/m at the frequency of 1 MHz to 0.24 dB/m at the frequency of 30 MHz . The average value of the characteristic impedance is 90Ω with variations of ±3Ω. Propagation velocity is very close to 150000 km/s, which means that the wavelength is approximately two times smaller than in free space.

The diagrams of calculating value of path attenuation dependence of frequency, the results of measurements in the mentioned installation cables, as well as for representative results from the literature, are shown in Fig. 2.

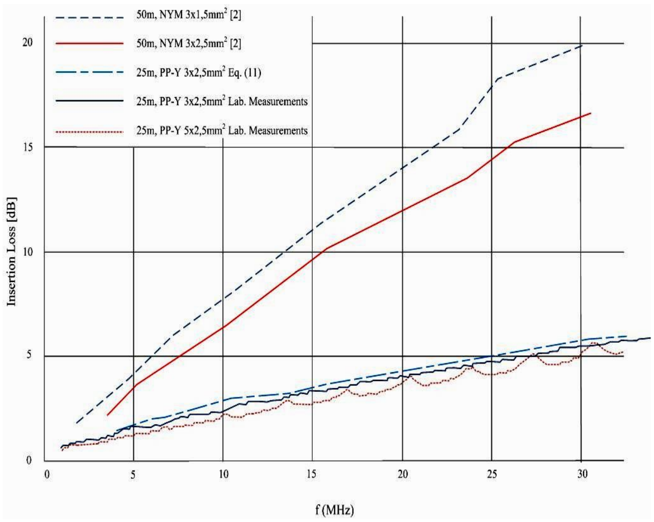

Fig.2 Insertion loss in function of frequency and type of power line cables

On the basis of presented material it follows the conclusion that the installation cables can be used for quality communications at distances of several tens and up to a hundred meters. Specific limits are determined by spanned attenuations of devices, installation topology, as well as communication modes.

III. TOPOLOGIES OF POWER LINE INSTALLATIONS

The standard power line installations in the facilities have basically the tree structure with two levels of branching. At the entrance to the facility (as a rule) is the main distribution cabinet where the first branching is done and from this point cables are led to residential or business units. Distribution boards exist in the each of these units where the second, local branching is done and from these boards cables are led to the individual consumers. Further discussion is limited to communications within the units, residential or business, i.e. to the local communication networks.

Local installations always have more or less extended structures with multiple branching points where the branches lengths are usually related with wavelengths of the signals. In the Fig. 3 is shown, as an example, single line diagram in a typical medium – sized residential unit.

The central point of this electrical installation is a distribution board where a large number, 15 – 20 or even more, of separate electrical circuits are met. These circuits are realized of the same number of three – core or five – core cords through which various consumers are powered. Often, these cables branch further to individual consumers, lighting bodies or power sockets.

In principle, it is considered that local network should provide the possibility of communication between any two plug points, which means that signal injected in one point should have, in all other plug points, characteristics which are sufficient for the quality of communication.

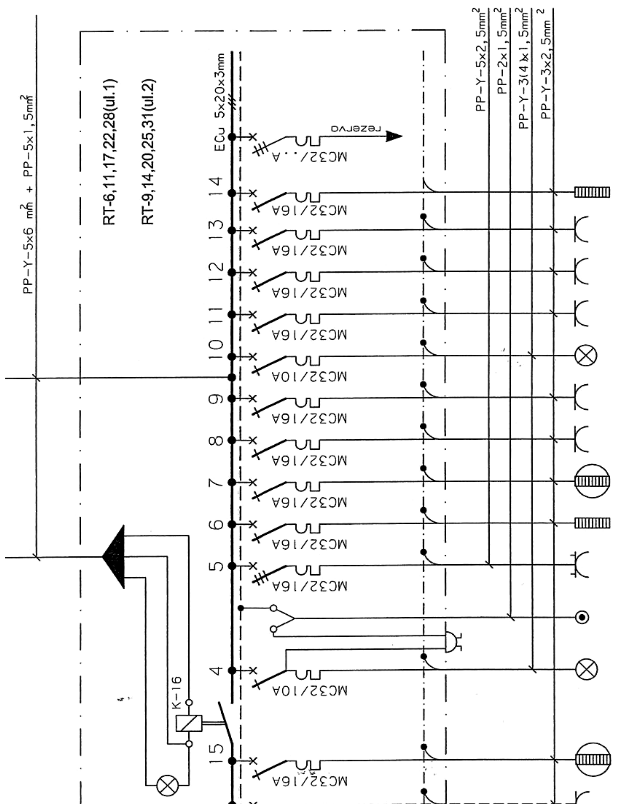

Fig. 3. Single line diagram of residential unit

In general, during the transmission between two plug points, a signal passes through several different branching points, and each of them is the discontinuity that degrades transfer conditions. Particularly adverse effect is manifested in the cases when the cables, which are branching during the way, are relatively short and the ends of them are open circuit or short-circuit. At the frequencies where the length of branches is close to multiples of signal wavelength quarters, input impedance of a branch becomes very small and represents a short-circuit for a transferred signal.

In the band 10 – 30 MHz and in the conductors with relative permittivity 3 – 4, wavelength is within the limits of, approximately, 5 and 15 meters, which means that each branch of length 1 – 4m is a potential “trap” for the signal. The results of measurement on the laboratory model are shown in [3], which had branches of length 1.6 – 2m and at the ends of them were open circuit state. In Fig. 4 is shown a transfer function against frequency diagram of that model. Large drop of transfer function module (i.e. increase of attenuation) is located around the frequency of 24 MHz, in which the wavelength quarter is very close to length of branch 1.6m.

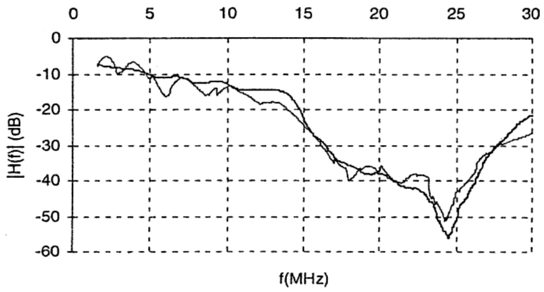

Fig. 4. Amplitude response of the sample channel; soft line represents simulation, and bold one corresponds to measured data [3]

Particularly important place in this consideration belongs to distribution board, which is a local communication network node. On the distribution board connectors a large number (up to and over 20) of conductors that belong to a separate electrical circuits are met. From the aspect of communication network that is a parallel connection of the same number of lines with very different nature and values of input impedances. Calculating of resultant impedance value in this point is quite complex and the value itself is exposed to variations due to changes in the installation states. The measurements showed that thermal component has an average value of approximately 10Ω, while the reactance changes in the limits of +/- a few tens of Ohms.

Low values of impedances in these points, as well as variations in the function of frequency, are the main causes for additional attenuations on the connections between the installation points that are at different electrical circuits. It has been determined that these attenuations are, on average, 15 – 20 dB, with a dominant frequency dependence.

The results of simulations, calculations and measurements in the laboratory model, which approximately corresponds to the configuration of smaller residential unit, are presented in [4]. Analysis and measurements were performed in the frequency band from 5 to 30 MHz. Graphical display of results is given in the Fig. 5. Large variations of transfer function module are evident in the range of about 30 dB. Variations are quasi-periodic with a period of about 5 MHz, and the average value has a tendency to descend with increasing of frequency in the range of approximately 5 dB.

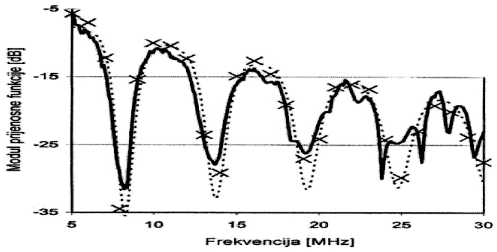

Fig. 5. Graphical display of results for laboratory model; dotted line represents simulation, bold line is for analytical measurements and crosses stand for laboratory measurements [4]

It is concluded that the same approach can be applied to the building as a whole. Single line diagram of a typical building part is shown in the Fig. 6. In this case the node of network is the main power distribution board, while the terminal points are the distribution units in the flats. It is also noted that the same approach can be applied for the standard administrative and business buildings, where the nodes are usually in the power distribution boards on every floor of the building.

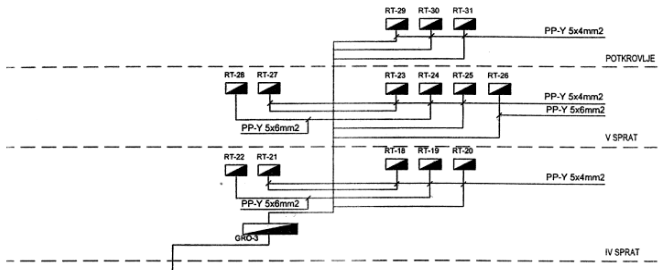

Fig. 6. Single line diagram of a building floor

IV. Conclusion

In the paper the results of the first research phase in a program [5], [6] are presented. The objectives of research in this phase were the identification of power line installations properties as a medium for transfer information and multimedia signals in frequency bands from 1 to 30 MHz. It was found that the standard installation cables, as homogeneous lines, can ensure quality transmission of signals to the lengths of several tens, and over a hundred meters.

Crucial influence on the potential of the whole electrical installation, viewed as a medium for transfer, have the local topology, and in particular the nodes – distribution boards and distribution cabinets. Accordingly, the main target of further work should be finding the ways of conditioning these segments of installations, and that will lead to the most efficient usage of the installation potential.

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