Characteristics of the Interferences in a Low Voltage Network*

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Abstract: The paper proposes an approach to investigate the fine structure of the voltages circulating in the industrial network within the range of 300 kHz-20 MHz, which serves to do some measurements of real lines in real operating mode. It is shown that the interferences can be divided into basic − with spectral density changing slowly with frequency alteration and narrow-band (frequency-pulse). It is also indicated that the frequency concentrated interferences occupy usually 1-5% of the frequency range studied and their intensity is deeply modulated with the doubled frequency of the power supply voltage. There are areas with distinctly expressed low interferences around the zero transitions. The study is motivated by the search for sophisticated methods of high-speed data exchange through the power network.

Keywords:low voltage network, information transmission, high-speed data exchange.

1. Introduction

The low voltage network (220 V) is very appropriate as a medium for information transfer because due to its wide spreading it reaches almost all points, which could be either a source or a user of information. The interest towards it has increased greatly in the last decade with the introduction of systems for house automation, local information networks and the wide use of Internet connections.

Nevertheless it is not very user-friendly as a medium for information flow channeling. Built as universal source of energy, it is not very appropriate for information signals transmission. The usual parameters that characterize a transmitting line –

constant of distribution, wave resistance, coefficient of the reflection are not very suitable for its description.

In their prevailing part the interferences are a result of commutations: injection on the part of electronic apparatus connected to the network, result of the functioning of different collector motors – from luminescent illumination, controlled halogen lamps, penetration of signals from radio waves propagation, especially in the range 5-10 MHz.

Investigations concerning the character of the voltages interfering in the network have been accomplished since many decades. At first they have been realized in conformance with some requirements for electromagnetic compatibility of different users switched on in the network. The requirements towards its use as a medium for information transmission have been defined since 1-2 decades. A survey of all the significant investigations may be found in [1, 2, 5].

The growth of the information flows in modern society stimulates the variability and the expansion of the physical media, through which these flows are transmitted, as well as the efficient use of the basic resources – time interval, frequency band and output power.

The linear or nonlinear suppression, including clipping with cutting out of the signal received in the regions where the interferences are concentrated, is a general approach in the fight with noise. This could be done in time, as well as in frequency domain, in localized areas of the frequency-time surface, suppression in different transformation regions, where the interference energy may be concentrated in a narrow band.

The paper presented has the purpose to investigate the fine structure of the interfering voltages circulating in a network within the range 200 kHz-20 MHz, to give quantitative estimates of the parameters, allowing evaluation of the network capacity, choice of constellation of the information signals, development of adequate methods for their suppression.

The method suggested enables the determination of the spectral constitution of the interfering voltages in a real network, its invariability, estimation of the speed of alteration, change of the spectrum as a function of the network voltage phase, separation of the narrow-band interferences, accumulating of statistics for different networks, in different hours of the day, as well as for certain days in the week or in different seasons.

2. Measurement equipment

In order to record the interferences, a measurement head is used comprising a high-ohm divider and a high frequency and a low-frequency filter serially connected, which limit the frequency band studied to the range of 300 kHz-20 MHz.

The interferences are examined synchronously with the network voltage for its separate complete periods. For this purpose a short pulse is generated at the beginning of the negative half-wave of the network voltage, which is accepted as measurement starting. The scheme is shown in Fig. 1.

The signals from the detector head and the synchronized signal as well are input to FRA20 circuit analyzer. After regulated amplification in it, the signal is sampled with frequency of digitization of 65 MHz, resolution of 200 μV in 14-bit words. The signal recorded, which is of 20 ms length (a complete period of the network frequency), is processed and represented by 32 frequency bands with the help of a short-time Fourier transform (STFT).
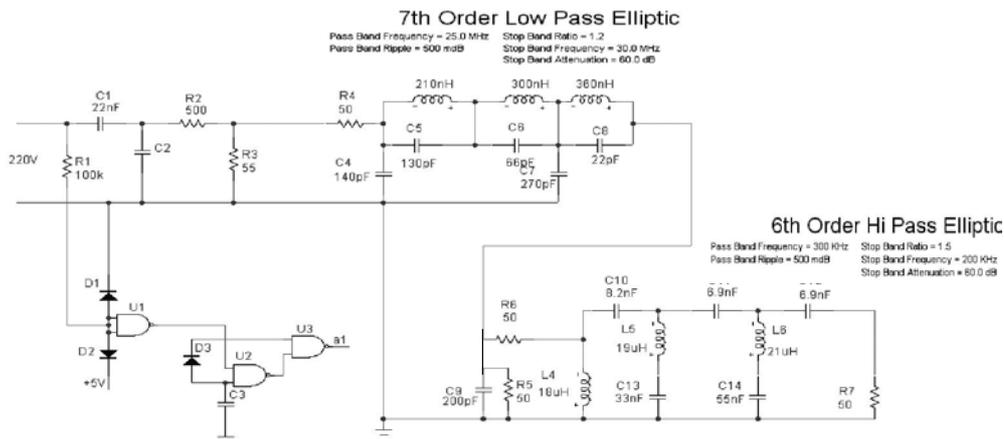
7th Order Low Pass Elliptic
Pass Band Frequency = 25.0 MHz Stop Band Ratio = 1.2
Pass Band Ripple = 500 mdB Stop Band Frequency = 30.0 MHz
Stop Band Attenuation = 60.0 dB

6th Order Hi Pass Elliptic
Pass Band Frequency = 300 KHz Stop Band Ratio = 1.5
Pass Band Ripple = 500 mdB Stop Band Frequency = 200 KHz
Stop Band Attenuation = 60.0 dB

Fig. 1. Measurement head

The structure, with the help of which the analysis is done, is shown in Fig. 2. The spectrum of the input flow $x(i)$ is shifted around the zero frequency, for middle of the band investigated f_k, after which a band of 200 kHz is filtered, then decimated 160-fold and the data obtained are Fourier transformed into 32 segments (each one with length of 625 μs). The frequency-time resolution obtained is 1.6 kHz × 625 μs.
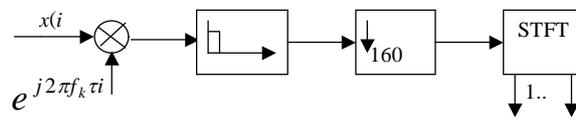
Fig. 2

3. General characteristics of the interferences

The intensity of the interferences depends mainly on the phases of the network voltage. They have their minimums around the zero transitions, and their maximums − around the peak values, the relation between them being always greater than 10 dB. Local maximums are also observed, though weakly expressed, which coincide with the maximums of the separate phases of the three-phase network. This character is preserved for the whole frequency range measured − from 300 kHz up to 20 MHz. In order to illustrate the above said the typical form of the interference is shown for the whole range of 0.3-20 MHz for a complete network cycle in Fig. 3a, and in Fig. 3b – the time development of a narrowband interference with frequency of 460 kHz for a complete line cycle also. The latter is obtained by inverse Fourier transform of the range selected
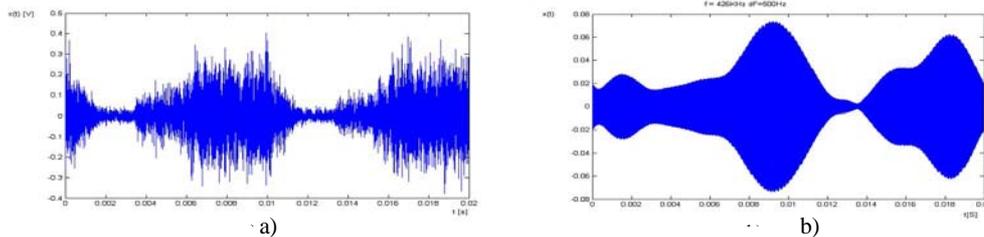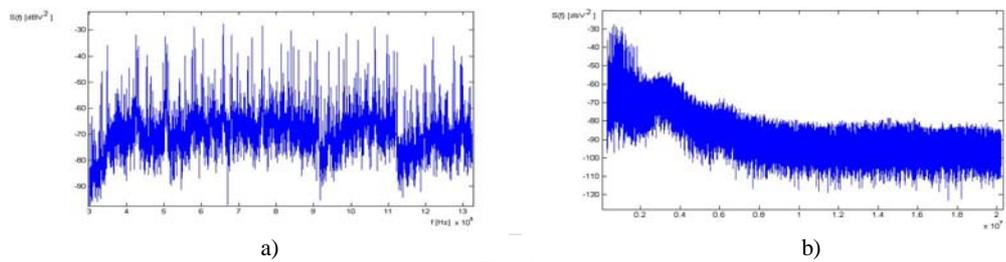

a) b)

Fig. 3

a)   b)

Fig. 4

for frequency representation. The deep amplitude modulation with doubled network frequency is observable.

The interferences in the frequency range have a well-defined discrete structure. They consist of separate narrow-band practically harmonic fluctuations. Fig. 4a shows the spectral characteristics of a given realization within the frequency range of 0.3-1.1 MHz, and Fig. 4b – for the range of 0.3kHz-20MHz. A narrower band is selected for the first figure in order to underline its discrete structure. The control computations for the separate narrow-band interferences show that their efficient band is within the limits 100-300 Hz. Such spectrum can be regarded as deeply amplitude-modulated harmonic variation.

It is typical for the interferences that they change too slowly. The alterations are caused by changes in the network load, consumers switching on or off .

Fig. 5a shows the spectrum of interferences within the range 0,3-20 MHz with resolution of 200 kHz for some realizations (60 in number) recorded through intervals of 7 min, and Fig. 5b – for different hours and days. The characteristics are recorded through 7 min for periods with smooth changes and for areas with different powers the realizations are in different days.
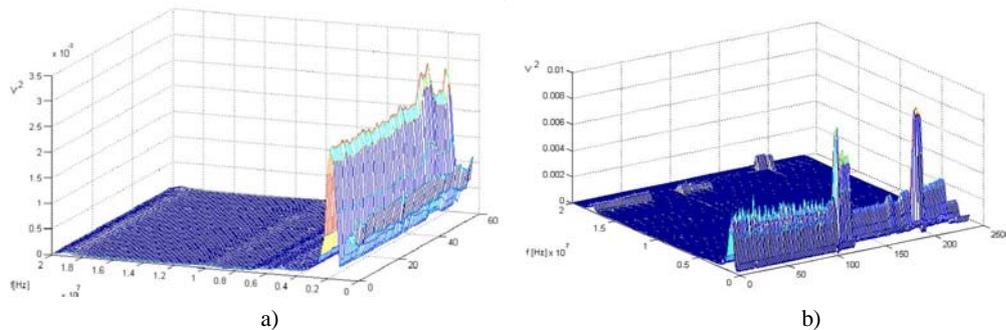

a)   b)

Fig. 5

4. Interferences representation

Convenient analytic representation of the interferences is possible in the time-frequency domain. We have chosen a short Fourier representation for our discussion, since it is close to tele-communication specialists and could be directly used in order to define some important parameters such as capacity, probability for error receiving, optimal modulation.

The power spectrum is determined by the expression:

7 6

$$S_X(j,k) = \left| \sum_{i=0}^{N-1} x(iT)h[(i-j)T] e^{j\frac{2\pi ki}{N}} \right|^2.$$

In the paper considered the window $h(i)$ is accepted as rectangular with length of 20/32 ms, one cycle of the network voltage is investigated into 32 time intervals, at achieved frequency resolution of 1600 Hz.

In order to estimate the alteration of the interferences during operation, the Euclidian distance between the time-frequency representations for the separate cycles of the network voltage is used according to the expression

$$d = \frac{\sqrt{\frac{1}{I}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=0}^{N-1}(S_i(j,k) - S_0(j,k))^2}}{\sigma_0^2}.$$

In this expression k denotes frequency, j – time window, i – the sequential number of the realization studied. Index 0 denotes the reference spectral line with respect to which the comparison is made, $\sigma_0 = \sum_j \sum_k S_0(j,k)$ – the power of the reference interference for a complete cycle of the network voltage. For $J=1$, the distance d gives gives an idea about the invariability of the integral spectral distribution for a complete cycle of the network volatge. Assuming the distribution averaged as $S_0(j,k)$ and for a sufficiently great I, d can be interpreted as distribution dispersion. The distance between successive realizations ($I=0$, $S_0(j,k) = S_{i-1}(j,k)$), detects efficiently the alterations in the interfering picture.

The interferences spectral characteristics give the basis for their division in two additive types – basic and pulse (frequency pulse). Those that have density, which depends slowly on frequency are basic, and the pulse (frequency pulse) are those with clearly expressed frequency dependence. The structure shown in Fig. 6 is used for division. The low-frequency filter 2 separates the basic interference, regarding as such any disturbance with spectral density greater than $1+\gamma$ times of the averaged value $S_t(k)$. In the present paper the one with $\alpha=0.1$ is considered as such, which corresponds to 0.4 dB over-passing of the averaged value. The node 3 forms the spectrum of the pulse interference and node 4 – the windows, in which the presence of pulse interference is registered. The division can be realized for separate realizations, for averaged realizations, and for separate time windows of the network cycle as well.
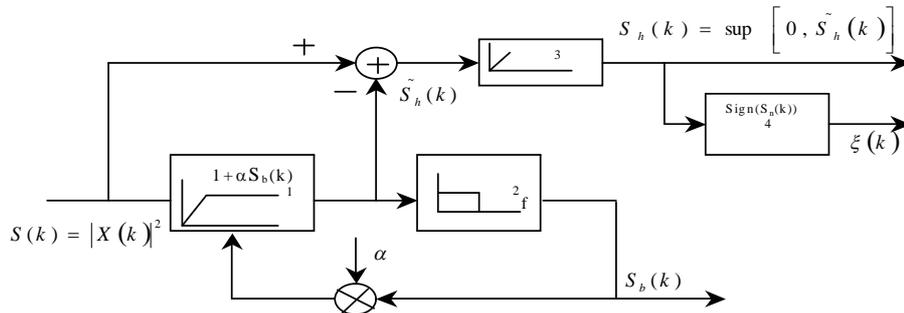

Fig. 6

The structure shown enables the definition of:

$S_0(k)$ – spectral characteristics of the basic interferences;

$S_h(k)$ – spectral characteristics of the pulse interferences;

$$\sigma_b^2 = \sum_{k \in K} S_{hi}(k) - \text{power of the basic interferences for a desired frequency range;}$$

$$\sigma_h^2 = \sum_{k \in K} S_{hi}(k) - \text{power of the pulse interferences for a desired frequency range;}$$

$$\gamma = \frac{\sigma_h^2}{\sigma_b^2 + \sigma_h^2} - \text{relative part of the pulse interferences in the total power;}$$

$$\beta = \frac{\sum \xi(k)}{N} - \text{relative part of the pulse interferences in the whole frequency range}$$

used;

$$\lambda = \frac{\sum S_h(k)\xi(k)}{N\left(\sigma_h^2 + \sigma_b^2\right)} - \text{weighed part of the pulse interferences in the frequency range}$$

used. It takes into account the interference power.

The present study estimates the invariability of the average frequency and the efficient frequency band of every narrow-band interference. They are evaluated as weight center and inertial radius respectively according to the expressions:

$$f_j = \frac{\sum_{k=k_{1j}}^{k_{2j}} k S(k)}{\sum_{k=k_{1j}}^{k_{2j}} S(k)} \Delta F = K_j \Delta F \; ; \qquad \Delta f_j = \sqrt{\frac{\sum_{k=k_{1j}}^{k_{2j}} \left(k - K_j\right) S(k)}{\sum_{k=k_{1j}}^{k_{2j}} S(k)}} \; \Delta F .$$

ΔF is the frequency expansion of the Fourier transform; k_{1j} and k_{2j} are the beginning and the end of j-th pulse interference.

The time form of the separate pulse interferences is obtained by inverse Fourier transform of the frequency representation for a complete cycle of the network voltage. As expected, the form is dominated by the deep amplitude modulation with doubled line frequency.

5. Experimental results

In order to accomplish the measurements and to obtain a number of indicators, the functional system shown in Fig. 7 is realized. It contains the nodes from Fig. 6 enhanced to a more detail form by functions computing the separate parameters, data storing and visualization.

A number of measurements have been accomplished at separate points of the network loaded with electronic apparatus, air conditioning, and illumination. Some of the typical results are shown here.
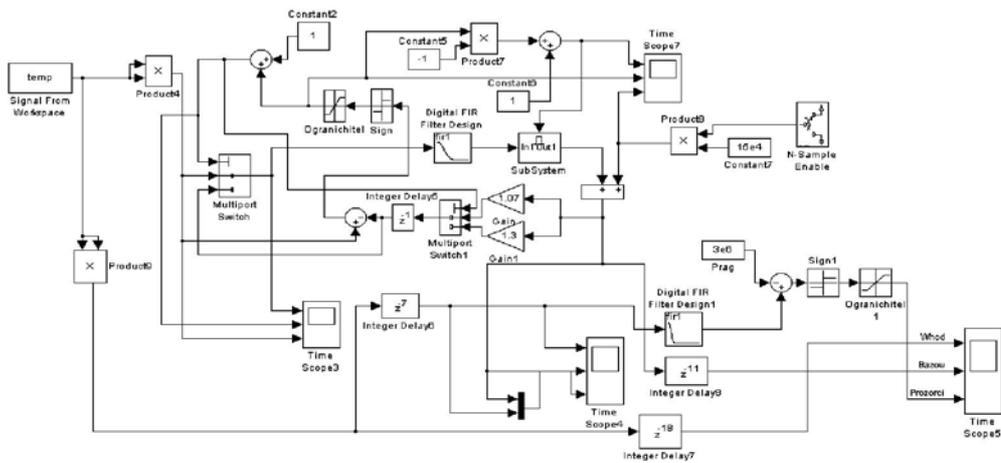
Fig. 7

Fig. 8a,b, c, d shows the time-frequency distribution of the interferences for the sub-ranges 0.3-2.1 MHz, 2.1-5 MHz, 5-10 MHz, 10-20 MHz. The time axis is shown in milliseconds and contains one full cycle of the network voltage of 20 ms.
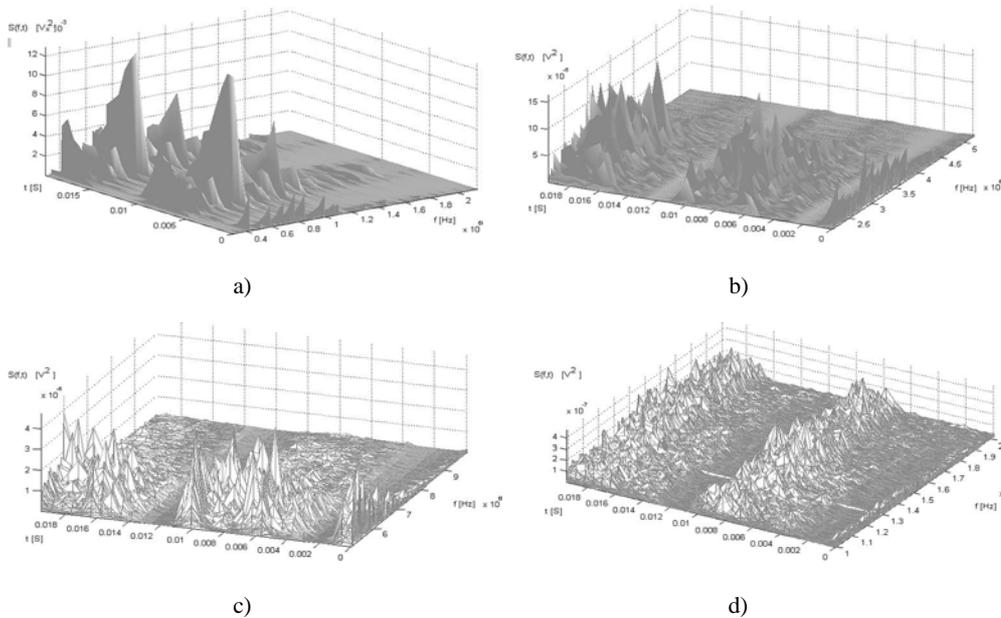

a)

b)

c)

d)

Fig. 8

A view upon the time-frequency picture shows the presence of deep planes in the time intervals around the network voltage transitions, where the interferences level is an order lower. There are planes, more in number and not so wide along the frequency axis as well. The interferences are particularly intensive in the range up to 1.5 MHz, getting very weak up to 4 MHz and above 7 MHz they decrease in several orders in comparison with the preceding areas.
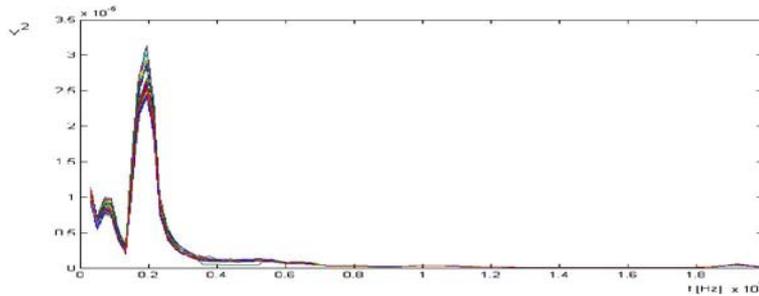
Fig. 9

The measurements show that the alterations are too slow. Fig. 9 shows the spectral density of the interferences for 60 realizations, taken down through intervals of 7 minutes. The variation field is too narrow, being under 10% in the extremum points.

Fig. 10a shows the spectrum of the basic interference for a separate realization within the range of 0.3-1.1 MHz, and Fig. 10b – the averaged spectrum for the same range of 100 realizations, recorded through intervals of 60 s. The character of the two figures is rather close. Gradual increase in the spectral density is noticed with frequency increase.

a)   b)
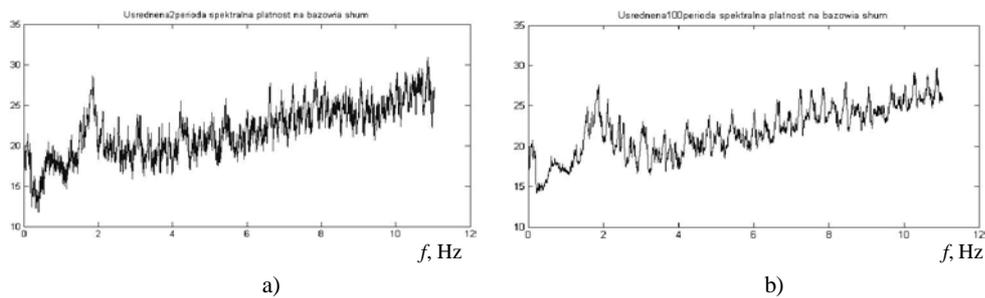
Fig. 10

Fig. 11 shows the power of the basic interference for 100 separate realizations from Fig. 10. The alterations lie within the limits ±10%, a value being too small for interferences in an interval of 100 min.

The frequency-pulse (narrow-band) components – the spectral density for a separate realization and the complete narrow-band power for the separate 100 realizations are shown in Fig. 10 and Fig. 12.

The distance between the time-frequency representations for successive realizations provides a more strict estimation of the interferences variability. Fig. 13a and b show these distances for 9 and 10 successive realizations. The distances are determined for different phases of the network voltage. The sharp peaks show rapid change in
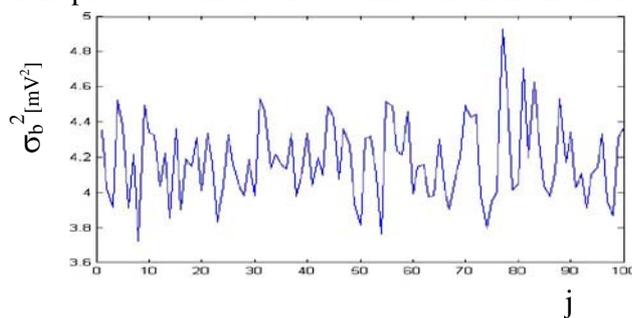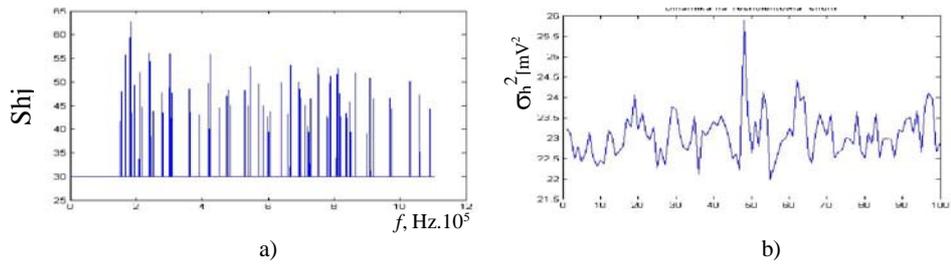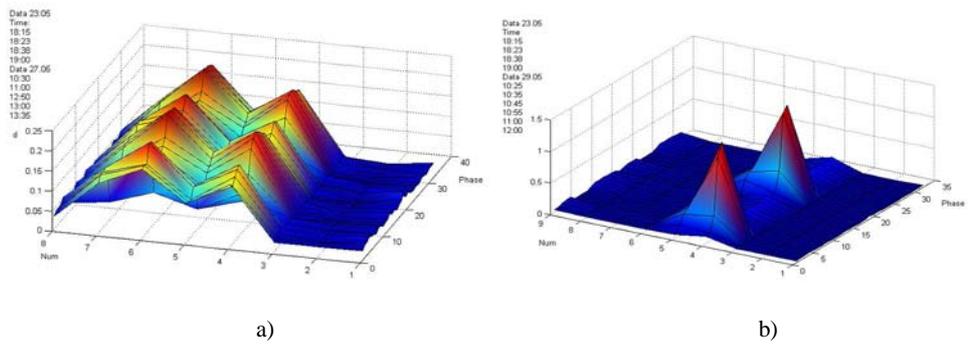

Fig. 11

8 0

a)

b)

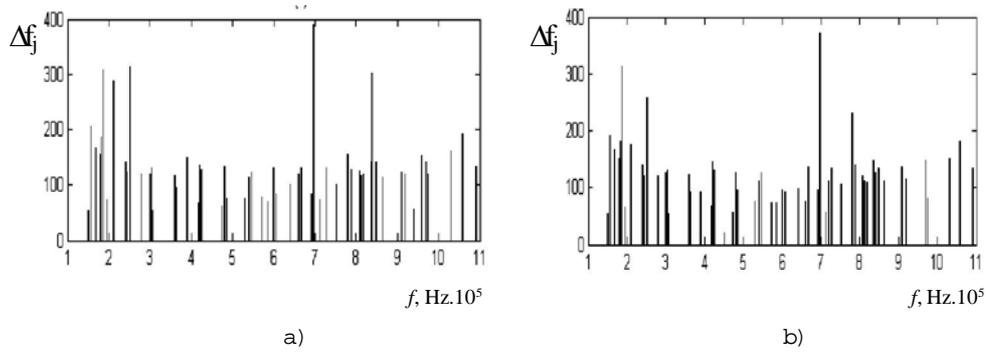Fig. 12

a)

b)

Fig. 13

a)

b)

Fig. 14

the line mode. Fig. 13b shows that before and after this alteration the differences are within the limit of 10 %.

Fig. 14 shows the efficient frequency band in Hz – for the different narrow-band interferences separated by 50 s for two realizations. The efficient frequency band occupied for the first and the second realization is 7.8 and 7.2 kHz respectively, which makes about 1% of the band investigated.

The sum of all the frequency windows $\xi(k)$ in Fig. 6 can be accepted as upper estimate for the band considered. This estimate does not take into account the energy of the separate interferences, considering as narrow-band interference each surpassing of the spectral density by 10% with respect to its near neighborhood. The narrowband interferences occupy 4% of the band studied in this approach.

It is interesting that the efficient width of the separate narrow-band interferences lies within the limits 100-400 Hz, which enables their interpretation as harmonic variations, amplitude modulated by the line doubled frequency.

It also should be noted that the frequency-concentrated interferences, though occupying a too narrow frequency band have power, that is considerably greater than the basic ones, in spite of the fact that their spectrum is continuous. This difference is 5-fold for the realizations in Figs. 11 and 12. In order to give a more complete idea about the interferences character, the results from measuring the spectral averaged interfering voltages for separate bands in the frequency range investigated, are given in the Appendix.

6. Conclusion

The measurements accomplished show that the industrial network possesses considerable possibilities relating to the interfering voltages for high-speed data exchange without the need of any additional procedures. The relative invariability of the interferences enables their efficient neutralization and compensation.

Taking into consideration of the cyclic character of the interferences power 6 offers additional potential to increase the network capcity.

7. Appendix

Fig. 15 a, b, c shows the spectral power density of the frequency-concentrated interferences, of the basic interferences and the frequency band of each one of the pulse interferences within the range 0.3-1.3MHz. The figures show the efficient value of the pulse and basic interferences and the frequency band occupied by every pulse disturbance.

Fig. 16 a, b and c shows these relations for the frequency band of 1.3-2 MHz, and Fig. 17 – for the band 2-3 MHz.

Figs. 18-23 give the computational results for the pulse interferences only.
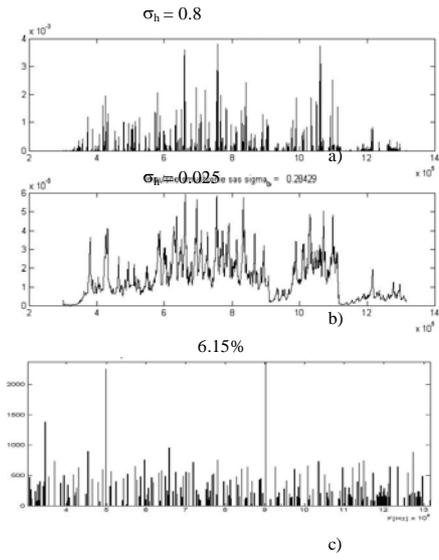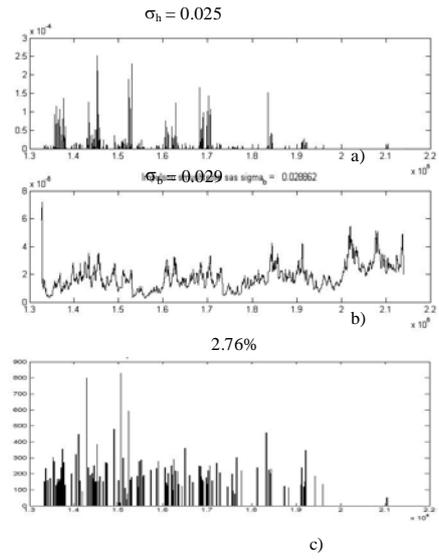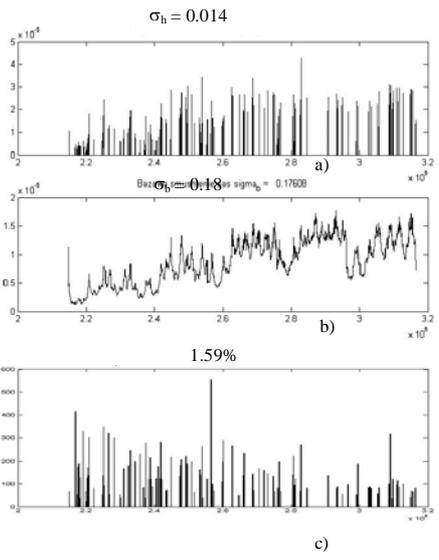
σ_h = 0.8

σ_h = 0.025

σ_h = 0.025 ... sas sigma_b = 0.28429

σ_h = 0.029 ... sas sigma_b = 0.029862

6.15%

2.76%

c)

c)

Fig. 15

Fig. 16

σ_h = 0.014

σ_h = 0.18 ... sas sigma_b = 0.17608

σ_h = 0.008

1.59%

1.19%

c)

b)

Fig. 17

Fig. 18

σ$_h$ =2e-3

a)

0.35%

h)

Fig. 19

σ$_h$ = 3.9e-5

a)

1.12%

b)

Fig. 20

Impulsno smushtenie sas sigma$_h$ = 2.1746e-005

σ$_h$ =2.2e-5

a)

1.1%

b)

Fig. 21

Impulsno smushtenie sas sigma$_h$ = 4.8792e-005
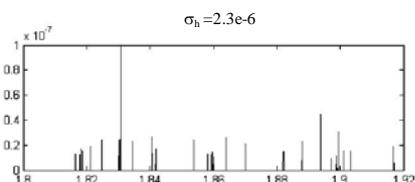
σ$_h$ =4.9e-5
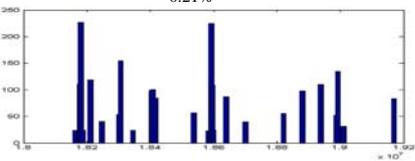
a)

1.78%

b)

Fig. 22

σ$_h$ =2.3e-6

a)

0.21%

b)

Fig. 23

8 4
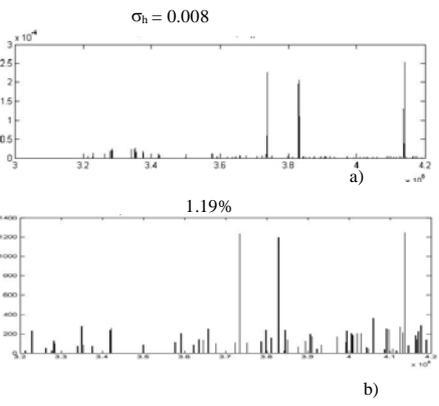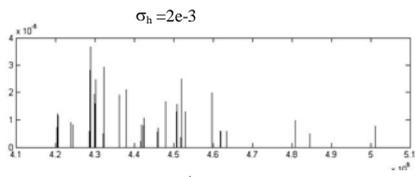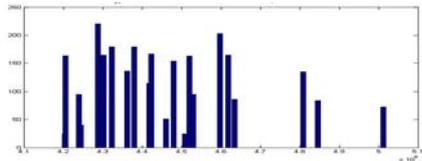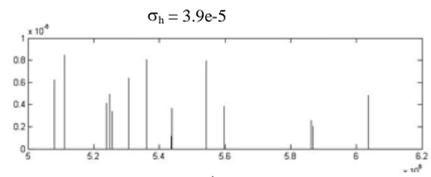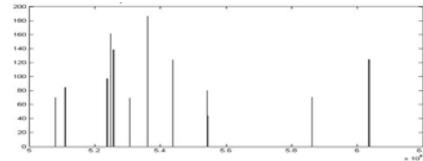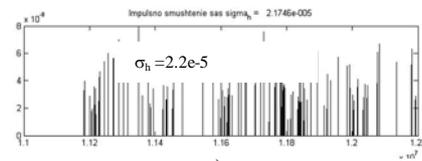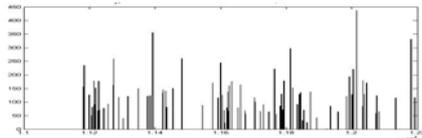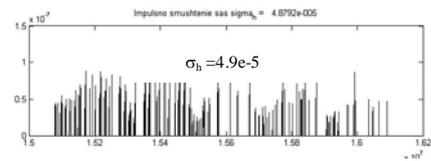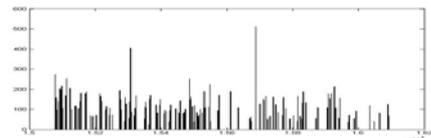
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Интерференции в мрежата ниско напрежение

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(Р е з ю м е)

Предлага се методика за изследване на фината структура на циркулиращите в промишлената мрежа напрежения в диапазона 300 kHz–20 MHz, по която са проведени редица измервания на реални мрежи в реален работен режим. Показано е, че смущенията може да се разделят на базови, с бавно променяща се с честотата спектрална плътност, и тесноленитови (честотно-импулсни). Показано е, че честотно съсредоточените смущения заемат обикновенно 1-5% от изследвания честотен диапазон и интензивността им е дълбоко модулирана с удвоената честота на мрежовото напрежение. Около нулевите преходи съществуват области с подчертано изразени ниски смущения. Изследването е мотивирано от търсенето на софистични методи за високоскоростен обмен на данни по силовата мрежа.