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Linear Frequency-Time Transformations for Industrial Mains Modelling

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One of the modern scientific tendencies is the time-frequency noise representation which provide the possibility for an access to a much more abundant information.

The present investigations accept the time-frequency noise representation accept the time-frequency noise representation by a short-time Furrier transformation and with a wavelet-packet transformation. The first case is realized by a standard software and for the second one new algorithms and programs are developed. Their visualization is three-dimensional with high interpretive possibilities.

I. Short-time Furrier transformation

The continuous-time Furrier transformation (CTFT) is an important mathematical tool for stationary signal processing. It decomposes the input signal on a harmonic functions basis. The signal representation in the new space is obtained by its dot product with complex exponents:

(1) $$F(w) = \int_{-\infty}^{\infty} f(t)\, e^{-iwt}\, dt.$$

Here $f(t)$ denotes the signal, $F(.)$ – its Furrier representation. Still CTFT has significant disadvantages:

– the transformation for a single frequency requires the whole information for the signal form as a function of the time;

– the integral notion of the signal makes the time argument anonymous.

The separate singularities often include the most significant information about the signal; in this case they become very fuzzy and can remain inconspicuous. To avoid these disadvantages one can use the so called short-time Furrier transformation (STFT) [16]:

(2) $$STFT(w, b) = \int_{-\infty}^{\infty} f(t)\, e^{-iwt}\, w(t-b)\, dt.$$

The weight function $w(t-b)$ is a window with a limited effective length which localizes the time transformation in the point b. The different STFT for different values of the time shifting parameter b are obtained by shifting the window along the time axis. In this way the transformation becomes time-dependant and it forms a frequency-time (two-dimensional) decomposition of the signal.

The weight function must be normalized for the inverse transform:

$$\int_{-\infty}^{\infty} [w(t)]^2 dt = 1. \tag{3}$$

Its effective length determines time resolution and is chosen to be equal to the stationary signal length. This decomposition can be observed as decomposition with modulated complex exponents.

STFT is very redundant. This allows with no loss of information the application of STFT for discrete values of the frequency w and the shift b. Most often the discretization is equisistant for the both variables.

STFT rounds off some of the CTFT disadvantages, but still it inherits its genetic shortcomings. The window w(t) deforms the spectral representation of the signal. Overlapping the adjacent windows improves to some extent the results. Still there are no precise selection criteria. The loss of spectral information is inevitable and it masks weak signals.

In spite of its failings especially when the problem is a refined solution, STFT can be successfully used for a more generalized conception. It represents well enough the processes in the case of the mains study where the estimates are of statistical character.

II. Wavelet-packet transformations

The analysis of oscillating signals with high-frequency components is based upon an extension of the wavelet bases theory which uses the so called wavelet-packet bases and the corresponding wavelet-packet transformation (WPT). To simplify the notation we deal only with the orthonormal case. WPT decomposes not only the low frequency component, but also the high frequency band in the pyramidal decomposition. At the first level we have the generated sequences Hx and Gx just like in the case of the wavelet transformation. At the second level we have generated four sequences H^2x, GHx, GHx, G^2x. The "splitting" of both the pyramid branches can be repeated J times and the final structure is a binary tree with a total number of the coefficients along the "nodes" equal to J^N if N ($N=2^{n0}$) is the number of the input reports. This procedure generates subspaces of the vector space R^N.

These subspaces (according to the tree nodes) differ in the frequency localization. If the wavelet transformation provides an unique tie between the frequency and the scale, the WPT has coefficients representing the signal for a fixed scale but wit different frequencies. That is why the decomposition is redundant; it can be proved that it has more than $2^{2(J-1)}$ different orthonormal bases. The wavelet-packet bases are organized as subsets (nodes) of the binary tree. Any node is an orthonormal sum of its daughter nodes. The connection of "branches" of the tree defines a basis from the orthonormal bases glossary. Another convenient representation of the coefficients is the table-like according to their time or frequency position. Table 1 shows the decomposition of an 8-dimensional vector ($N=8$) $\{x_1, x_2, ..., x_8\}$ where the wavelet-packet coefficients are ordered according to their frequency. Every next line is a result of the previous one which is G- or H-handled and this has the sense of differentiation (high frequency filtration) – d or integration (low frequency filtration) – s. For example the series $\{ss_1, ss_2\}$ is the result of H-processing of $\{s_1, s_2, s_3, s_4\}$ and $\{ds_1, ds_2\}$ is the result of G-processing of the same input series. Numbered and

Fig 2

Fig 2

successive lines follow the successive scales. With an N-dimensional input vector the total number of scales (lines) is $\log N$.

The line with number m in the table can be resorted from the lien with number $m+1$ by H^*-processing of the left part (the left daughter tree node) and by G^*-processing of the right part with a following sum in the parent node. The presence of $N \log N$ wavelet coefficients allows different interpretations of the information redundancy. In fact the wavelet-packet decomposition is a generalization of the decomposition with different levels of separation which has been proposed by Mallat. The precise restoration of the signal by N wavelet coefficients is possibly due to the orthonormal properties of the decomposition. The following tables illustrate two different orthonormal properties of the decomposition; Table 2a shows the known wavelet basis with bold symbols and Table 2b – another arbitrary wavelet-packet basis.

The WPT differs from CTFT also because its is a real transformation thus reducing the expenses during the frequency-time signal representation processing. The WPT allows on any scale level the energy control in the output wavelet-packet coefficients; the descent can be stopped under certain conditions (on levels and frequency bands with ignorable little energies, high entropy levels, etc.). In this way the WPT allows an adequate frequency solution power avoiding the unnecessary processing.

The dynamic determination of the important from an energetic point of view frequency bands makes possible the modelling of channels which can be used for digital information transfer in a way where for every time slice there can be found frequency bands which are broad enough and free of noise.

III. Natural noise measurements in the industrial mains

Fig. 2 shows a low-frequency filter which is used to study the noise in the mains for the 10-400 kHz range. Its cutting frequency is 2 kHz with a slope of 30 dB per oct. The following processing is digital. Data input is by a Nicolet 3091 digital oscilloscope. The discretization frequency is 1 MHz and the analog-to-digital conversion is of 12-bits solution property. Data is grouped in packets with 4000 discretes each.

The data presented are a result from a standard socket in rooms in both IIT buildings. They depict the mains state in a research centre with 5-10 PCs.

The noise voltage in Fig. 1 is for one cycle of the mains voltage. The maximums coincide with the mains voltage maximums. The picture is typical for an hour observation, too. While keeping the morphology constant the greatest increase of the amplitudes is up to twice.

The voltage is evidently non-stationary and its spectral picture provides a rather simplified and too integral notion. The representation is based on the time-frequency transformations which are stated in II. STFT is modelled by a standard program with 256 points, 50% overlapping and a Hening weight function. It is equivalent to a bank of evenly distributed 4 kHz strip bands. The signal in Fig. 1 responds to the transformation in Fig. 3 a, b, c, d and e. The 20 ms interval is divided into 5 successive segments, 4 ms and 4000 discretes each.

The separation is motivated for technical reasons and for a finer representation.

The spectral filling depends strongly on the mains voltage phase. The spectral peaks coincide with its maximums. This can be explained with the on-line electronic devices which enable the mains precisely in these intervals. The evident crests though with different intensities are of constant commutation frequency; they are generated by the pulse supplies which are connected to the mains. It is important to note that the whole 150 kHz space is strongly saturated with noise signals. There are sharp peaks of a relatively small area but with a great concentration of the interference energy. There are also dips which are almost interference-free.

The wavelet-packet transformation is the other energy approach in the time-frequency plain which is free of the tough for interpretation window functions. In accordance with the already explained theoretical formulation in the previous chapter a new algorithm is developed with its corresponding software for such transformations. A certain set of basic functions-wavelets is programmed, too.

The exposition shows that the interference in the frequency and in the time domains are of a local character. This is due to the measurements which have taken place in the vicinity of the sources. These are the natural conditions for an information interchange in a separate building. For remote to the sources places the interference becomes broad-banded with decreasing oscillations due to the carrier filtration and also due to the integration of the interference sources.

The methodology used for the interference representation offers considerable interpretive possibilities. The time-frequency nous representation provides a more abundant notion. The results from the measurements show that the interference effecting the town mains are of a little energy which is concentrated in the spectrum up to 150 kHz. There are frequency and time windows which are connected with the industry mains phase, but are free of noise; there are other windows in which the interference is concentrated. In principle the corollaries are valid, but the statistical representativeness needs a wider experimental basis. For example the depicted frequencies do not show the interference of luminescent light which is much easier to evaluate than the conventional approaches.

References

1. Coifman, R., Y. Meyer. Orthonormal Wave Packet Bases. Preprint, Yale University, 1990.
2. Coifman, R., Y. Meyer, S. Quake, M. Wickerhauser. Signal Processing and Compression with Packets. Preprint, Yale University.
3. Daubechies, I. The Wavelet transform, time-frequency localization and signal analysis. – IEEE Trans. on Inf. Theory, **36**, Sept., 1990, No 5, 961–1005.
4. Daubechies, I. Orthonormal bases of compactly supported wavelets. – Comm. in Puer and Applied Math., **41**, 1988, No 7, 909–996.
5. Follot, G., P. Guillemois. Transmission en temps reel d'ordres tarifaires on de sauvegarde et de message d'alterne. – RGE, 1993, No 8.
6. Franks. Signals Theory. Moscow, Sovetskoe Radio, 1974 (in Russian).
7. Gabor, D. Theory of communication. – J. of IEE, **93**, 1946, 429–457.
8. Gardinli, R., R. Tonon, D. Vannucci, D. Menozzi. Le systeme de teleconduite du resau. – MT d'ENEL", RGE, 1993, No 8.
9. Grossmann, A., J. Morlet. Decomposition of Hardy functions into square integrable wavelets of constant shape. – SIAM J. of Math. Analysis, **15**, 1984, 723–736.
10. Lobert, J. P., C. Delannoy, D. Chaffanjion, P. Handebourg. Les courants porteurs: l'energie, communicaute. – Revue General d'Electricite, 1992, No 10.
11. Mallat, S. A theory of multiresolution decomposition: the wavelet representation. – In: IEEE PAMI, **11**, July, 1989, No 7, 674–693.
12. Meyer, Y. Ondelettes et operateurs. Vol. 1. Hermann, Paris, 1990.
13. Nicholson, J. R., J. A. Malack. RF impedance of power line and line impedance stabilization networks in conducted interference measurements. – In: IEEE Trans. on Electromagnetic Compatibility, May, 1973.
14. Rabiner, L., B. Gold. Theory and application of signals digital processing. Moscow, Mir, 1978 (in Russian).
15. Teyssander, Ch., S. Theodore, J. M. Verdier. Systemes de transmission sur les reseax moyenne tension. – Revue General d'Electricite, 1992, No 10.
16. Benedetto, J., M. Frazier (eds). Wavelets: Mathematics and Applications. CRC Press. 1994.
17. Wayne, T. Mitchell. – Electronic Design, 1982, No 23.

Линейные частотно-временые трансформации для моделирования промышленной сети

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(Р е з ю м е)

В работе представлены возможности исследования помех в промышленной сети. Для этой цели использованы частотно-времевые представления помехающих напряжений.

При сокращенном представлении Фурье трансформация зависит от времени и формирует двумерную декомпозицию сигнала, дающую обобщенную идею для динамики исследуемого процесса.

Для анализа осциллирующих сигналов, характеризирующихся с высоко-частотными компонентами, применена волновая пакетная трансформация, которая является реальным преобразованием и позволяет получения модели каналов передачи информации. В работе сделан анализ наблюдаемых помех.