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## DESIGN OF PASSIVE RESONANCE FILTERS FOR ATTENUATION OF HIGHER CURRENT HARMONICS IN SINGLE-PHASE INSTALLATIONS

**Summary.** The paper describes a program created for current harmonics filter design in Scilab environment. Computation algorithm is described in reference to inner data structure of the program. Exemplary filter designed with the help of the program is also presented, as well as current transients and harmonics spectrum calculated for lighting installation with applied designed filter.

**Keywords:** resonance filter, LC filter, passive filter, current harmonics

## PROJEKTOWANIE PASYWNYCH FILTRÓW REZONANSOWYCH DO TŁUMIENIA WYŻSZYCH HARMONICZNYCH PRĄDÓW W INSTALACJACH JEDNOFAZOWYCH

**Streszczenie.** W artykule opisano program utworzony w środowisku Scilab, służący do projektowania filtrów harmonicznego prądu. Algorytm obliczeniowy opisano w odniesieniu do wewnętrznej struktury danych programu. Opisano również przykładowy filtr zaprojektowany przy użyciu programu i zaprezentowano obliczone przebiegi i widmo harmonicznego prądu instalacji oświetleniowej, w której zastosowano zaprojektowany filtr.

**Słowa kluczowe:** filtr rezonansowy, filtr LC, filtr pasywny, harmoniczne prądów

### 1. INTRODUCTION

Modern light sources such as discharge lamps or LEDs are used more and more often. They are characterized by strongly non-linearity, which leads to significant distortion of the supply network current. Higher harmonics of the supply current due to this distortion may be eliminated using parallel resonance filter [1,2,3,4]. Resonance filters are widely used for improving quality of electrical energy. They may operate in standalone mode, as passive

filters [5,6], or may co-operate with active filters as composite-type filters [7,8]. Resonance filter should be designed with a particular application in mind, taking into account impedance of the supply network at the point of load connection, harmonics spectra generated by a given load and legal regulations (standards) appropriate in analyzed case.

A passive resonant filter for attenuation of higher current harmonics is discussed here. Structure of this filter has been described in [1]. Filter consists of arbitrary number of LC branches. Resonant frequency of each branch is equal to a frequency of selected  $h^{\text{th}}$  harmonic of the waveform with fundamental harmonic frequency equal to  $f_1$ . The selection of  $L$  and  $C$  values is simple, a formula resulting from the series resonance condition is used:

$$\omega L = \frac{1}{\omega C} \quad \text{gdzie} \quad \omega = 2\pi h f_1. \quad (1)$$

However, number of computations and their complexity increases, when a real filter has to be designed (since it consists of real elements with non-zero internal resistances and exact allowable RMS and peak values of currents and voltages). In order to automate the filter's design calculations, a dedicated program has been created in Scilab environment. The computational algorithm and exemplary results of analysis obtained with this program are presented in current paper.

## LIST OF SYMBOLS

### Quantities:

- $u, i$  – instantaneous values of voltage and current;
- $u(t), i(t)$  – voltage and current waveforms, represented in the program by vectors of instantaneous values;
- $h$  – order of higher harmonic;
- $f_1$  – frequency of fundamental harmonic ( $h = 1$ ),  $f_1 = 50$  Hz;
- $\underline{I}, \underline{U}, \underline{Z}$  – complex maximum values of current, voltage and impedance, for  $h$ th harmonic; represented by vectors for different harmonics in the program.

### Subscripts:

- $r, l, c$  – designation for a single branch element –resistor, coil and capacitor, respectively;
- $R, L, C$  – designation for a group of elements in a given branch –resistors, coils and capacitors, respectively;
- $g$  – designation of a given branch;
- $n$  – designation of rated value;
- $s, f, o$  – quantities related to supply network, filter and load (lighting appliance), respectively
- $_{\text{rec}}$  – designation for quantities recorded before application of filter;
- $\text{RMS}, \text{PK}$  – RMS and peak values of currents and voltages.

## FILTER DESIGN

Before design is started, analysis of harmonic content in the load current must be run (Fig.1a) and obtained results must be compared with the limits set by appropriate legal regulations. In case of the discussed lighting installation standard [9] should be applied. Then, structure of the filter must be set, by determining number and type of branches and their resonant frequencies (Fig. 1c). The filter branches consist of  $L$  and  $C$  elements connected appropriately in series and in parallel; we can obtain the required values of capacitance and inductance (determined by set resonant frequency of a given branch) using commercially available elements. The next step is to solve the equivalent circuit (Fig. 1b and 1c) in the frequency domain (for every harmonic of  $h^{\text{th}}$  order) and to apply inverse Fourier transform to calculate peak and RMS values of currents and voltages of different elements. RMS and peak values and active powers are calculated in order to verify whether the rated values of elements  $L, C$  and  $R$  used in the filter have not been exceeded.

The constructed program contains a user interface (Fig.2) and libraries of event handling functions, recalled by different interface elements. The event handling functions use, in turn, library of mathematical functions, which contains computational algorithms of the program.

The work is started by creating an internal database indispensable for design and analysis of the filter. Current and voltage waveforms recorded at the filter leads must be input (these assume the form of oscillograms recorded in .csv file). Files in .xls format containing libraries of  $R, L$  and  $C$  elements prepared on the basis of manufacturers' catalogue data must also be loaded as well as the .xls file containing harmonic limits set in accordance with standard [9]. When input data is complete, program analyzes the harmonic spectrum of the provided current waveform and points out the harmonics exceeding limits set by standard [9].

The next step is to construct filter structure, using the in-built editor, which makes it possible to add and remove different resonant branches of the filter and different  $L$  and  $C$  branch elements. This phase of work is assisted by „Kalkulator elementów gałęzi” which uses formula (1) and by impedance chart of branch under construction (which is continuously updated). Branch may additionally contain high-frequency resistors  $R_{\text{HF}}$  [1].

When structure of the filter is complete, analysis algorithm must be started. The program solves equivalent circuit, i.e. representation of supply network with filter and load (Fig.1) and calculates (on the basis of standard [10]) the peak ( $PK$ ) and RMS ( $RMS$ ) values of all currents and voltages,  $PF$  and  $THD$  coefficients and active powers  $P$ . The calculated values are compared with rated values found in the element database.

The last step is to display the most important data in the program window. These data are: filter impedance chart and harmonic spectrum of network current, which has been calculated with filter operating in the circuit. These data let us verify whether the designed filter fulfils the adopted assumptions and allow us to introduce modifications (if necessary). The remaining data are exported to files.

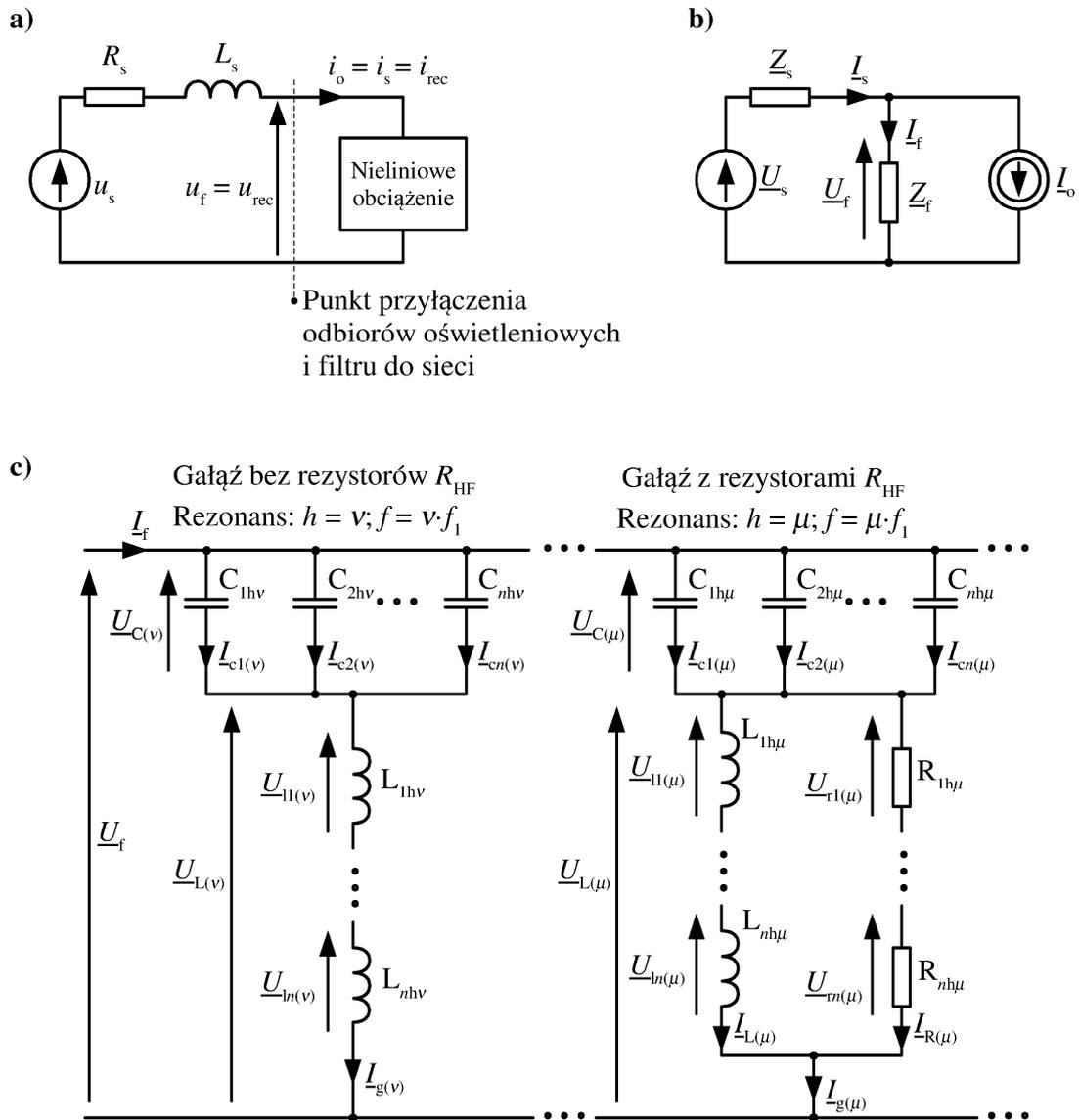


Fig. 1. Equivalent diagrams of the circuit before the filter application (a), the circuit with the filter – diagram for harmonics (b), inner structure of the filter (c)

Rys. 1. Schematy zastępcze obwodu przed zastosowaniem filtra (a), obwodu z filtrem – schemat dla harmoniczných (b), wewnętrznej struktury filtra (c)

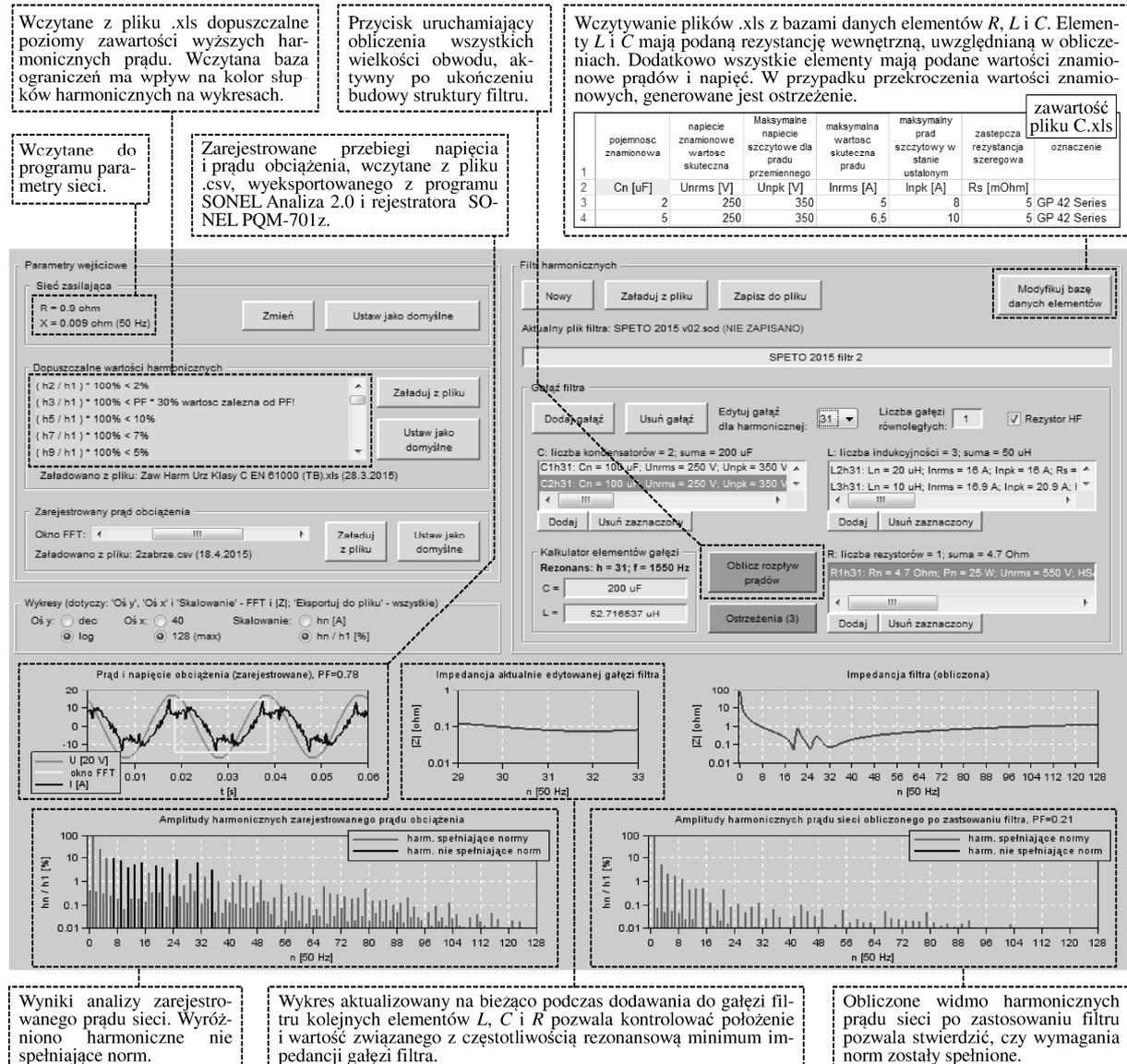


Fig. 2. The user interface of the created program

Rys. 2. Interfejs użytkownika utworzonego programu

## DATA STRUCTURE AND CALCULATION ALGORITHM

The basic problem encountered during construction of the program was an appropriate arrangement of the data, keeping in mind that the amount of data changes along with changes in structure of designed filter. The arrangement of these data should also provide a possibility of using computational algorithms, which will always act in the same way regardless of filter structure, i.e. number of its branches and number of elements in different branches.

The computational algorithm data have been divided into three classes, each class is represented by a single structure (type „struct” in Scilab program). Structure Parametry (Fig.3) contains data describing filter's operating conditions, i.e. equivalent supply network

impedance  $Z_s$ , load voltage and current waveforms ( $i_{rec}(t)$ ,  $u_{rec}(t)$ ) recorded before application of the filter, allowable harmonic content and imported databases of  $R$ ,  $L$  and  $C$  elements.

Data describing filter construction have been collected into structure *Filtr* (Figs. 4 and 5). Possibility of scaling the database has been obtained by using vectors in appropriate fields of the structure. For instance, information on filter branches is recorded in vector at the address *Filtr.Galezie*. Number of vector rows in field *Galezie* is equal to number of filter branches. Adding another branch to the filter corresponds to adding another row to vector *Filtr.Galezie*. Elements of this vector are complex structures; the fields contain information on groups of inductors, capacitors and possibly resistors in the branches. For instance, field *.C* of  $i^{\text{th}}$  element of vector *Filtr.Galezie* is in itself a vector of structures, with number of rows equal to number of capacitors connected in parallel and operating in  $i^{\text{th}}$  branch. If another capacitor should be added to the  $i^{\text{th}}$  branch of filter, it is sufficient that another row is introduced into vector *Filtr.Galezie(i).C*. Such a structure may be easily modified when filter is edited, and its treelike form facilitates fast location of any filter element, by appropriate addressing of successive vector elements of nested fields of the structure.

The third structure called *Analiza* (Figs. 6, 7 and 8) contains results of calculations conducted for filter described with *Filtr*. The configuration of its fields mirrors the arrangement of the fields in structure *Filtr* structure. Hence, using the same scheme for addressing (identical numbers of vector elements contained in corresponding fields of both structures) it is possible to get at element data in *Filtr* structure and results of calculations obtained for this element and contained in structure *Analiza*.

The adopted sectioning of algorithm data into three structures is also due to practical reasons, related to methods of dealing with issues in the proposed program. For instance, in order to archive the designed filter, it is sufficient to write structure *Filtr* into the binary file *.sod*, and reading this structure in from a file lets us return easily to edition and analysis of previously created filter.

Structures *Parametry*, *Filtr* i *Analiza* store data related to program's computational algorithms. Apart from this, program contains separate data structures containing the characteristics of graphic interface objects, parameters for event handling functions and environmental variables. These data are indispensable from the viewpoint of program operation, but since they are not utilized in computational algorithm, they will not be discussed here. Structures *Parametry*, *Filtr* and *Analiza* also contain fields storing some auxiliary data, not related to current computations. These fields have been omitted in Figs. 3 to 8.

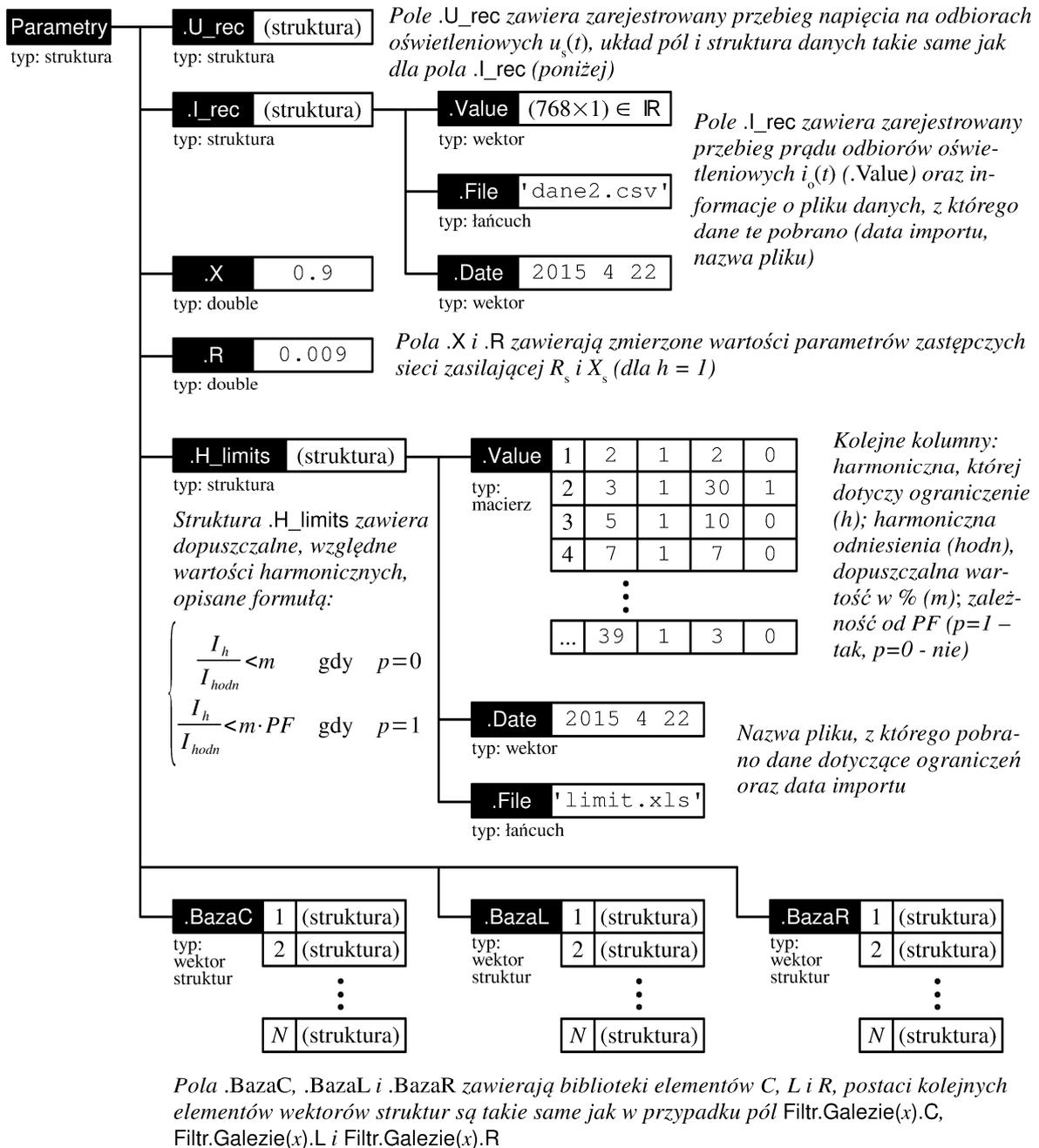


Fig. 3. Data structure describing operation conditions of the filter  
Rys. 3. Struktura danych opisujących warunki pracy filtru

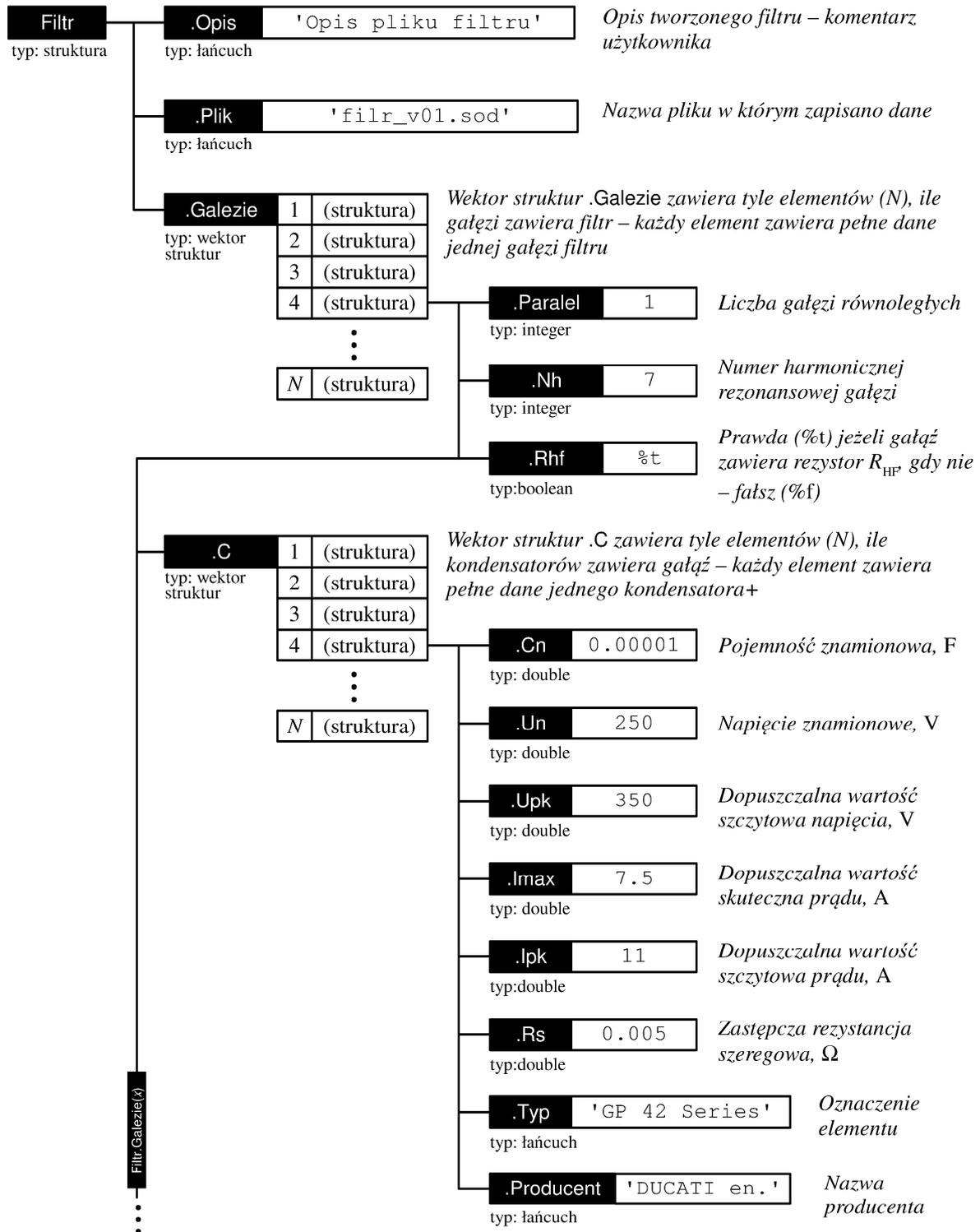


Fig. 4. Data structure of the filter  
Rys. 4. Struktura danych filtru

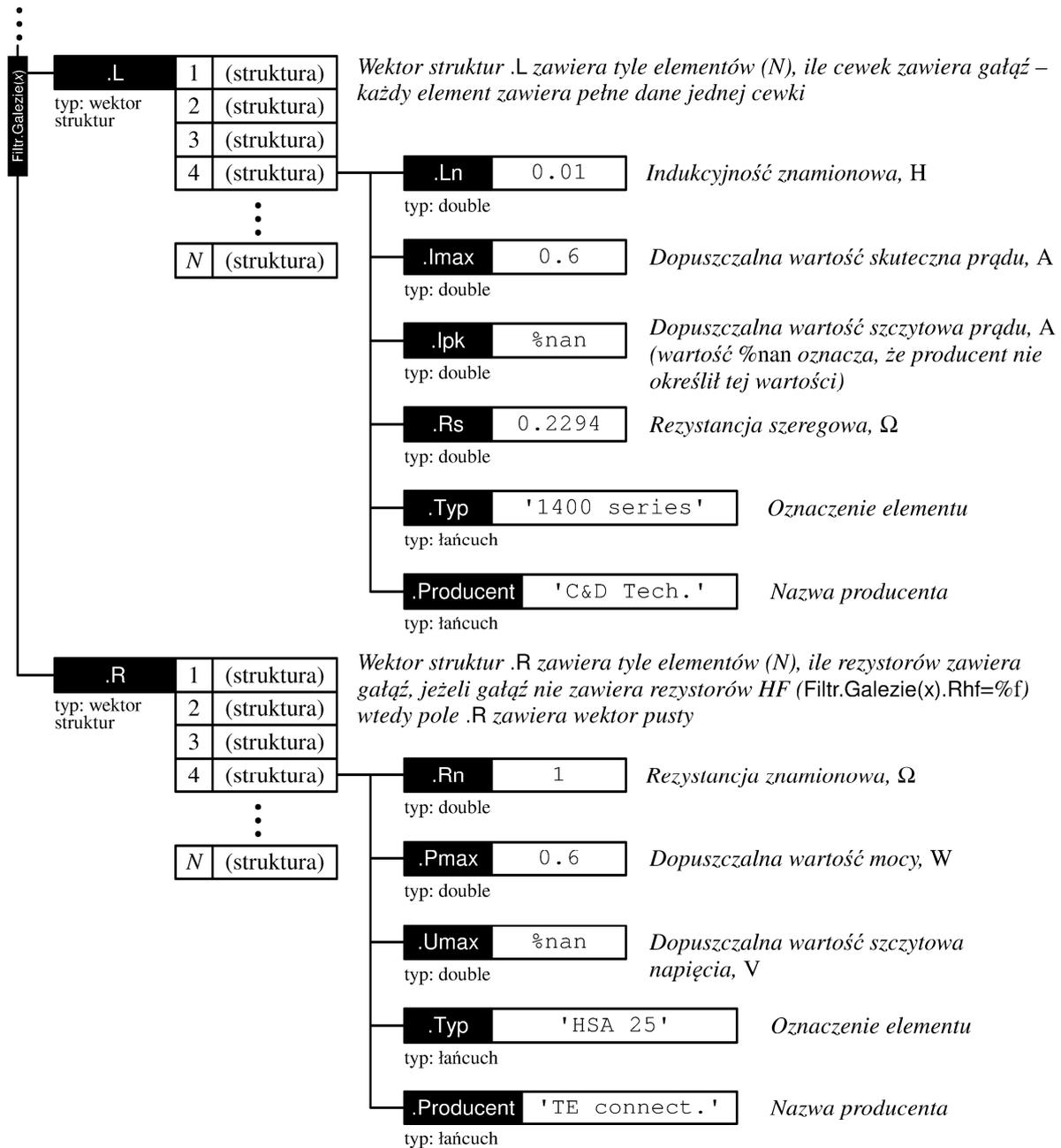


Fig. 5. Data structure of the filter (continued from fig. 4)

Rys. 5. Struktura danych filtru (ciąg dalszy z rys. 4)

When computational algorithm is started, at first impedances of different elements  $L$ ,  $C$  and  $R$  in each branch are calculated (they are denoted as  $\underline{Z}_{li}$ ,  $\underline{Z}_{ci}$  i  $\underline{Z}_{ri}$ , where  $i$  – number of element in a group). For instance, impedance  $\underline{Z}_{l2}$  calculated for each harmonic of the second inductor of filter branch No.4, with inductance and resistance recorded at addresses `Filtr.Galezie(4).L(2).Ln` and `Filtr.Galezie(4).L(2).Rs` (Fig. 5), will be recorded in successive elements of vector at the address `Analiza.Galezie(4).L(2).Z` (Fig. 7).

Numbers of vector elements correspond to successive harmonics up to order  $h = 127$ . Calculations are run for 127 harmonics; this is due to the fact, that waveforms  $u_{rec}(t)$  and

$i_{rec}(t)$  are recorded with SONEP PQM-701Z device, where resolution is equal to 256 samples per one period of fundamental harmonic.

In the next step, impedances of groups of elements in each branch are calculated. For example, total impedance  $\underline{Z}_C$  of all capacitors connected in parallel in branch No.3 will be recorded into vector at the address Analiza.Galezie(3).Zc, while capacitor data will be imported from appropriate fields of structure vector Filtr.Galezie(3).C. Element and element group impedances are calculated from expressions:

$$\underline{Z}_{ci} = R_{ci} + (j2\pi hf_1 C_{ni})^{-1}, \quad \underline{Z}_C = \left( \sum_{i=1}^N \underline{Z}_{ci}^{-1} \right)^{-1}, \quad i \in [1; N], \text{ for } h \in [1; 127], \quad (2)$$

$$\underline{Z}_{li} = R_{li} + j2\pi hf_1 L_{ni}, \quad \underline{Z}_L = \sum_{i=1}^N \underline{Z}_{li}, \quad i \in [1; N], \text{ for } h \in [1; 127], \quad (3)$$

$$\underline{Z}_{ri} = R_{ni}, \quad \underline{Z}_R = \sum_{i=1}^N \underline{Z}_{ri}, \quad i \in [1; N], \quad (4)$$

where  $N$  denotes number of elements in a group, that is number of branch capacitors connected in parallel or inductors or resistors connected in series. The calculations for resistors are run only when a given branch contains HF resistors, i.e. when Boolean variable at the address Filtr.Galezie(x).Rhf assumes value "truth" (Fig. 4).

Next, impedances of successive branches are calculated:

$$\underline{Z}_g = \begin{cases} \left( \sum_{i=1}^p \left( \frac{\underline{Z}_R \underline{Z}_L}{\underline{Z}_R + \underline{Z}_L} + \underline{Z}_C \right)^{-1} \right)^{-1} & \text{when } R_{HF} < \infty \\ \left( \sum_{i=1}^p (\underline{Z}_L + \underline{Z}_C)^{-1} \right)^{-1} & \text{when } R_{HF} = \infty \end{cases}, \quad \text{for } h \in [1; 127], \quad (5)$$

where  $p$  denotes number of parallel branches (Filtr.Galezie(x).Paralel, Fig. 4). In order to decrease impedance for a given harmonic, filter may contain more than one branch with identical structure. Results are recorded in subsequent cells of vector Analiza.Galezie(x).Z (Fig. 6).

At the end of this stage, filter total impedance  $\underline{Z}_f$  is calculated:

$$\underline{Z}_f = \left( \sum_{i=1}^N \underline{Z}_{gi}^{-1} \right)^{-1}, \quad i \in [1; N], \text{ for } h \in [1; 127], \quad (6)$$

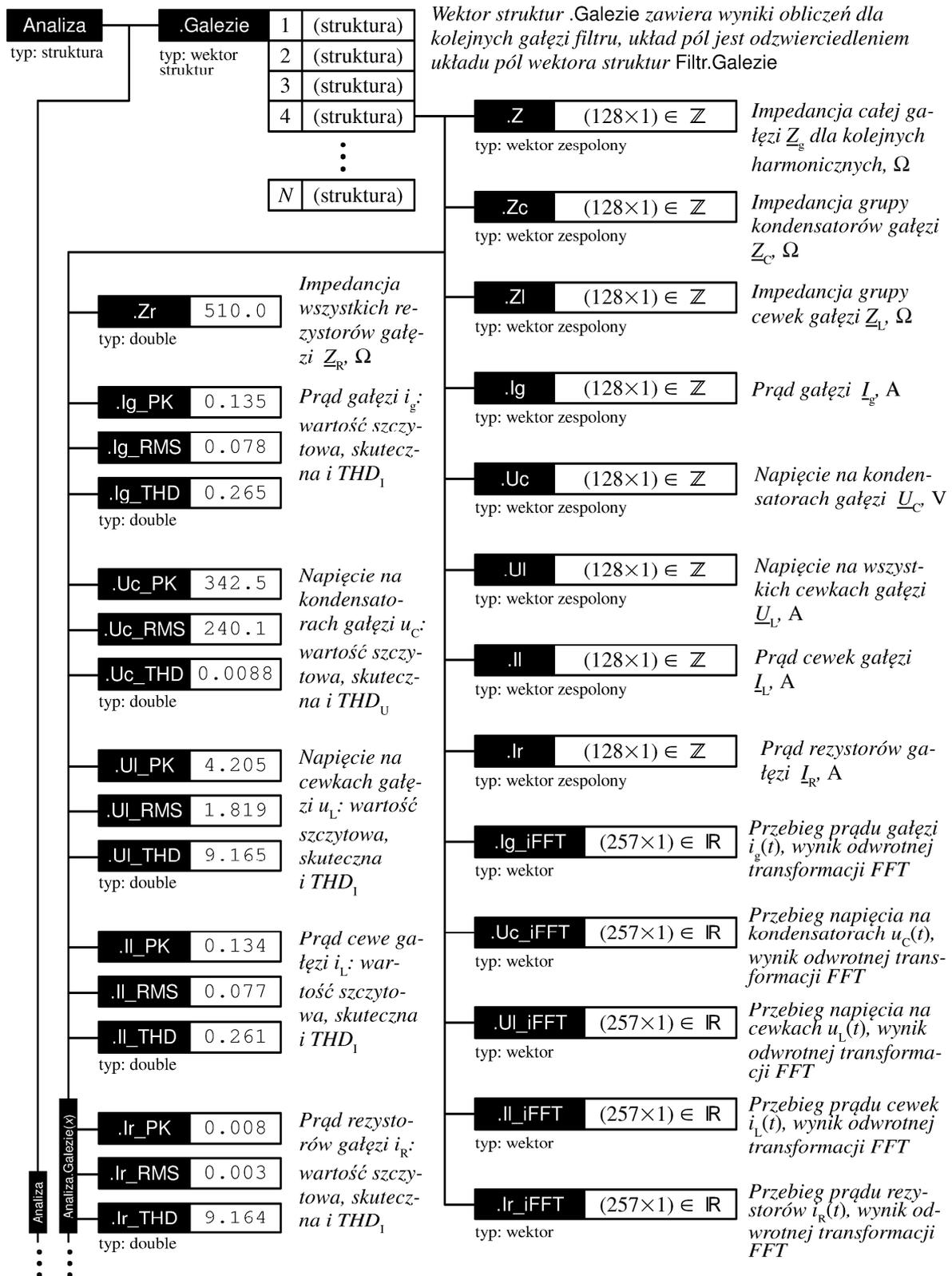


Fig. 6. Data structure containing calculation results  
Rys. 6. Struktura danych przechowująca wyniki obliczeń

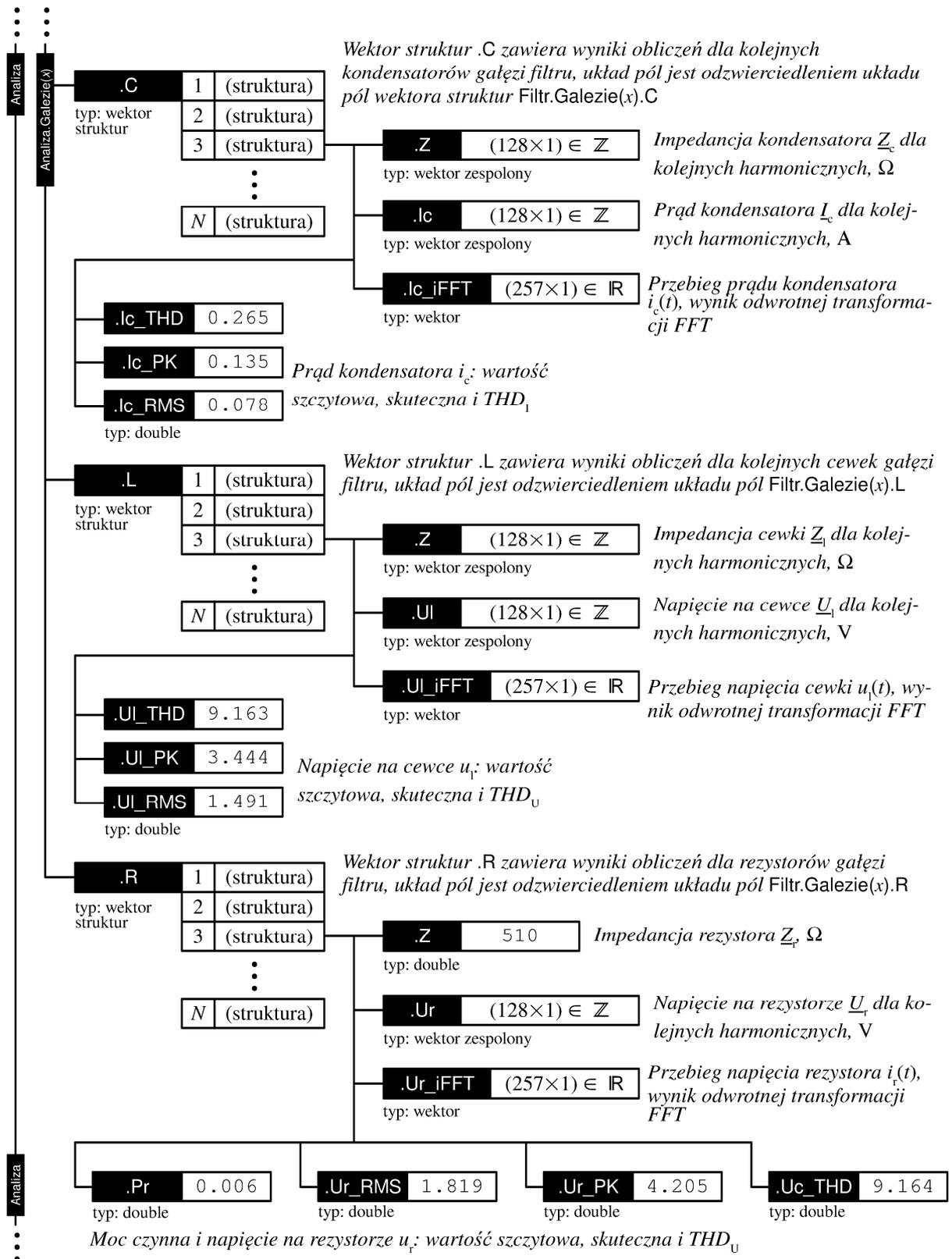


Fig. 7. Data structure containing calculation results (continued from Fig. 6)

Rys. 7. Struktura danych przechowująca wyniki obliczeń (ciąg dalszy z rys. 6)

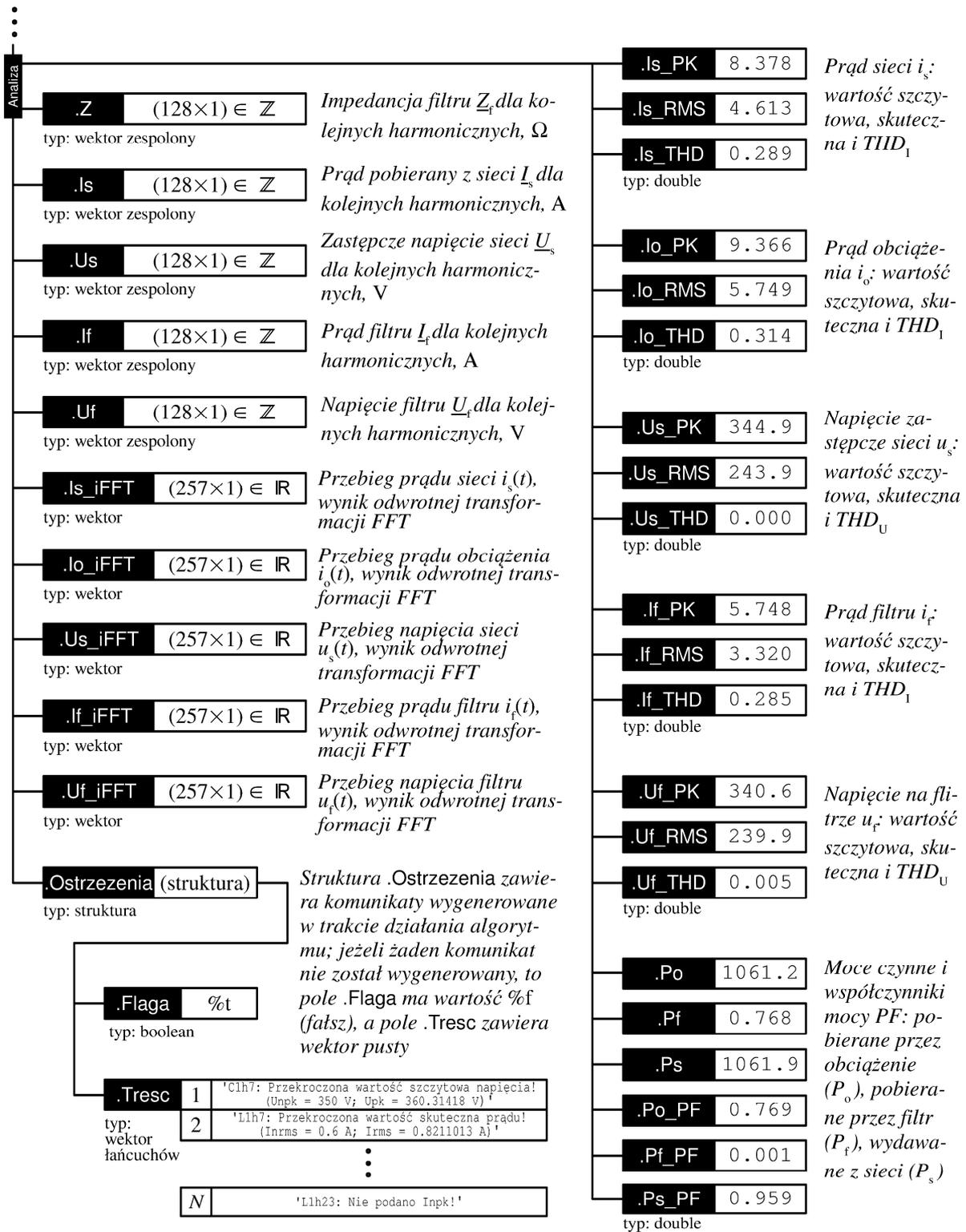


Fig. 8. Data structure containing calculations result (continued from Figs. 6 and 7)  
 Rys. 8. Struktura danych przechowująca wyniki obliczeń (ciąg dalszy z rys. 6 i 7)

where  $N$  denotes number of branches in filter. Results are recorded in vector at the address Analiza.Z (Fig. 8).

In the second stage of calculations, voltage and currents for circuit shown in Fig.1b are calculated ( $\underline{U}_f$  by node-voltage method,  $\underline{U}_s$  by using 2nd Kirchhoff's Law and  $\underline{I}_f$  by using Ohm's Law):

$$\underline{I}_f = \frac{\underline{U}_f}{\underline{Z}_f}, \quad \underline{I}_s = \underline{I}_o + \underline{I}_f, \text{ for } h \in [1; 127]. \quad (7)$$

$$\underline{U}_f = \frac{\underline{U}_s \underline{Z}_{f^{-1}} - \underline{I}_o}{\underline{Z}_{s^{-1}} + \underline{Z}_{f^{-1}}}, \text{ for } h \in [1; 127], \quad (8)$$

$$\underline{U}_s = \begin{cases} \underline{U}_{\text{rec}} + (R_s + j2\pi hf_1 L_s) \underline{I}_{\text{rec}} & \text{when } h = 1, \text{ for } h \in [1; 127]. \\ 0 & \text{when } h \neq 1 \end{cases} \quad (9)$$

Internal currents and voltages of the filter, shown in Fig.1c, are calculated from the equations:

$$\underline{I}_g = \frac{\underline{U}_f}{p \underline{Z}_g}, \underline{U}_C = \underline{I}_g \underline{Z}_C, \underline{U}_L = \begin{cases} \underline{I}_g \frac{\underline{Z}_L \underline{Z}_R}{\underline{Z}_L + \underline{Z}_R} & \text{when } R_{\text{HF}} < \infty, \text{ for } h \in [1; 127], \\ \underline{I}_g \underline{Z}_L & \text{when } R_{\text{HF}} = \infty \end{cases} \quad (10)$$

$$\underline{I}_L = \begin{cases} \underline{U}_L \underline{Z}_L^{-1} & \text{when } R_{\text{HF}} < \infty, \text{ for } h \in [1; 127], \\ \underline{I}_g & \text{when } R_{\text{HF}} = \infty \end{cases} \quad (11)$$

$$\underline{I}_R = \underline{U}_L \underline{Z}_R^{-1}, \text{ when } R_{\text{HF}} < \infty, \text{ for } h \in [1; 127], \quad (12)$$

$$\underline{I}_c = \underline{U}_C \underline{Z}_c^{-1}, \underline{U}_l = \underline{I}_L \underline{Z}_l, \text{ for } h \in [1; 127], \quad (13)$$

$$\underline{U}_r = \underline{I}_R \underline{Z}_r, \text{ when } R_{\text{HF}} < \infty, \text{ for } h \in [1; 127]. \quad (14)$$

The calculated values of harmonics of total load and filter current ( $\underline{I}_s$ ) are compared with values allowed by standard (Parametry.H\_limits.Value, Fig. 3) and displayed in the main window of the program (Fig. 2).

When current flow and voltage distribution are determined, active powers of resistors, RMS values of currents and voltages and THD coefficients are calculated [10]:

$$P = \sum_h 0.5 \cdot \operatorname{Re}\{ \underline{U} \underline{I}^* \}, S = 0.5 \cdot \sqrt{\left( \sum_h |\underline{U}|^2 \right) \left( \sum_h |\underline{I}|^2 \right)}, PF = \frac{P}{S}, \quad (15)$$

$$U_{\text{RMS}} = \sqrt{0.5 \cdot \sum_h |\underline{U}|^2}, I_{\text{RMS}} = \sqrt{0.5 \cdot \sum_h |\underline{I}|^2}, \quad (16)$$

$$THD_U = \frac{\sqrt{\sum_{h \neq 1} |\underline{U}|^2}}{|\underline{U}_{(h=1)}|}, THD_I = \frac{\sqrt{\sum_{h \neq 1} |\underline{I}|^2}}{|\underline{I}_{(h=1)}|}. \quad (17)$$

The 0.5 constants seen in formulas (15) and (16) are due to the fact that program computations are conducted using complex amplitudes of current and voltages instead of using complex RMS values. The values of power factor  $PF$  and  $\operatorname{tg}\varphi$  for the fundamental harmonic are determined for entire network load (filter and lighting loads); they are displayed in the main window of the program, above the chart of calculated current harmonics  $I_s$  (Fig. 2).

$$\operatorname{tg} = \operatorname{tg}(\arg(\underline{U}_{f(h=1)}) - \arg(\underline{I}_{s(h=1)})). \quad (18)$$

All circuit currents and voltages, represented by vectors of complex maximum values for successive harmonics, are subjected to inverse Fourier transform. For instance, vector of calculated complex maximum values of current in branch No. 5  $\underline{I}_g$ , which is recorded at the address `Analiza.Galezie(5).lg`, is subjected to inverse FFT transform; the result is current waveform  $i_g(t)$  for this branch, for one period of fundamental harmonic, recorded at the address `Analiza.Galezie(5).lg_iFFT` (Fig. 6). The determined waveforms are the basis for calculating peak values ( $PK$ ) of currents and voltages:

$$U_{\text{PK}} = \max((u(t)), I_{\text{PK}} = \max((i(t))). \quad (19)$$

The last step in the algorithm of filter analysis is comparison of calculated RMS and peak values of currents and voltages (in case of resistors also comparison of active power) of different elements with the rated values. For instance, calculated value of peak voltage across capacitors in branch No. 7 of the filter (`Analiza.Galezie(7).Uc_PK`, Fig. 6), is compared with allowable value for each  $n^{\text{th}}$  capacitor in this branch (`Filtr.Galezie(7).C(n).Upk`, Fig. 4). If allowable value is exceeded, a warning is generated and recorded in the subsequent element of chain vector at the address `Analiza.Ostrzezenia.Tresc` (Fig. 8). Warnings may be displayed by using appropriate button in the main window of the program (Fig.2).

All calculated harmonic spectra, waveforms and impedance value for different harmonics are exported to.csv files. All of program data are also recorded in binary file .sod; this allows for their possible future processing in Scilab environment. A text file (calculation report) is also generated. It contains a full description of the designed filter structure together with calculation results. Summarized contents of one such file are presented in the appendix.

## ANALYSIS RESULTS OF EXEMPLARY FILTER

The exemplary filter designed in the proposed program consists of twelve LC branches, with resonant frequencies appropriate for all eleven harmonics whose values in the recorded load current waveform were excessive (Fig. 9). In addition, a twelfth resonance branch was added in order to attenuate 15<sup>th</sup> harmonic; this harmonic value exceeded the allowable level after application of the filter only. The cause of increase in 15<sup>th</sup> harmonic may be traced to decrease in the fundamental harmonic current. Standard [9] defines higher harmonic content limits in relative values (referenced to fundamental harmonic). The decrease in value of current fundamental harmonic caused by compensation of reactive power due to filter application, led to increase of relative content of 15<sup>th</sup> harmonic.

Network current fulfilled the demands set by standard [9] after application of the designed filter. This is proven by diagrams shown in Fig. 9 and by calculated values. Moreover, introduction of the filter improved power factor value  $PF$ .

Application of the filter has improved  $THD$  coefficient of the supply current only slightly. This is caused by most disadvantageous character of analyzed load, which consists of LED and discharge lamps [11]. The current higher harmonics emitted into the network by this type of load are characterized by similar amplitudes over a wide frequency range. In the discussed case, one or several dominant harmonics cannot be distinguished in the harmonic spectrum; attenuation of such harmonics would cause a significant improvement in  $THD$  coefficient, if filter with just a few branches were applied.

It should be noted that for fundamental harmonic impedance of each filter branch is of capacitive character. Adding successive branches to the filter structure causes a decrease in load  $\text{tg}\varphi$  for the fundamental harmonic. This is beneficial as long as  $\text{tg}\varphi > 0$ , but if too many branches are connected into the filter structure, the reactive power may be over-compensated.

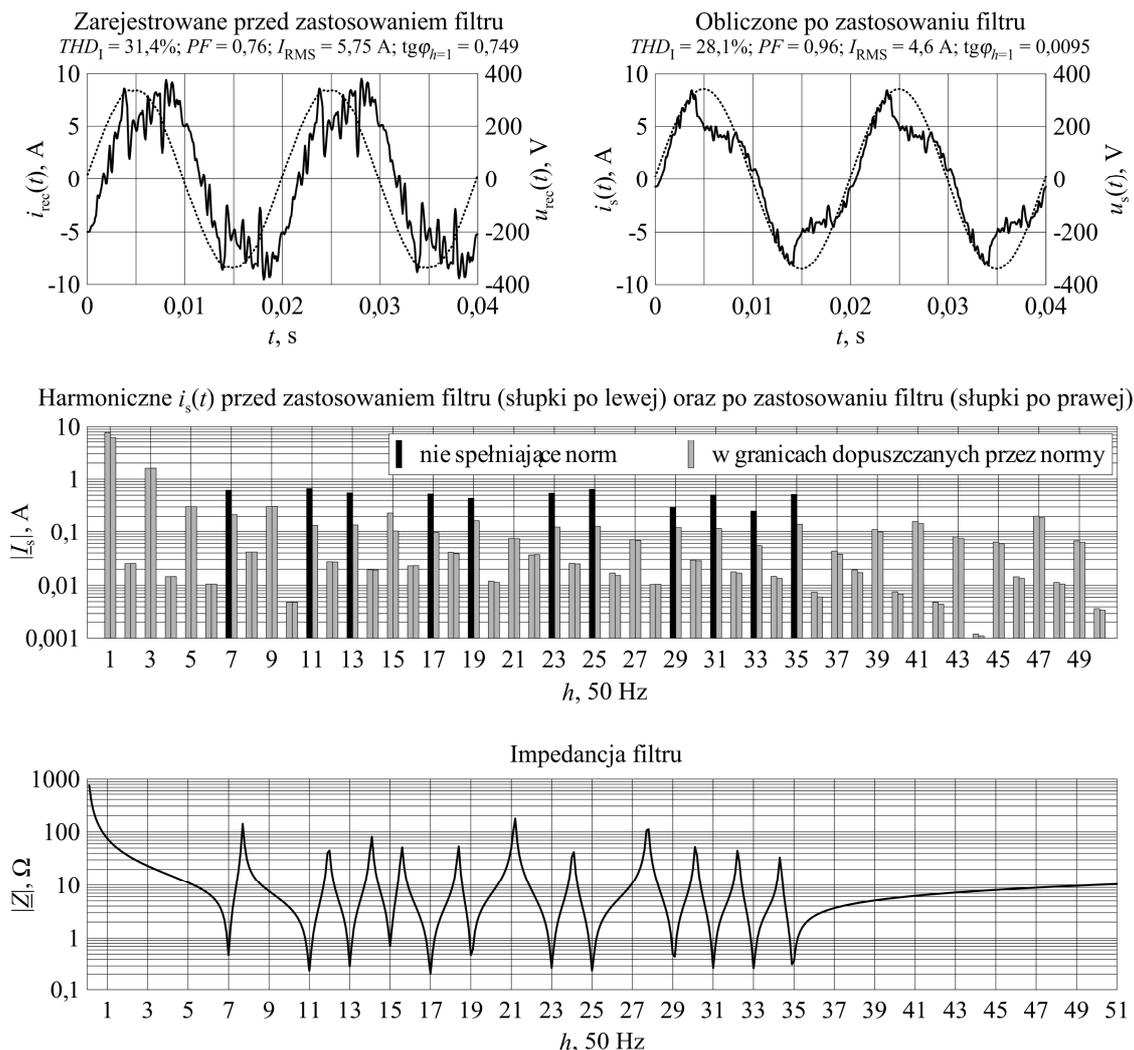


Fig. 9. Recorded and calculated with the created program transients of supply network voltage and current, current harmonics and impedance of the designed filter

Rys. 9. Zarejestrowane oraz obliczone przez utworzony program przebiegi prądu i napięcia sieci, widmo harmonicznych prądu oraz zależność impedancji zaprojektowanego filtra od częstotliwości

## CONCLUSION

A Scilab environment program has been created, for CAD design and analysis of current harmonics' properties in resonance filters. The program has been used to design exemplary filter for lighting installation containing modern energy-saving light sources. On the basis of analysis results we may state that passive resonance filter makes it possible to limit emission of current harmonics down to the values allowed by standard [9]. At the same time compensation of reactive inductive power is ensured. This is not an optimum solution. Lots of filter branches require application of numerous  $L$  and  $C$  elements, so that filter structure is very complex and it cannot be justified from economic point of view. Moreover, on account of possibility of overcompensating the reactive power, filters of this type cannot be used alongside light sources equipped with systems for power factor correction (PFC).

## APPENDIX

Summarized contents of computation report:

## CURRENT HARMONIC FILTER COMPUTATION REPORT

generated 2015/04/22 at 22:47:51

by Projektant Filtrów v01 software

## WARNINGS:

\*\*\* C1h7: Peak voltage value exceeded! (Unpk = 350 V; Upk = 360.43792 V)

\*\*\* L1h11: RMS current value exceeded! (Inrms = 0.8 A; Irms = 0.8476790 A)

...

## Analyzed filter:

File: SPETO 2015 v04.sod

Date of last filter record: 2015/04/22 22:21:39

Filter description: exemplary filter

## Recorded current and voltage waveforms:

Source file: 2zabrze.csv

Date of waveform import: 2015/04/22 20:52:20

Identifier of voltage waveform: U\_L1\_[V]

Identifier of current waveform: I\_L1\_[A]

## Equivalent impedance of supply network:

R = 0.9 Ohm

X = 0.009 Ohm (for f = 50 Hz)

## Allowable harmonic values:

Source file: Zaw Harm Urz Klasy C EN 61000 (TB).xls

Data of waveform import: 2015/03/28 14:31:25

## Imported limitations:

(h2/h1)\*100% < 2%

(h3/h1)\*100% < PF\*30% value dependent on PF!

(h5/h1)\*100% < 10%

...

## Analysis results (values calculated with filter on):

## Network:

## Filter and load voltages:

Ufrms = 239.94622 V; Ufpk = 340.63277 V; THDu = 0.4714665%

## Supply network current :

Isrms = 4.6036492 A; Ispk = 8.3909296 A; THDi = 28.061653%

## Power output of supply network:

P = 1062.0953 W; PF = 0.9614957; tg(fi) = 0.0094596 dla h = 1

## Load:

## Load current:

Iorms = 5.7496866 A; Iopk = 9.3664582 A; THDi = 31.400577%

## Load power:

P = 1061.315 W; PF = 0.7692831; tg(fi) = 0.0094596 for h = 1

## Filter Structure and calculated values:

## Total filter current:

Ifrms = 3.3331655 A; Ifpk = 5.6796557 A; THDi = 29.904957%

## Active power consumed by filter:

P = 0.7803706 W; PF = 0.0009757

## Number of filter branches: 12

## Branch No.1 (h = 7; frez = 350 Hz):

Number of parallel branches: 1

Branch contains HF resistor: no

## Branch current:

Igrms = 0.8212571 A; Igpk = 1.481569 A; THDi = 37.284846%

## Voltage at branch capacitors:

Ucrms = 245.29244 V; Ucpk = 360.43792 V; THDu = 5.3463403%

## Sum of voltages across branch inductances (and resistors):

Ulrms = 13.977909 V; Ulpk = 26.744101 V; THDu = 260.29817%

## Branch capacitors:

## C1h7:

Rated and catalogue data: Cn = 10 uF; Unrms = 250 V; Unpk = 350 V; Inrms = 7.5 A;

Inpk = 11 A; Rs = 5 mOhm; GP 42 Series; DUCATI energia;  
 Calculated values: Icrms = 0.8212571 A; Icpk = 1.481569 A; THDi = 37.284846%

Branch inductances:  
 L1h7:  
 Rated and catalogue data: Ln = 10 mH; Inrms = 0.6 A; Inpk = Nan A; Rs = 229.4 mOhm;  
 1400 series;  
 Calculated values: Ulrms = 6.7591248 V; Ulpk = 12.932177 V; THDu = 260.30302%

L2h7:  
 Rated and catalogue data: Ln = 10 mH; Inrms = 0.6 A; Inpk = Nan A; Rs = 229.4 mOhm;  
 1400 series;  
 Calculated values: Ulrms = 6.7591248 V; Ulpk = 12.932177 V; THDu = 260.30302%

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Branch No.2 (h = 11; frez = 550 Hz):  
 Number of parallel branches: 1  
 Branch contains HF resistor: no  
 Branch current:  
 Igrms = 0.8476790 A; Igpk = 1.5687033 A; THDi = 49.373569%

Voltage at branch capacitors:  
 Ucrms = 242.18788 V; Ucpk = 358.6317 V; THDu = 4.5127438%

Sum of voltages across branch inductances (and resistors):  
 Ulrms = 11.036125 V; Ulpk = 18.449261 V; THDu = 541.08337%

Branch capacitors:  
 C1h11:  
 Rated and catalogue data: Cn = 10 uF; Unrms = 250 V; Unpk = 350 V; Inrms = 7.5 A;  
 Inpk = 11 A; Rs = 5 mOhm; GP 42 Series; DUCATI energia;  
 Calculated values: Icrms = 0.8476790 A; Icpk = 1.5687033 A; THDi = 49.373569%

Branch inductances:  
 L1h11:  
 Rated and catalogue data: Ln = 6.8 mH; Inrms = 0.8 A; Inpk = Nan A; Rs = 188.4 mOhm;  
 1400 series;  
 Calculated values: Ulrms = 8.968217 V; Ulpk = 14.992326 V; THDu = 541.0153%

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