Krzysztof LUDWINEK, Jan STASZAK

Politechnika Świętokrzyska, Katedra Maszyn Elektrycznych i Systemów Mechatronicznych

Possibility of graphical environment applications for evaluating of equivalent circuit parameters and time constants

***Abstract.** The article discusses possibility of using the LabView graphical environment for visualization and for quick and simple identification of electromagnetic synchronous machine parameters. For this purpose, two programs were elaborated which by changing the analog knob properties representing the equivalent circuit parameters and time-constants may be shaped the frequency characteristics, approximating the characteristics obtained in a numerical or an experimental way*

***Streszczenie.** W artykule omówiono możliwości zastosowania środowiska graficznego LabView do wizualizacji oraz do szybkiej i prostej identyfikacji parametrów elektromagnetycznych maszyny synchronicznej. W tym celu opracowano program, w którym poprzez zmianę nastaw analogowych zadajników reprezentujących parametry schematu zastępczego oraz stałe czasowe możliwe jest kształtowanie charakterystyk częstotliwościowych, aproksymujących charakterystyki otrzymane na drodze obliczeń numerycznych lub w sposób eksperymentalny. (**Zastosowania środowiska graficznego LabView do wizualizacji oraz do szybkiej i prostej identyfikacji parametrów elektromagnetycznych maszyny synchronicznej**)*

Key words: equivalent circuit diagram parameters, time-constant, identification, graphic environmental, LabView
Słowa kluczowe: parametry schematu zastępczego, stałe czasowe, identyfikacja, środowisko graficzne, LabView

Introduction

In analysis of steady and transient states of electrical machines [1] is necessary to know the parameters of equivalent circuit, which are calculated from the approximation of spectral impedance frequency characteristics.

Frequency characteristics can be evaluated e. g. by numerical calculations, based on the analysis of electromagnetic field distribution, using programs such as Flux, Maxewll, Opera and others. This method of calculation requires a detailed knowledge of construction materials, which are not always known.

Identification of equivalent circuit parameters can also be done in an experimental way [2, 3, 4, 5], mostly on a stationary machine, using the DC decay method or frequency method SSFR (StandStill Frequency Response). These methods of evaluating the frequency characteristics and equivalent circuit parameters and time constants are presented in many works [2, 3, 4, 5, 7]. In the case of electrical machines investigation only difficulty consists in maintaining the various frequencies and the same current value to about 0.1 I_N. Above this value, particularly for low frequencies, it is seen the influence of changes in the armature circuit resistance on the course of the frequency characteristics. An example of the influence of the armature resistance on the course of the frequency characteristics is also presented in this paper.

Frequency characteristics of the synchronous machine obtained in a field distribution analysis or as an experimental test, are used to identify the equivalent circuit parameters or time-constants. Generally identification of the electromagnetic parameters is carried out in a numerical way by using preset algorithms e. g. in Matlab [6] or by using own programs.

In the article, the authors presented the possibility of using the LabView graphical environment for quick and easy approximation of the frequency characteristics of equivalent circuit parameters and time constants. Approximation of frequency characteristics was carried out for the magnitude of spectral reactance and impedance of synchronous machine in d-axis.

Presented in the paper the graphically way of identify the electromagnetic synchronous machine parameters, except that it is quick, simple and allows continuous visualization of the influence of individual parameters or fixed time constants on the course of frequency characteristics, based on the synchronous machine equivalent circuit model or depending on the amount of time constants searching.

Equivalent circuit model

In Figure 1 and Figure 2 shows distributed–lumped model block diagram of the synchronous machine in the longitudinal - d and transverse - q coordinate system. The distributed–lumped model in the longitudinal coordinate system is represented by the parameters R_a, $L_{s\sigma}$, L_{ad}, R_f, $L_{f\sigma}$, R_{kD}, L_{kD}, which do not depend on frequency. The distributed–lumped model in the transverse coordinate system is represented by the parameters R_a, $L_{s\sigma}$, L_{aq}, R_{kQ}, $L_{kQ\sigma}$, which also do not depend on frequency.

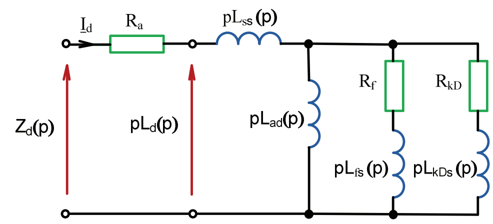


Fig. 1. Distributed–lumped model block diagram of the synchronous machine in the longitudinal - d coordinate system

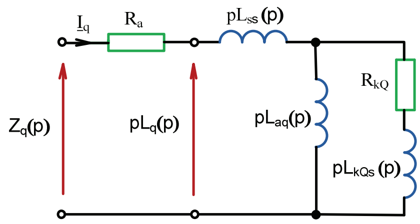


Fig. 2. Distributed–lumped model block diagram of the synchronous machine in the transverse - q coordinate system

Armature inductances of synchronous machine in distributed–lumped model block diagram of the synchronous machine in Figure 1 and Figure 2 are defined as follows:

(1) $$L_d(p) = \frac{\Psi_d(p)}{I_d(p)}$$

(2) $$L_q(p) = \frac{\Psi_q(p)}{I_q(p)}$$

The armature inductances (1) and (2) are evaluated from the armature voltage equations in the d - q coordinate system for the rotor rotational speed ω = 0, which for the based electrical system have the form:

(3) $$U_d(p) = p\Psi_d(p) + R_a I_d(p)$$

(4) $$U_q(p) = p\Psi_d(p) + R_a I_q(p)$$

Evaluated from the relationships (3) and (4) equivalent operator inductance $L_d(p)$ and $L_q(p)$ are respectively:

(5) $$pL_d(p) = \left[\frac{U_d(p)}{I_d(p)} - R_a\right] = \left[Z_d(p) - R_a\right]$$

(6) $$pL_q(p) = \left[\frac{U_q(p)}{I_q(p)} - R_a\right] = \left[Z_q(p) - R_a\right]$$

Assuming the above dependencies for the operator $p = j\omega$, we obtain the spectral reactance (inductance) frequency characteristics in the longitudinal and transverse axes:

(7) $$\omega_1 L_d(j\omega_1 \nu) = \frac{Z_d(j\omega_1\nu) - R_a}{j\nu} = \frac{\mathrm{Im}\{Z_d(j\omega_1\nu)\}}{\nu} - j\frac{\mathrm{Re}\{Zd(j\omega_1\nu)\} - R_a}{\nu}$$

(8) $$\omega_1 L_q(j\omega_1 \nu) = \frac{Z_q(j\omega_1\nu) - R_a}{j\nu} = \frac{\mathrm{Im}\{Z_q(j\omega_1\nu)\}}{\nu} - j\frac{\mathrm{Re}\{Z_q(j\omega_1\nu)\} - R_a}{\nu}$$

where: $\omega_1 = 2\pi f_1$ – basic pulse, ν – relative frequency referenced to the fundamental frequency f_1 = 50 Hz, R_a – the one phase armature winding resistance measured at constant current.

Spectral inductance are calculated from the recorded waveforms of voltage and current, when two phases of the armature winding of stationary synchronous machine are powered by sinusoidal voltage of adjustable frequency. The impedance of armature winding one phase $Z_{d,\,q}$ in the d - q coordinate system is defined as follows:

(9) $$Z_{d,q}(j\omega_1\nu) = \frac{1}{2}\frac{U_{am}(\nu)}{I_{am}(\nu)} e^{j\varphi(\nu)}$$

where: $U_{am}(\nu)$, $I_{am}(\nu)$ – respectively, magnitude of armature voltage and current, $\varphi(\nu)$ – phase angle between voltage and current waveforms.

On the basis of spectral inductance from measurements, the equivalent circuit parameters and time constants of synchronous machine are evaluated. Evaluated on the basis of equivalent circuit parameters (Figures 1 and 2) the frequency characteristics are calculated from the relationship:

(10)
$$j\omega L_d(j\omega) = j\omega L_\sigma + \frac{1}{\frac{1}{j\omega L_{ad}} + \frac{1}{R_f + j\omega L_{f\sigma}} + \frac{1}{R_{kD} + j\omega L_{kD\sigma}}}$$

(11) $$j\omega L_q(j\omega) = j\omega L_\sigma + \frac{1}{\frac{1}{j\omega L_{aq}} + \frac{1}{R_{kQ} + j\omega L_{kQ\sigma}}}$$

The synchronous machine spectral characteristics can also be obtained on the basis of time constants knowledge of transfer functions. With the acceptance of the equivalent circuit shown in Figure 1 there are four time constants T_d'', T_{d0}'', T_d', T_{d0}', while in the case of Figure 2 there are two time constants T_q', T_{q0}'.

(12) $$\omega L_d(j\omega) = X_d \frac{(1 + j\omega T_d')(1 + j\omega T_d'')}{(1 + j\omega T_{d0}')(1 + j\omega T_{d0}'')}$$

(13) $$\omega L_q(j\omega) = X_q \frac{1 + j\omega T_q'}{1 + j\omega T_{q0}'}$$

Evaluated values of the reactance X_d, X_q, time constants T_d'', T_{d0}'', T_d', T_{d0}' and T_q', T_{q0}' allow to calculate the parameters of equivalent circuit [6].

Equivalent circuit parameter and time constants identification

On the basis of evaluated in numerical or experimental way of the synchronous machine frequency characteristics, identification of the electromagnetic parameters in d-q coordinate systems (Fig. 1 and Fig. 2) and time constants are carried out, making approximation of spectral reactance magnitude and phase characteristics $X_d(j\omega)$ i $X_q(j\omega)$.

Identification of equivalent circuit parameters and time constants rely on the selection of the vector of parameters in the d-axis $\chi_d = \{L_\sigma, L_{ad}, L_{kD\sigma}, R_{kD}, R_f, L_{f\sigma}\}$ or $\chi_d = \{(X_d, T_d'', T_{d0}'', T_d', T_{d0}')\}$ and in the q-axis $\chi_q = \{L_\sigma, L_{aq}, L_{kQ\sigma}, R_{kQ}\}$ or $\{(X_q, T_q', T_{q0}')\}$, in such a way that magnitude and phase functions defined by expressions (10) and (11) or (12) and (13) approximate with the smallest possible error of the magnitude and phase courses evaluated from measurements. This problem can be solved using optimization methods [7].

According to the least squares minimization, the best parameters of vectors χ_d and χ_q are those, for which the sum of squared deviations ε_{dm}, ε_{qm}, $\varepsilon_{d\varphi}$, $\varepsilon_{q\varphi}$ is the smallest:

(14) $$\varepsilon_{dm} = \sum_{i=1}^{m}\left\{\left|L_d(j\omega_i)\right| - \left|L_d^*(j\omega_i, \chi_d)\right|\right\}^2$$

(15) $$\varepsilon_{qm} = \sum_{i=1}^{m}\left\{\left|L_q(j\omega_i)\right| - \left|L_q^*(j\omega_i, \chi_q)\right|\right\}^2$$

(16) $$\varepsilon_{d\varphi} = \sum_{i=1}^{m}\left\{\varphi_d(j\omega_i) - \varphi_d^*(j\omega_i, \chi_d)\right\}^2$$

(17) $$\varepsilon_{q\varphi} = \sum_{i=1}^{m}\left\{\varphi_q(j\omega_i) - \varphi_q^*(j\omega_i, \chi_q)\right\}$$

where: $\left|L_{d,q}(j\omega_i)\right|$, $\varphi_{d,q}(j\omega_i)$ – respectively, magnitude and phase of spectral inductance in d–q axes evaluated in experimental way, $\left|L_{d,q}^*(j\omega_i, \chi_d)\right|$, $\varphi_{d,q}^*(j\omega_i, \chi_d)$ – respectively, magnitude and phase of spectral inductance in d–q axes evaluated on a basis of the equivalent circuit parameters (Figure 1 and Figure 2) or on the basis of transfer function (12) and (13), m – number of measured points, ω_i –pulse.

Functions (14) ÷ (17) are nonlinear expressions due to the search values. This problem of mean square minimization is reduced to nonlinear programming.

Percentage mean square error of magnitude – δ_{dm}, δ_{qm} and phase – $\delta_{d\varphi}$, $\delta_{q\varphi}$ characteristics in d– q axes are defined as follows:

(19) $$\delta_{dm} = 100\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left[\frac{\left|L_d(j\omega_i)\right| - \left|L_d^*(j\omega_i, \chi_d)\right|}{\left|L_d(j\omega_i)\right|}\right]^2}$$

(20) $$\delta_{d\varphi} = 100\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left[\frac{\varphi_d(j\omega_i) - \varphi_d^*(j\omega_i, \chi_d)}{\varphi_d(j\omega_i)}\right]^2}$$

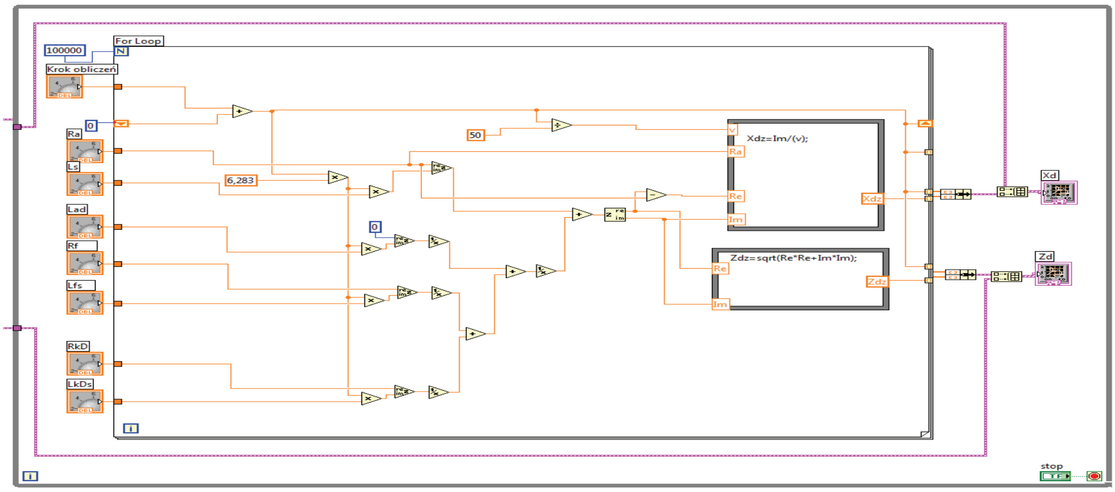
(21) $$\delta_{qm} = 100\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left[\frac{\left|L_q(j\omega_i)\right| - \left|L_q^*(j\omega_i, \chi_q)\right|}{\left|L_q(j\omega_i)\right|}\right]^2}$$

(22) $$\delta_{q\varphi} = 100\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left[\frac{\varphi_q(j\omega_i) - \varphi_q^*(j\omega_i, \chi_q)}{\varphi_q(j\omega_i)}\right]^2}$$

Graphical identification of equivalent circuit parameters

Graphical identification of equivalent circuit parameters is carried out in the graphical programming language *G* in LabView. Graphical programming utilization for manual identification of the electromagnetic parameters will be presented on the example of the spectral magnitude of reactance and impedance characteristics of synchronous machine in d-axis. Figure 3a shows the Block Diagram window of the fragment of *G* graphical programming language for the graphical identification of equivalent circuit parameters. Figure 3b shows the Front Panel window of the visualization magnitude created characteristics of reactance and impedance in the d-axis (view during setting the inductance L_{ad} with the initial non-zero values of excitation and damping circuit parameters).

a)



b)

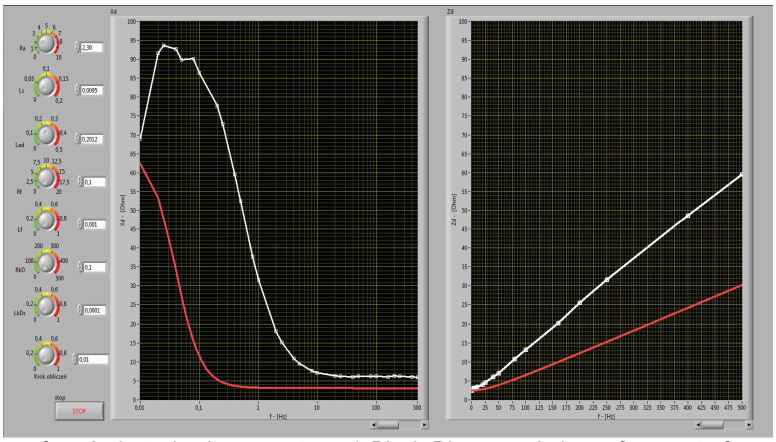


Fig. 3. Graphical identification of equivalent circuit parameters a) Block Diagram window - fragment of graphical programming b) Front Panel window - view during setting the inductance L_{ad}

Figure 3b shows two windows. The window on the left represents the frequency characteristic of spectral reactance magnitude (shown in the diagram of Figure 1) referred to the relation (7). The window on the right represents the frequency characteristic of spectral impedance magnitude (shown in the input terminals in the diagram of Figure 1) referred to the relation (9). Both spectral reactance and impedance magnitude are evaluated by SSFR experimental methods and approximated by means of developed graphical program in LabView (Figure 3).

Resistance R_a was evaluated by technical method, while the leakage inductance L_σ (*Ls* in Figure 3) was calculated from the Potier triangle, based on experimental data of the investigated synchronous machine. In the visible fragment of the developed graphical program in the LabView (window Block Diagram - Figure 3a) was used "for loop", analog numeric knobs used to settings the value of equivalent circuit parameters {R_a, L_σ (*Ls* in Figure 3), L_{ad}, $L_{kD\sigma}$ (*LkDs* in Figure 3), R_{kD}, R_f, $L_{f\sigma}$ (*Lfs* in Figure 3), which set up vertically on the left side}, mathematical functions from Numeric palette, two Formula Nodes and two graph indicators. In this example, magnitude characteristics marked with white lines are obtained in experimental way, while magnitude characteristics marked with red lines are obtained during identification equivalent circuit parameters in LabView. The graphical approximation is started with the introduction of non-zero parameter settings R_a, L_σ, L_{ad}, $L_{kD\sigma}$, R_{kD}, R_f, $L_{f\sigma}$ (as it was shown in Figure 3b), next, successively through another settings to the moment when the magnitude characteristics obtained during identification the best cover the frequency characteristics derived in experimental way.

As already mentioned, on the initial course of the spectral characteristics of the reactance (relationship (7)) has big impact the accuracy of the measured armature resistance R_a. During performing measurements in the SSFR method, the value of armature resistance was changing, especially for low frequencies up to 0.1 Hz (due to the long duration of measurement e. g. for frequency 0.01 Hz the measurement time of one period is 100 s).

To significantly reduce the problem of armature winding resistance changes due to influence of temperature changes on the accuracy of the measurement magnitude characteristics, for low frequencies up to 0.1 Hz, the armature resistance value should be measured in a continuous manner or at least after each measurement for a given frequency. Therefore, for the synchronous machine under test was repeated measurements in the range of 0.01 Hz - 0.1Hz, in which, after each investigation R_a values was measured. These values for individual frequencies were: R_a = 2.3915Ω (0.01 Hz), R_a = 2.3917 Ω (0.02 Hz), R_a = 2.3918 Ω (0.025 Hz), R_a = 2.3916Ω (0.04 Hz), R_a = 2.3915 Ω (0.05 Hz), R_a = 2.3915 Ω (0.08 Hz), R_a = 2.3912Ω (0.1 Hz). For other frequencies the influence of the armature resistance during the investigation is small and with increasing frequency can be neglected. Therefore, for the frequency above 0.1 Hz, assumed value of R_a = 2.39 Ω. For low frequencies (0.01 Hz - 0.1 Hz) introduced a more precise value of the armature resistance, increases significantly the course of the magnitude spectral characteristics of reactance in the d-axis. The situation is shown in Figure 4 (for comparison was taking into account the same analog settings shown in Figure 3).

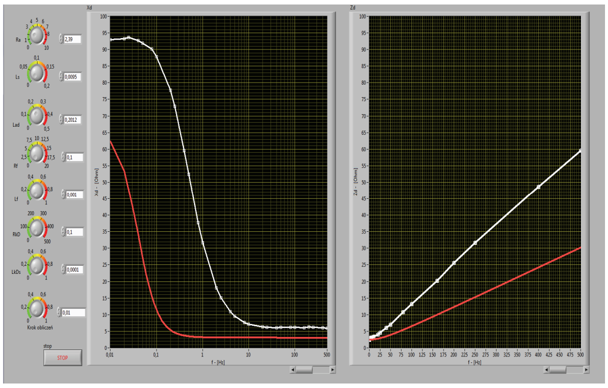


Fig. 4. Front Panel window - graphical identification of equivalent circuit parameters after taking into account a more precise value of the armature resistance changes

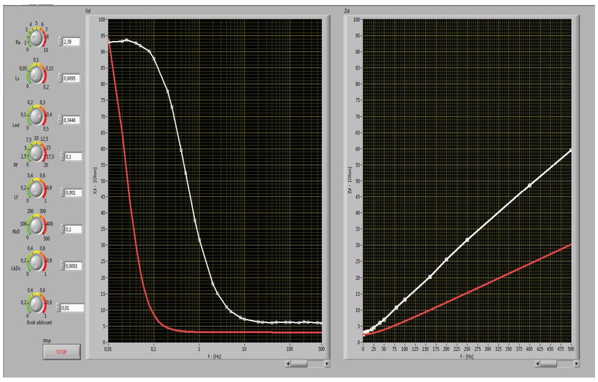


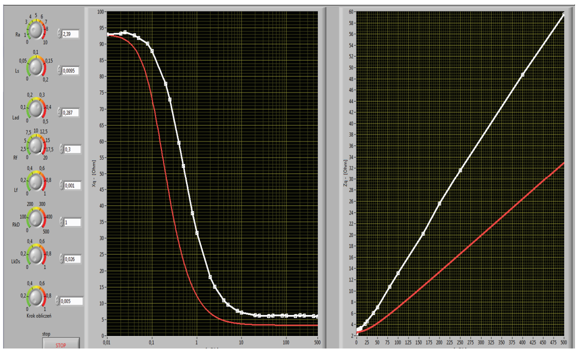
Fig. 5. Front Panel window - influence of small values of excitation and damping equivalent circuit parameters on the course of the frequency characteristics

During searching the equivalent circuit parameters can be continuously viewed the influence of various parameters on the shaping of frequency characteristics. An example of the influence of the excitation R_f, $L_{f\sigma}$ and damping R_{kD}, $L_{kD\sigma}$ circuit parameters on the course of the frequency characteristics is shown in Figure 5.

For low frequencies up to 1 Hz the shape of frequency characteristics is achieved by changing L_σ, L_{ad}, R_f and R_{kD}. Figure 6 shows a graphical view of the R_f and R_{kD} search parameters and their influence on the shape of spectral magnitude of reactance and impedance characteristics of the investigated synchronous machine in d-axis.

Above 1 Hz, the spectral magnitude of reactance and impedance characteristics are shaped using the leakage inductance $L_{f\sigma}$ of excitation circuit and leakage inductance $L_{kD\sigma}$. of damping circuit. For low frequencies below 5Hz increasing R_f value improves the initial value of magnitude reactance characteristic but its too small value is moved in the direction of the lower frequencies ($L_{f\sigma}$ from the assumed range of 0 - 0.1 Hz). For the investigation synchronous machine, growth value of the adjustable inductance $L_{f\sigma}$ improves the course of magnitude characteristics in d-axis for the frequency above 5Hz. Waveforms of spectral impedance obtained from the graphical approximation and from the measurements almost coincide. If we only would like to approximate the course of impedance magnitude - relationship (9), that for the case shown in Figure 6b (the diagrams on the right) it could be considered that the settings of value R_f, $L_{f\sigma}$ and R_{kD} i $L_{kD\sigma}$ are correct.

a)



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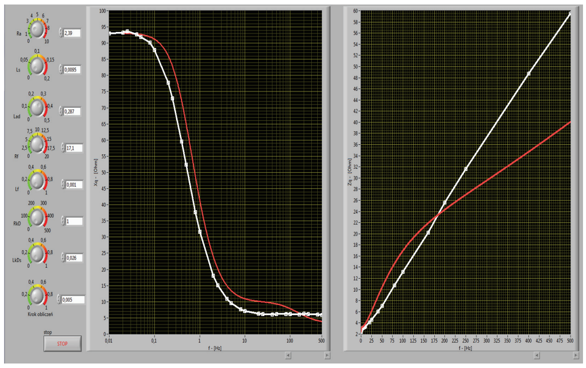

Fig. 6. Front Panel window - graphical identification of equivalent circuit parameters a) influence R_f after taking into account started value $L_{f\sigma}$ = 0.001H, b) too high R_f value with correct R_{kD} and $L_{kD\sigma}$ values

In the case of graphical searching of equivalent circuit parameters of the investigation synchronous machines, better values are obtained in the case of approximation of the frequency spectrum reactance logarithmic scale for the x-axis. The frequency logarithmic scale for the x-axis shows more precisely in all frequency decades. Influence of R_{kD} and $L_{kD\sigma}$ parameters is small on the shape of the magnitude. It shows a strong influence of the excitation circuit on the course frequency characteristics. Figure 7 shows the course of magnitude characteristics in d-axis of the investigation synchronous generator. As a result of the graphical approximation of the frequency characteristics, equivalent circuit parameters were obtained as follows: L_{ad} = 0.287H, R_f = 1.9Ω, $L_{f\sigma}$ = 0.016H, R_{kD} = 1 Ω, $L_{kD\sigma}$ = 0.026 H (parameters R_σ = 2.39 Ω and L_σ= 0.0095 H were obtained experimentally).

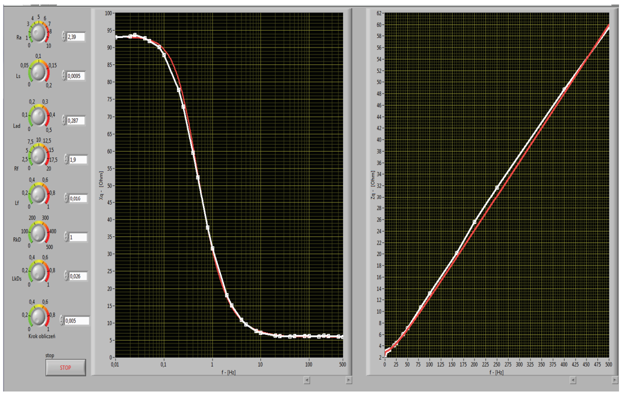

Fig. 7. Front Panel window -the final graphical identification of equivalent circuit parameters L_{ad} = 0.287 H, R_f = 1.9 Ω, $L_{f\sigma}$ = 0.016 H, R_{kD} = 1 Ω, $L_{kD\sigma}$ = 0.026 H, (parameters R_σ = 2.39 Ω and L_σ= 0.0095 H were obtained experimentally)

Above 1 Hz, the spectral magnitude of reactance and impedance characteristics are shaped using the leakage inductance $L_{f\sigma}$ of excitation circuit and leakage inductance $L_{kD\sigma}$. of damping circuit. For low frequencies below 5Hz increasing R_f value improves the initial value of magnitude reactance characteristic but its too small value is moved in the direction of the lower frequencies ($L_{f\sigma}$ from the assumed range of 0 - 0.1 Hz). For the investigation synchronous machine, growth value of the adjustable inductance $L_{f\sigma}$ improves the course of magnitude characteristics in d-axis for the frequency above 5Hz. Waveforms of spectral impedance obtained from the graphical approximation and from the measurements almost coincide. If we only would like to approximate the course of impedance magnitude - relationship (9), that for the case shown in Figure 7b (the diagrams on the right) it could be considered that the settings of value R_f, $L_{f\sigma}$ and R_{kD} i $L_{kD\sigma}$ are correct. In the case of graphical searching of equivalent circuit parameters of the investigation machines, better values are obtained in the case of approximation of the frequency spectrum reactance logarithmic scale for the x-axis. The frequency logarithmic scale for the x-axis shows more precisely in all frequency decades. Influence of R_{kD} and $L_{kD\sigma}$ parameters is small on the shape of the magnitude. It shows a strong influence of the excitation circuit on the course frequency characteristics. Figure 8 shows the course of magnitude characteristics in d-axis of the investigation synchronous generator. As a result of the graphical approximation of the frequency characteristics, equivalent circuit parameters were obtained as follows: L_{ad} = 0.287H, R_f = 1.9Ω, $L_{f\sigma}$ = 0.016H, R_{kD} = 1 Ω, $L_{kD\sigma}$ = 0.026 H (parameters R_σ = 2.39 Ω and L_σ= 0.0095 H were obtained experimentally).

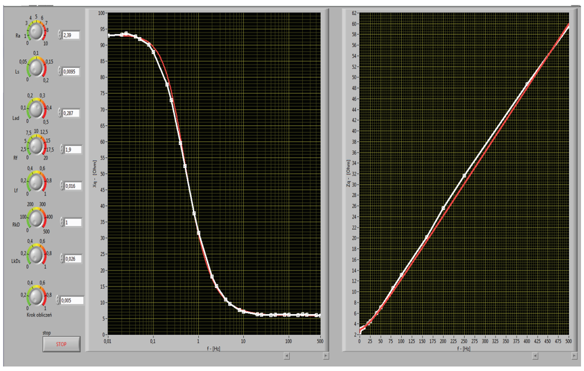

Fig. 8. Front Panel window -the final graphical identification of equivalent circuit parameters L_{ad} = *0.287 H,* R_f = *1.9 Ω,* $L_{f\sigma}$ = *0.016 H,* R_{kD} = *1 Ω,* $L_{kD\sigma}$ = *0.026 H, (*parameters R_σ = *2.39 Ω and* L_σ= *0.0095 H* were obtained experimentally*)*

Graphical identification of time constants

Graphical identification of time constants is carried out in a similar way as the graphical identification of equivalent circuit parameters, for that purpose the similar program was carried out in the graphical programming language in LabView. Graphical identification of four time constants will be presented on the example of the modular characteristics of reactance and impedance of synchronous machine in d-axis. Figure 9 shows the Block Diagram window of the fragment of graphical programming language G for the graphical identification of time constants. The visible fragment of the developed graphical program was based on the structure of Formula Node.

Presented in Figure 9 the fragment of a program as distinguished from the program shown in figure 3a was done exclusively taking into account the structure of Formula Node. This way of programming is much shorter and simpler than using mathematical functions from Numeric palette illustrated in Figure 3a. Writing equations in the structure of Formula Node is similar to programming in Matlab, with the exception of the declaration of variables. However, in the structure of Formula Node is not possible calculations using complex numbers. Therefore, in Figure 3a because of the complex numbers, equivalent circuit parameters of both reactance and impedance spectrum has been built outside the structure of the Formula Node

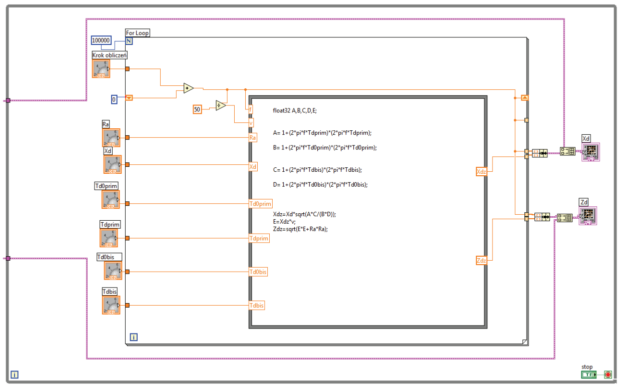

Fig. 9. Block Diagram window - the fragment of G graphical programming language for the graphical identification of time constants

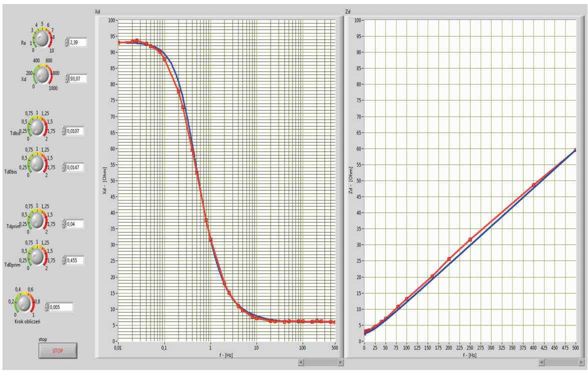

Fig. 10. Front Panel windows of time constants set experimentally

Figure 10 shows views of the Front Panel window of time constants set experimentally and the Front Panel window of time constants set taking into account the same parameters as in Figure 8. Figure 10 and Figure 11 shows two Front Panel windows, in which were sought four time constants T_d'', T_{d0}'', T_d', T_{d0}' – relationship (12). The time constants are used to approximate magnitude reactance and impedance spectral frequency characteristics of the investigated synchronous machine in d-axis. Shown in Figure 10 waveforms were obtained experimentally by setting the analog knobs. Shown in Figure 11 waveforms were obtained by calculation of the analog knobs settings taking into account the parameters L_{ad} = 0.287 H, R_f = 1.9 Ω, $L_{f\sigma}$ = 0.016 H, R_{kD} = 1 Ω, $L_{kD\sigma}$ = 0.026 H i L_σ= 0.0095 H.

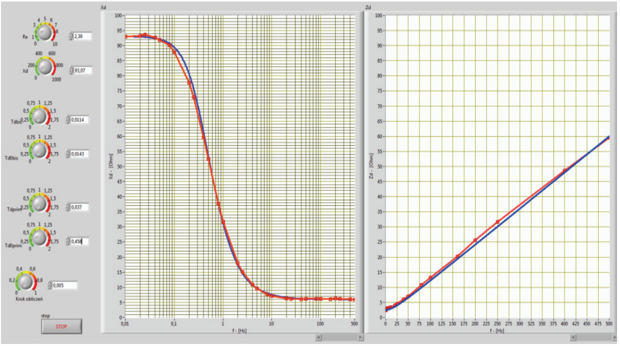

Fig. 11. Front Panel windows of time constants set taking into account the parameters (as in Figure 8)

Table 1 and Table 2 show respectively the values of equivalent circuit parameters and the time constants, which was obtained from the graphical approximation of the spectral frequency characteristics of the investigated synchronous machine in d-axis in LabView. The Table 2 also shown, the time constants calculated on the basis of obtained parameters listed in Table 1. The Table 1 and Table 2 also shown the sum of squared deviations ε_{dm} value and percentage mean square error of magnitude – δ_{dm} that were calculated on the basis of the relationship (14) and (18).

Table 1. Values of equivalent circuit parameters and the sum of squared deviations ε_{dm} value and percentage mean square error of magnitude – δ_{dm}

L_d [H]	R_f [Ω]	$L_{f\sigma}$ [H]	R_{kD} [Ω]	$L_{kD\sigma}$ [H]	ε_{dm} -	δ_{dm} [%]
0.296	1.9	0.016	1	0.026	0.017	0.399

Table 2. Time constants and the sum of squared deviations ε_{dm} value and percentage mean square error of magnitude – δ_{dm}

Calculated values	X_d [Ω]	T_d'' [s]	T_{d0}'' [s]	T_d' [s]	T_{d0}' [s]	ε_{dm} -	δ_{dm} [%]
from parameters - table 1	93.15	0.0114	0.0143	0.0371	0.4581	0.015	0.375
from approximation in LabView	93.07	0.0107	0.0147	0.0400	0.4550	0.017	0.398

Conclusions

The article discusses possibility of using the LabView graphical environment for simple and quick identification of equivalent circuit parameters and time constants on the example of magnitude characteristics of the reactance and impedance spectral synchronous machine in d-axis. For this purpose, two programs were elaborated which by changing the analog knob properties representing the equivalent circuit parameters and time-constants may be shaped the frequency characteristics, approximating the characteristics obtained in an experimental or numerical way. The programs were elaborated on the base of Formula Node structure. The advantage of the structure is fact, that this way of programming is much shorter and simpler than using mathematical functions from Numeric palette. Writing equations in the structure of Formula Node is similar to programming in Matlab, with the exception of the declaration of variables. However, in the structure of Formula Node is not possible calculations using complex numbers.

Presented in the work the graphical way of equivalent circuit parameters and time constant identification allows continuous visualization of the influence demand parameters on the approximated frequency characteristics waveforms. As shown in this work, in the case of graphical searching of equivalent circuit parameters and time constants of the investigation synchronous machine, better values are obtained in the case of approximation of the frequency spectrum reactance logarithmic scale for the x-axis and frequency spectrum impedance linear scale for the x-axis.

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Autors: *DSc. Krzysztof Ludwinek, Politechnika Świętokrzyska, Al. Tysiąclecia PP. 7, 25–314 Kielce, Poland, E–mail: k.ludwinek@tu.kielce.pl*

DSc. Jan Staszak, Politechnika Świętokrzyska, Al. Tysiąclecia PP. 7, 25–314 Kielce, Poland, E–mail: j.staszak@tu.kielce.pl