UDC 621.3.049.001.57:004.457

SIMULATION OF CIRCUITS EXCITED BY PULSE INPUTS IN MATLAB

I. Tomčíková
Technical University in Košice
Park Komenského, 3, Košice, 042 00, Slovakia. E-mail: iveta.tomcikova@tuke.sk

Purpose. The paper deals with the proposal for simulation of dynamic circuits excited by pulse inputs in MATLAB environment. **Methodology.** Simulation of circuits excited by pulse signals can be done in the time domain or in the complex frequency domain, but in the both cases, it is time-consuming activity. In the time domain, finding the complete response of such circuit means to solve a dynamic circuits that have not only resistors but also dynamic elements (inductors and/or capacitors) that can be linear or nonlinear ones. Simulation of these circuits is sometimes very demanding activity, because the equations for such type of circuits take the form of integrodifferential equations with the right-hand side having the form of voltage or current pulses. Another tool for the simulation of linear dynamic circuits is to transform the circuit with its initial conditions directly into the complex frequency domain using the Laplace transform. After transforming of given circuit into the complex frequency domain, it can be dealt with it as if it consisted of sources and resistors only, because the passive elements have impedances, which can be regarded as generalized resistances. **Results.** The formulation of the circuit equations is done using sparse tableau analysis. The complete response is obtained using symbolic calculus that is one of significant advantages of MATLAB. The graphical representation of the input pulse and the output complete responses is shown for given circuit element parameters of three types of circuits. **Originality.** For the first time, we have carried out the integrated research of the circuit simulation and graphical representation of the complete responses for three linear circuits excited by the pulse input signal by solving the problem in MATLAB environment. **Practical value.** Developed solutions could be used for teaching students to the principles of simulation of circuits excited by pulse input in MATLAB environment. References 15, figures 11.

Key words: circuit simulation, sparse tableau analysis, Laplace transform, MATLAB, complete response.

МОДЕЛЮВАННЯ ЕЛЕКТРИЧНИХ КІЛ ПРИ ІМПУЛЬСНОМУ ЗБУРЕННІ В СЕРЕДОВИЩІ MATLAB

І. Томчікова
Технічний університет Кошице
Парк Коменского, 3, Кошице, 042 00, Словаччина. E-mail: iveta.tomcikova@tuke.sk

Роботу присвячено моделюванню динамічних кіл, збурених вхідними імпульсами в середовищі MATLAB. Моделювання кіл, що збурюються імпульсними сигналами, може бути виконано в частотній області або в комплексно-частотній області, проте в обох випадках це є доволі часозатратною операцією. У часовій області задача пошуку повного відгуку такого кола має на увазі розв’язання динамічного кола, що містить не тільки резистори, а й також динамічні елементи (індуктивності та/або ємності), які можуть бути або лінійними, або нелінійними. Моделювання таких кіл у певних випадках є досить вимоглива операція, оскільки вирази для такого типу кіл є інтегродиференціальними, де права частина приймає форму пульсацій струму або напруги. Іншим інструментом для моделювання лінійних динамічних кіл є їх перетворення з існуючими початковими умовами напряму в частотну область за допомогою перетворення Лапласа. Після перетворення даного кола в частотну область його можна аналізувати як таке, що містить лише джерела та опори, оскільки пасивні елементи мають імпеданси, які можуть розглядатися як узагальнені опори. Формування колових рівнянь виконано з використанням аналізу методом розріджених таблиць. Повний відгук отримано з використанням символьних обчислень, що є однією із значних переваг середовища MATLAB. Графічне подання вхідного імпульсу та повного вихідного відгуку було надано для даних параметрів елементів кіл трьох типів.

Ключові слова: схемне моделювання, метод розріджених таблиць, перетворення Лапласа, MATLAB, повний відгук.

PROBLEM STATEMENT. Circuit simulation is an important area of research because is used in a wide spectrum of applications from microelectronic to electric power distribution networks.

Simulation of circuits excited by pulse signals can be done in the time domain or in the complex frequency domain, but in the both cases, it is time-consuming activity.

In the time domain, finding the complete response of such circuit means to solve a dynamic circuits that have not only resistors but also dynamic elements (inductors and/or capacitors) that can be linear or nonlinear ones. Simulation of these circuits is sometimes very demanding activity, because the equations for such type of circuits take the form of integrodifferential equations with the right-hand side having the form of voltage or current pulses.

Another tool for the simulation of linear dynamic circuits is to transform the circuit with its initial conditions directly into the complex frequency domain using the Laplace transform. After transforming of given circuit into the complex frequency domain, it can be dealt with it as if it consisted of sources and resistors only, because the passive elements have impedances, which can be regarded as generalized resistances.

In the complex frequency domain, the problem of finding the complete response of such circuits it could be done by applying the Laplace transform together with the sparse tableau analysis that enables to formulate the circuit equations in systematic and automatic way.

Combining this procedure together with the symbolic computation of MATLAB, there is no difficulty in simulating of dynamic circuits, because formulation of the circuit equations, solving the obtained equations, and taking the inverse Laplace transform are executed in MATLAB environment.

MATLAB greatly reduces the effort demanded to solve the set of algebraic equations and to take the inverse Laplace transform made by a hand, thus there is no difficulty in simulating of the circuits excited by pulse input signals.

The MATLAB environment is very user-friendly with powerful built-in routines that enable to solve a very wide variety of computations. Its great advantage is the fact that the user has not to spend time in learning software but he can spend time in learning the principles of s problem.

Simulation of electric circuits

Simulation of the electric circuits is defined as the process where a computer is used to evaluate a model of the circuit [1–7]. Model of the circuit is a mathematical description of the circuit. The model is described by the input and output relationships that for analog circuits form a set of algebraic and differential equations.

The set of these equations consists of the equations depend on the topology of the circuit and the equations depend on the type of the circuit elements.

The equations, depending on the topology of the circuit, represent how the circuit elements are connected to one another in the circuit. These equations are called the connection equations.

The equations, which depend on the type of the circuit element, describe the voltage-current relationship and they are called the element equations or branch equations.

There exist many techniques for the mathematical description of the circuits there, e.g. mesh current analysis, nodal voltage analysis, direct using of the Kirchhoff's laws. Better ones are those techniques, which enable to formulate equations in systematic and automatic way, e.g. modified nodal analysis and sparse tableau analysis.

Sparse tableau analysis

Sparse tableau analysis is a very useful method for systematic and automatic formulation of the circuit equations for every circuit as well as for dynamic circuits.

In general, circuit equations, setting up using sparse tableau analysis, take form of a system of differential-algebraic equations.

For purely resistive and linear circuit the circuit equations take form of a set of simultaneous linear algebraic equations as it can be seen in next text.

The connection equations are obtained by applying Kirchhoff's laws to the circuit, which leads to the two sets of linear algebraic equations in terms of the element currents and the element voltages. The set of connection equations must be linearly independent.

The first set of the connection equations can be expressed [1]

$$\mathbf{A}\,\mathbf{i} = \mathbf{0}\,, \tag{1}$$

where $\mathbf{i}$ is a matrix of element currents; $\mathbf{A}$ being the node versus branch reduced-incidence matrix, having the coefficients $+1, -1, 0$.

The second set of the connection equations can be expressed in terms of the element voltages using the fundamental loop versus branch incidence matrix. The better way is to write this set of the equations in terms of the element voltages and the node voltages as [1]

$$\mathbf{u} = \mathbf{A}^{\mathrm{T}}\mathbf{v}\,, \tag{2}$$

where $\mathbf{A}^{\mathrm{t}}$ is the transposed matrix $\mathbf{A}$; $\mathbf{u}$ being the element voltage vector; $\mathbf{v}$ being the node voltage vector.

The element equations are related according to the voltage-current characteristics of the elements. For linear circuits containing all the basic linear elements with the exception of dynamic ones, the element equations can be expressed [1]

$$\mathbf{K}_{\mathrm{u}}\mathbf{u} + \mathbf{K}_{\mathrm{i}}\mathbf{i} = \mathbf{s}\,, \tag{3}$$

where $\mathbf{K}_{\mathrm{u}}, \mathbf{K}_{\mathrm{i}}$ are the matrices containing the coefficients that define the linear voltage-current relationships for the circuit elements uniquely; $\mathbf{s}$ being the vector containing the parameters of the independent voltage and current sources.

The element equations for dynamic linear circuits can be expressed [1]

$$\mathbf{K}_{\mathrm{u}}\mathbf{u} + \mathbf{D}_{\mathrm{u}}\mathbf{u}' + \mathbf{K}_{\mathrm{i}}\mathbf{i} + \mathbf{D}_{\mathrm{i}}\mathbf{i}' = \mathbf{s}\,, \tag{4}$$

where $\mathbf{D}_{\mathrm{u}}, \mathbf{D}_{\mathrm{i}}$ are the matrices containing the coefficients that define the voltage-current relationships for the linear dynamic circuit elements uniquely; $\mathbf{u}', \mathbf{i}'$ are the vectors containing the time derivatives of the element voltages and element currents.

Assembling the equations (1), (2), and (3), the sparse tableau equations for linear resistive circuits are constituted. It is convenient to rewrite the sparse tableau equations as a single matrix equation [1]

$$\mathbf{T}\,\mathbf{x} = \mathbf{w}\,, \tag{5}$$

where $\mathbf{T}$ is the square tableau matrix; $\mathbf{x}$ being the vector of unknown variables in sparse tableau analysis; $\mathbf{w}$ being the vector containing zero vectors of appropriate dimensions and the vector $\mathbf{s}$.

Assembling the equations (1), (2), and (4), the sparse tableau equations for linear dynamic circuits are constituted. It is convenient to rewrite the sparse tableau equations as a single matrix equation [1]

$$\mathbf{T}\,\mathbf{x}(t) + \mathbf{D}\,\mathbf{x}'(t) = \mathbf{w}(t)\,, \tag{6}$$

where $\mathbf{D}$ is the square tableau matrix; $\mathbf{x}'$ being the vector of the first order time derivatives of unknown variables.

In case of circuit consisting of nonlinear resistive elements, the sparse tableau equations can be written as [1]

$$\mathbf{T}\,\mathbf{x} + \mathbf{H}\,\mathbf{g}(\mathbf{x}) = \mathbf{w}\,, \tag{7}$$

where $\mathbf{H}$ is a matrix having the coefficients $+1,-1,0$; $\mathbf{g}(\mathbf{x})$ is a vector of functions of all the nonlinear resistive elements.

In case of circuit consisting of nonlinear resistive and linear dynamic elements, the sparse tableau equations take form that can be written [1]

$$\mathbf{T}\,\mathbf{x}(t) + \mathbf{H}\,\mathbf{g}(\mathbf{x}) + \mathbf{D}\,\mathbf{x}'(t) = \mathbf{w}(t)\,. \tag{8}$$

In case of circuit consisting of nonlinear resistive and dynamic elements, the sparse tableau equations take form that can be written [1]

$$\mathbf{T}\,\mathbf{x}(t) + \mathbf{H}\,\mathbf{g}(\mathbf{x}) + \mathbf{D}(\mathbf{x})\,\mathbf{x}'(t) = \mathbf{w}(t)\,, \tag{9}$$

where $\mathbf{D}(\mathbf{x})$ is a matrix that includes contributions from all linear and nonlinear capacitance and inductance terms.

The tableau matrix has many zeros and is said to be sparse. Sparse systems consist of very large systems of equations and they always have to be solved by special routines. Sparse matrix solver is also available as MATLAB built-in routine.

Sparse tableau analysis is most general formulation of the equations describing the circuit because the solution provides the currents through all elements, the voltages across all elements and all nodal voltages simultaneously. It offers a systematic and automatic approach for assembling and solving the circuit equations [1].

Using the equation (6) for simulation of linear dynamic circuit has a disadvantage because the equation (6) takes form of differential-algebraic equations. Nowadays the techniques for solution of such type of equations have not yet fully understood and developed [1].

The better way is to use the Laplace transform, form a set of algebraic equations in the complex frequency domain, solve them and at last use the inverse Laplace transform for return back to the time-domain.

The Laplace transform and the inverse Laplace transform. The Laplace transform for a time-domain function $f(t)$ (must be zero for $t<0$) of a real variable t is [2], [3]

$$\hat{f}(p) = \mathscr{L}\{f(t)\} = \int_0^{\infty} f(t)e^{-pt}\mathrm{d}t\,, \tag{10}$$

where p is a complex variable (meaning the complex frequency; $p=\sigma+\mathrm{j}\omega$), and $\hat{f}(p)$ is a complex frequency function.

The inverse Laplace transform is defined by the integral [2], [3]:

$$f(t) = \frac{1}{2\pi j}\int_{\sigma-j\infty}^{\sigma+j\infty} \hat{f}(p)e^{pt}d\,p\,, \tag{11}$$

where j= $\sqrt{-1}$ is an imaginary unit.

Complex frequency-domain representation of basic circuit elements

The complex frequency-domain representation of basic circuit elements is obtained by taking the Laplace transform of their voltage-current relationships.

The voltage-current relationship for a linear resistor having resistance R in the complex frequency domain [2], [3]

$$\hat{u}(p) = R\,\hat{i}(p)\,, \tag{12}$$

where $\hat{u}(p)$ is the Laplace transform of voltage $u(t)$ across the resistor, and $\hat{i}(p)$ is the Laplace transform of current through the resistor.

The voltage-current relationship for a linear inductor having inductance L in the complex frequency domain [2], [3]:

$$\hat{u}(p) = pL\hat{i}(p) - Li(0)\,, \tag{13}$$

where $\hat{u}(p)$ is the Laplace transform of voltage $u(t)$ across the inductor; $\hat{i}(p)$ is the Laplace transform of current through the inductor, and $i(0)$ is the initial condition.

The equation (13) is used to represent the linear inductor in the complex frequency domain as the series connection of two circuit elements that corresponds to the sum of voltages on the right-hand side of (13).

The voltage-current relationship for the coupled inductors having self-inductances L_1, L_2 and mutual inductance M in the complex frequency domain [2], [3]:

$$\begin{bmatrix}\hat{u}_1(p)\\ \hat{u}_2(p)\end{bmatrix} = \begin{bmatrix} pL_1, & \pm pM\\ \pm pM, & pL_2\end{bmatrix}\begin{bmatrix}\hat{i}_1(p)\\ \hat{i}_2(p)\end{bmatrix} - \begin{bmatrix} L_1, & \pm M\\ \pm M, & L_2\end{bmatrix}\begin{bmatrix} i_1(0)\\ i_2(0)\end{bmatrix}, \tag{14}$$

where $\hat{u}_1(p), \hat{u}_2(p)$ is the Laplace transform of voltages $u_1(t), u_2(t)$ across the inductors L_1, L_2 respectively; $\hat{i}_1(p), \hat{i}_2(p)$ is the Laplace transform of currents through the inductors L_1, L_2 respectively; $i_1(0), i_2(0)$ are the initial conditions.

The voltage-current relationship for a linear capacitor having capacitance C in the complex frequency domain [2], [3]:

$$\hat{u}(p) = \frac{1}{pC}\hat{i}(p) + \frac{u(0)}{p}\,, \tag{15}$$

where $\hat{u}(p)$ is the Laplace transform of voltage $u(t)$ across the capacitor; $\hat{i}(p)$ is the Laplace transform of current through the capacitor; $u(0)$ is the initial condition.

The equation (15) is used to represent the linear capacitor in the complex frequency domain as the series connection of two circuit elements that corresponds to the sum of voltages on the right-hand side of (15).

Independent voltage and current sources are represented by the Laplace transform of their voltages and currents.

Dependent linear voltage and current sources are represented by the Laplace transform of their voltages and currents.

The ideal operational amplifier operates the same way in the complex frequency domain as it does in the time domain, thus the Laplace transform of its operating conditions is applied in the complex frequency domain.

Complex frequency-domain representation of sparse tableau equations

Applying the Laplace transform to the equations (1), (2), (3), and (4) the following equations are obtained:

$$\mathbf{A}\hat{\mathbf{i}} = \mathbf{0}, \tag{16}$$

where $\hat{\mathbf{i}}$ is a vector of the complex frequency-domain representation of branch currents of the circuit,

$$\hat{\mathbf{u}} = \mathbf{A}^{\mathrm{T}}\hat{\mathbf{v}}, \tag{17}$$

where $\hat{\mathbf{u}}$ is a vector of the complex frequency-domain representation of branch voltages of the circuit; $\hat{\mathbf{v}}$ being a vector of the complex frequency domain of node voltages of the circuit,

$$\hat{\mathbf{K}}_{\mathrm{u}}\hat{\mathbf{u}} + \hat{\mathbf{K}}_{\mathrm{i}}\hat{\mathbf{i}} = \hat{\mathbf{s}}, \tag{18}$$

where $\hat{\mathbf{K}}_{\mathrm{u}}$, $\hat{\mathbf{K}}_{\mathrm{i}}$ are the matrices containing the coefficients that define the complex frequency domain linear voltage-current relationships for the circuit elements uniquely; $\hat{\mathbf{s}}$ being the vector containing the complex frequency-domain parameters of the independent voltage and current sources and the initial conditions.

The sparse tableau equations expressed as the single matrix equation in the complex frequency domain using the Laplace transform is

$$\hat{\mathbf{T}}\hat{\mathbf{x}} = \hat{\mathbf{w}}, \tag{19}$$

where $\hat{\mathbf{T}}$ is the square tableau matrix expressed in the complex frequency domain; $\hat{\mathbf{x}}$ being the vector of unknown variables in the complex frequency domain; $\hat{\mathbf{w}}$ being the vector containing zero vectors of appropriate dimensions and the vector $\mathbf{s}$ in the complex frequency domain.

Pulse signal and its description in the time domain and the complex frequency domain

In general, pulse signal $f_{\mathrm{signal}}(t)$ can be expressed as a sum of elementary functions [3]:

$$f_{\mathrm{signal}}(t) = \sum_{k=1}^{N} f_{\mathrm{signal}}^{(k)}(t), \tag{20}$$

where $f_{\mathrm{signal}}^{(k)}(t)$ is the *k*-th elementary function of time; *N* is the number of the elementary functions, which are necessary for description of given pulse signal.

The Laplace transform of the pulse signal $f_{\mathrm{signal}}(t)$ is given [2], [3]:

$$\hat{f}_{\mathrm{signal}}(p) = \sum_{k=1}^{N} \hat{f}_{\mathrm{signal}}^{(k)}(p), \tag{21}$$

where $\hat{f}_{\mathrm{signal}}^{(k)}(p)$ is the Laplace transform of the pulse $f_{\mathrm{signal}}^{(k)}(t)$, working on the presumption that $f_{\mathrm{signal}}^{(k)}(t)$ is zero for all $t < 0$.

EXPERIMENTAL PART AND RESULTS OBTAINED. All the steps for finding the complete response of dynamic circuits to the pulse input can be easily executed using the MATLAB environment.

In next text, the proposed procedure for circuit simulation in MATLAB environment is applied to three representative circuits and the output of the simulation is the graphical representation of obtained circuit responses. The examples comprise three circuits excited by the square pulse input. The first circuit is the series *RL* circuit, the second one is the series *RC* circuit, and the last one is the second-order *RLC* circuit.

The Example A. The circuit of this example is *RL* circuit given in Fig. 1 – left and the input voltage of the voltage source is shown in Fig. 1 – right. It is supposed that all the initial conditions are equal zero.

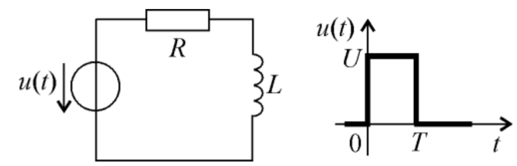

Figure 1 – The *RL* circuit and the input voltage

The given signal has the following parameters: the amplitude *U* and the duration T. The aim is to find the complete response of the circuit to given input in MATLAB environment.

The input of the circuit is the voltage pulse specified graphically by the plot thus it is necessary to express the time domain representation of the pulse during the time T. The equation of the pulse voltage is

$$u(t) = U.1(t) - U.1(t-T). \tag{22}$$

Since the circuit is linear, the principle of superposition can be used and find the responses to $U.1(t)$ and to $-U.1(t-T)$.

The Laplace transform of (22) is

$$\hat{u}(p) = \frac{U}{p}\left(1 - e^{-pT}\right). \tag{23}$$

The complete response of the current $i(t)$ for $t > 0$ is

$$i(t) = \mathscr{L}\left\{\frac{1}{R + pL}\frac{U}{p}\left(1 - e^{-pT}\right)\right\}. \tag{24}$$

The complete response of the voltage across the resistor $u_R(t)$ for $t > 0$ is

$$u_R(t) = \mathscr{L}\left\{\frac{R}{R+pL}\frac{U}{p}\left(1-e^{-pT}\right)\right\}. \qquad (25)$$

The complete response of the voltage across the inductor $u_L(t)$ for $t>0$ is

$$u_L(t) = \mathscr{L}\left\{\frac{pL}{R+pL}\frac{U}{p}\left(1-e^{-pT}\right)\right\}. \qquad (26)$$

The current and the element voltages are found after running the program composed in MATLAB environment using the sparse tableau analysis, the Laplace transform, and the inverse Laplace transform.

The corresponding graphical representations of all the responses of the circuit are given for the following values of the circuit parameters: T = 1 s; U = 2 V, and three different sets of values of R, L for passive circuit elements:

a) R = 0.1 Ω, L = 0.1 H, ($\tau/T = 1$, where τ is the time constant);

b) R = 1 Ω, L = 0.1 H, ($\tau/T << 1$);

c) R = 0.01 Ω, L = 0.1 H, ($\tau/T >> 1$),

and they are depicted in the figures Fig. 2, Fig. 3, and Fig. 4.

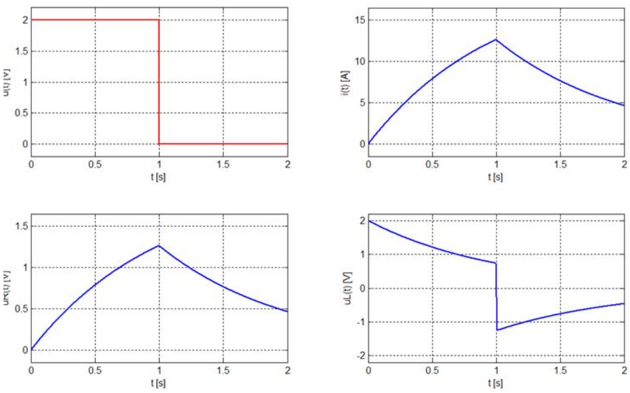

Figure 2 – MATLAB plot of input pulse and complete response of the *RL* circuit for case a)

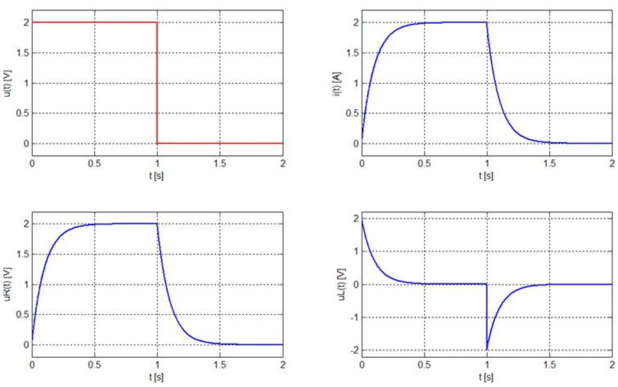

Figure 3 – MATLAB plot of input pulse and complete response of the *RL* circuit for case b)

It can be seen that waveform of the voltage across the inductor (Fig. 3) is good derivative of the input signal, because it has the form of two very short exponential pulses of the same amplitude but the opposite signs. In this case, the time constant of the given circuit must be much less than the duration T of the input voltage pulse.

The waveform of the voltage across the resistor in Fig. 4, the case when the time constant of the given circuit is greater than the duration T of the pulse, is a good integration of the input signal.

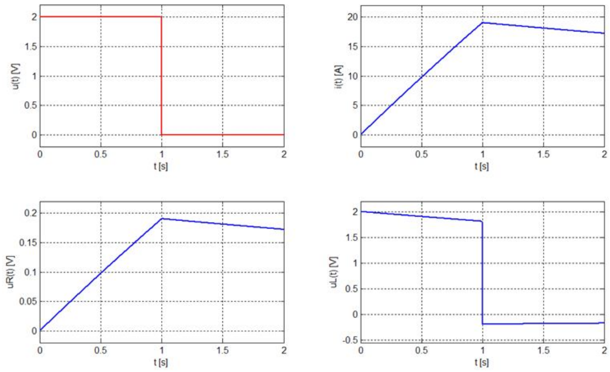

Figure 4 – MATLAB plot of input pulse and complete response of the *RL* circuit for case c)

The Example B. The circuit of this example is *RC* circuit shown in Fig. 5 (left). The voltage, $u(t)$, of the voltage source is the pulse square wave shown in Fig. 5 (right) applied at time $t=0$. The aim is to find all the element currents and voltages for $t>0$ if the initial condition is equal zero.

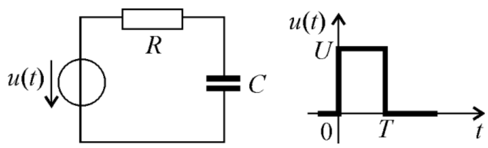

Figure 5 – The *RC* circuit and the input voltage

Since the plot specifies the input of the circuit graphically, at first it is necessary to express the time domain representation of the input voltage. The equation for the square pulse is given by the equation (22). The results for the problem given in the *Example B* were obtained by running the program composed in MATLAB environment.

The corresponding graphical representations of all the responses of the circuit are given the following values of the circuit parameters: T = 1 s; U = 2 V; three different sets of values of R, C :

a) R = 1 MΩ, C = 1 μF, ($\tau/T = 1$);

b) R = 100 kΩ, C = 1 μF, ($\tau/T << 1$);

c) R = 10 MΩ, C = 1 μF, ($\tau/T >> 1$),

and they are depicted in the figures Fig. 6, Fig. 7, and Fig. 8.

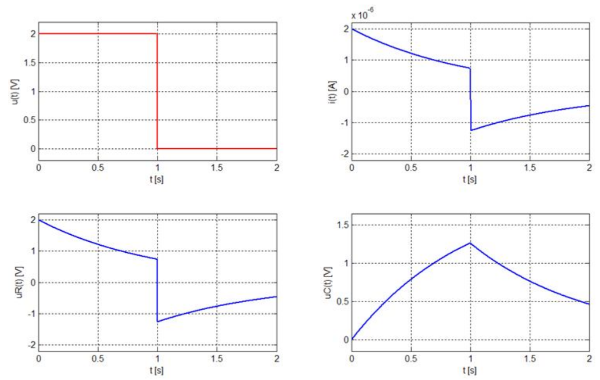

Figure 6 – MATLAB plot of input pulse and complete response of the *RC* circuit for case a)

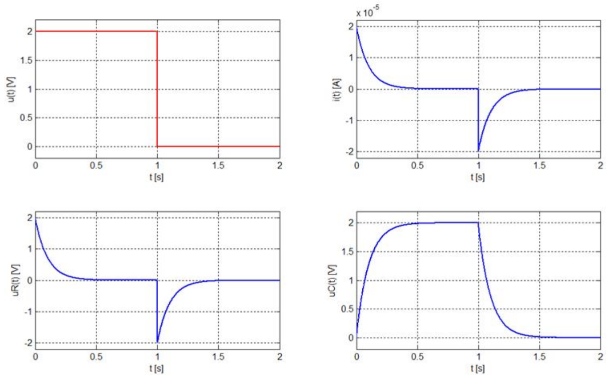

Figure 7 – MATLAB plot of input pulse and complete response of the *RC* circuit for case b)

The waveform of the voltage across the resistor (Fig. 7) is good derivative of the input signal, because it has a form of two short exponential pulses, which have the same amplitude but the opposite signs. In this case, the time constant is smaller than the duration T of the pulse.

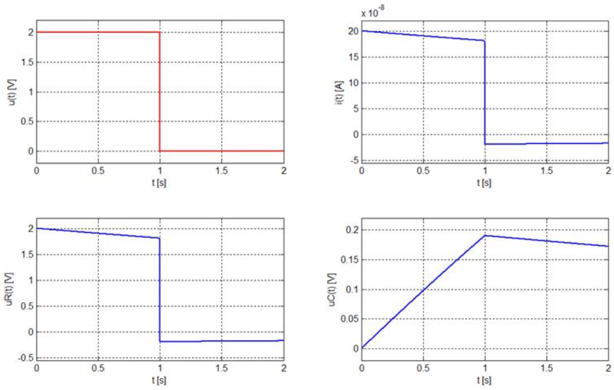

Figure 8 – MATLAB plot of input pulse and complete response of the *RC* circuit for case c)

It is evident that the waveform of the voltage across the capacitor in Fig. 8 is good integration of the input signal. It is the case when the time constant of the given circuit is greater than the duration T of the input voltage pulse.

The Example C. The circuit of this example is the second-order circuit shown in Fig. 9 (left). The voltage, $u(t)$, of the voltage source is the square pulse shown in Fig. 9 (right) applied at time $t = 0$. The aim is to find all the element currents and voltages for $0 < t < 3\,\text{s}$.

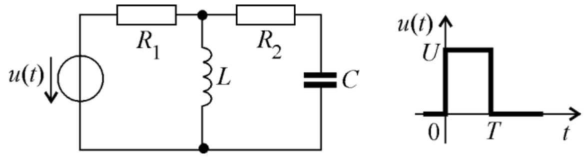

Figure 9 – The *RLC* circuit and the input voltage

After running the program composed in MATLAB environment, the graphical representations of all the element currents and voltages of the circuit given in *Example C* are obtained.

They are depicted in the figures Fig. 10 and Fig. 11 for the following element parameters: T = 1 s; U = 10 V; R_1 = 1 Ω; R_2 = 1 Ω; L = 0.25 H; C = 1/24 F.

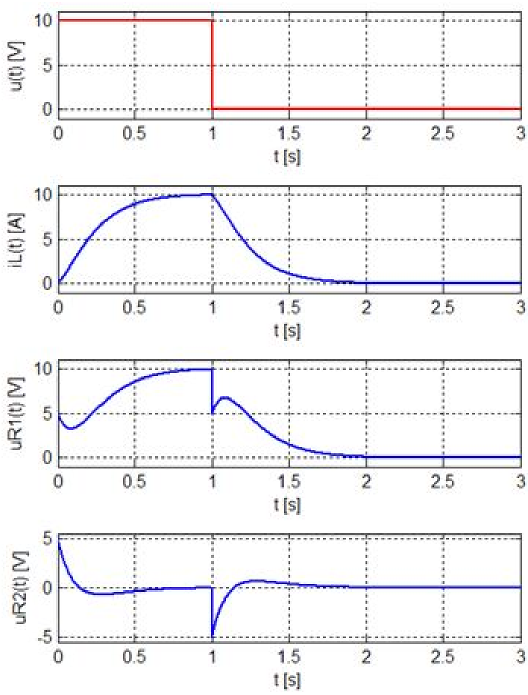

Figure 10 – MATLAB plot of input pulse and complete response of the *RLC* circuit (part 1)

Since the source is zero for all negative time, the initial conditions for given circuit are zero. All the responses of given circuit for $0 < t < 3\,\text{s}$ are due to the application of two-step constant sources, the first of value U occurring at time $t = 0$ s and the second equal to $-U$ occurring at time $t = 1$ s. It is seen that the responses have the form, which corresponds to overdamped case with two distinct real characteristic roots, and they consist of two waves that have the same values but the opposite signs for the intervals $0 \text{ s} < t < 1 \text{ s}$ and $1 \text{ s} < t < 2 \text{ s}$.

The current flowing through the inductor and the voltage across the capacitor is continuous over time. It is seen that the voltage across the resistors, the voltage across the inductor, the current flowing through resistors, and capacitor change instantaneously in the time when the second source of two-step constant source is applied.

Obtained results are in accordance with the fact that the simulated circuit of *Example C* is the second-order circuit excited by the pulse input consisting of two constant sources applied in two different times.

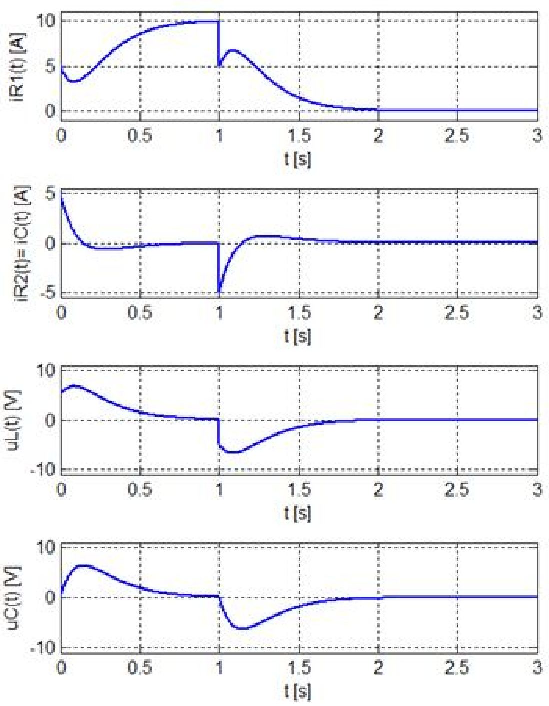

Figure 11 – MATLAB plot of input pulse and complete response of the *RLC* circuit (part 2)

CONCLUSIONS. The circuit simulation and graphical representation of the complete responses for three linear circuits excited by the pulse input signal are found by solving the problem in MATLAB environment.

The program composed in MATLAB environment has many advantages over the calculus made by hand. It saves a lot of time, effort and provides the very simple visualization of the obtained results.

The elapsed time that represents the processing and execution of the instructions in the composed MATLAB program for given representative examples of the circuit analysis takes very short time.

It is evident that the effort demanded to solve such type of problems is greatly reduced because it is not necessary to solve the set of algebraic equations and to take the direct and inverse Laplace transform.

Since the MATLAB environment is very user-friendly, the user has not to spend time in learning software but he can spend time in learning the fundamental principles of a solved problem.

ACKNOWLEDGEMENT. *We support research activities in Slovakia / Project is co-financed from EU funds. This paper was developed within the Project "Centre of Excellence of the Integrated Research & Exploitation the Advanced Materials and Technologies in the Automotive Electronics", ITMS 26220120055.*

REFERENCES

1. Najm, F.N. (2010), Circuit Simulation, *John Wiley & Sons, Inc.,* New Yersey.
2. Dorf, R.C. and Svoboda, J.A. (2007), Introduction to Electric Circuits, *John Wiley & Sons, Inc.*, New Yersey.
3. Mayer, D. (1978), Introduction to Theory of Electric Circuits, *SNTL/ALFA*, Prague.
4. Vlach, J. and Singhal, K. (1994), Computer Methods for Circuit Analysis and Design, *Van Nostrand Reinhold Co.,* ISBN 978-0442011949, New York.
5. Myslík, J. (1984), Solved Examples from Analysis of Electric Circuits, *SNTL/ALFA*, Prague.
6. Tomčíková, I. (2013), Simulation of Circuits Containing Operational Amplifiers in MATLAB, *Electromechanical and energy saving systems*, ISSN 2072-2052, Vol. 22, no. 2, pp. 348–350.
7. Tomčíková, I. (2015), Complete Response of Linear Circuits to Pulse Inputs in MATLAB, *SSIEE 2015, Proceeding of scientific and student's works in the field of Industrial Electrical Engineering,* ISBN 978-80-553-2151-6, Vol. 4, pp. 198–199.
8. Tomčíková, I. (2011), Symbolic Analysis of Linear Electric Circuits, *Technical Computing Prague 2011, 19th Annual Conference Proceedings, 2011,* ISBN 978-80-7080-794-1, p. 116.
9. Dziak, J. (2013), Selection of method for computer-based circuits simulation, *SCYR 2013, 13th Scientific Conference of Young Researchers, Proceedings from conference,* ISBN 978-80-553-1422-8, Košice, Slovakia, pp. 398–400.
10. Dziak, J. (2014), Linear circuit simulation using MATLAB and modeling of nonlinear elements, SCYR 2014, *14th Scientific Conference of Young Researchers, Proceedings from conference,* ISBN 978-80-553-1714-4, Košice, Slovakia, pp. 70–71.
11. Dziak, J. (2015), Models of nonlinear elements and nonlinear circuit simulation using MATLAB, SCYR 2015, *15th Scientific Conference of Young Researchers, Proceedings from conference,* ISBN 978-80-553-2130-1, Košice, Slovakia, pp. 86–87.
12. MATLAB 7 – User's Guide – Mathematics (2009), *MathWorks.*

13. MATLAB 7 – User's Guide – Programming Fundamentals (2009), *MathWorks.*

14. MATLAB 7 – User's Guide – Programming Tips (2009), *MathWorks.*

15. MATLAB 7 – User's Guide – Symbolic Math Toolbox (2012), *MathWorks.*

МОДЕЛИРОВАНИЕ ЭЛЕКТРИЧЕСКИХ ЦЕПЕЙ ПРИ ИМПУЛЬСНОМ ВОЗМУЩЕНИИ В СРЕДЕ MATLAB

И. Томчикова

Технический университет Кошице

Парк Коменского, 3, Кошице, 042 00, Словакия. E-mail: iveta.tomcikova@tuke.sk

Работа посвящена моделированию динамических цепей, возмущенных/возбужденных входными импульсами в среде MATLAB. Моделирование возмущающихся цепей импульсными сигналами может быть выполнено в частотной области или в комплексно-частотной области, однако в обоих случаях это является довольно времязатратной операцией. Во временной области задача поиска полного отзыва такой цепи подразумевает решение динамической цепи, содержащей не только резисторы, но также динамические элементы (индуктивности и/или емкости), которые могут быть или линейными, или нелинейными. Моделирование таких цепей в определенных случаях достаточно требовательная операция, поскольку выражения для такого типа цепей является интегродифференциальными, где правая часть принимает форму пульсаций тока или напряжения. Другим инструментом для моделирования линейных динамических цепей является их преобразование с существующими начальными условиями направления в частотную область с помощью преобразования Лапласа. После преобразования данной цепи в частотную область ее можно анализировать как содержащую только источники и сопротивления, поскольку пассивные элементы имеют импеданс, которые могут рассматриваться как обобщенные сопротивления. Формирование круговых уравнений выполнено с использованием анализа методом разреженных таблиц. Полный отзыв, полученный с использованием символьного вычисления, является одной из значительных преимуществ среды MATLAB. Графическое представление входного импульса и полного выходного отклика было предоставлено для данных параметров элементов цепей трех типов.

Ключевые слова: схемное моделирование, метод разреженных таблиц, преобразование Лапласа, MATLAB, полный ответ.

Стаття надійшла 18.05.2016.