ENGINEERING.
IMPACTO CIENTÍFICO EDITORA

PHYSICAL SYSTEMS MODELING - RLC CIRCUIT GRAPHICAL SIMULATOR

MODELAGEM DE SISTEMAS FÍSICOS - SIMULADOR GRÁFICO DE CIRCUITOS RLC

MODELADO DE SISTEMAS FÍSICOS – SIMULADOR GRÁFICO DE CIRCUITOS RLC

https://doi.org/10.56238/edimpacto2025.086-005

Gabriel Fontini Ferreira[1], João Gabriel Villwock[2], Flávio Luiz Rossini[3]

ABSTRACT

This article presents the user manual for the application entitled: Modelagem de Sistemas Físicos - Simulador Gráfico de Circuitos RLC (SimuRLC), developed to assist students in the field of Electrical and Electronic Engineering in understanding the mathematics for analyzing RLC circuits and the application of the Laplace Transformation involved in the process. This topic is highly relevant in the current context of accelerated digital transformation, where connectivity and the advancement of the Internet are key-factors. In the industrial sector, this evolution requires the use of mathematical models as a tool to face challenges in production environments more efficiently. The manual is divided into stages: (i) Application installation; (ii) Presentation of the Laplace Transformation used; (iii) Presentation of the application interface; (iv) Case study of a circuit applied in the application; (v) Graphical validation via LTspice®. The results obtained through simulations in the application, when compared to other software, indicate good agreement and numerical stability. The conclusions obtained offer important contributions to the academic field, providing useful information for the resolution and analysis for passive RLC circuits.

Keywords: Electric Circuits. Switched RLC Electric Circuits. Laplace Transform. MATLAB®. LTspice®.

RESUMO

Este artigo apresenta o aplicativo denominado: Modelagem de Sistemas Físicos - Simulador Gráfico de Circuitos RLC (SimuRLC), esse foi desenvolvido com o objetivo de auxiliar estudantes da área de Engenharia Elétrica e Eletrônica, quanto a compreensão da matemática para análise de circuitos RLC, e a aplicação da Transformada de Laplace envolvida no processo. Este tema é de grande relevância no contexto atual de transformação digital acelerada, onde a conectividade e o avanço da Internet são fatores-chave. No setor industrial, essa evolução necessita do uso de modelos matemáticos como ferramenta para

[1] Undergraduated student in Electronic Engineering. Universidade Tecnológica Federal do Paraná (UTFPR-CM). E-mail: gabrielfontini@alunos.utfpr.edu.br
[2] Undergraduated student in Electronic Engineering. Universidade Tecnológica Federal do Paraná (UTFPR-CM). E-mail: joaovillwock@alunos.utfpr.edu.br
[3] Professor. Universidade Tecnológica Federal do Paraná. Paraná, Brazil. E-mail: flrossini@utfpr.edu.br
Orcid: 0000-0002-6159-4469 Lattes: 8616413126997528

enfrentar desafios em ambientes de produção com mais eficiência. Dividiu-se o artigo em etapas sendo elas: (i) Instalação do aplicativo; (ii) Apresentação da Transformada de Laplace utilizada; (iii) Apresentação da interface do aplicativo; (iv) Estudo de caso de um circuito aplicado no aplicativo; (v) Validação gráfica via LTspice®. Os resultados obtidos indicam por meio das simulações no aplicativo ao compará-los outros softwares indicam boa concordância e estabilidade numérica. As conclusões obtidas oferecem contribuições importantes para a área acadêmica, fornecendo informações úteis para a resolução e análise de circuitos passivos RLC chaveados.

Palavras-chave: Circuito Elétrico. Circuito Chaveado. Transformada de Laplace. MATLAB®. LTspice®.

RESUMEN
Este artículo presenta el manual de usuario de la aplicación Modelagem de Sistemas Físicos - Simulador Gráfico de Circuitos RLC (SimuRLC) desarrollada para ayudar a los estudiantes de Ingeniería Eléctrica y Electrónica a comprender las matemáticas para el análisis de circuitos RLC y la aplicación de la transformada de Laplace. Este tema es de gran relevancia en el contexto actual de rápida transformación digital, donde la conectividad y el avance de Internet son factores clave. En el sector industrial, esta evolución requiere el uso de modelos matemáticos como herramienta para afrontar con mayor eficiencia los retos de los entornos de producción. El manual se divide en las siguientes etapas: (i) Instalación de la aplicación; (ii) Presentación de la Transformada de Laplace utilizada; (iii) Presentación de la interfaz de la aplicación; (iv) Estudio de caso de un circuito aplicado en la aplicación; (v) Validación gráfica mediante LTspice®. Los resultados obtenidos mediante simulaciones en la aplicación, comparados con otros programas, muestran una buena concordancia y estabilidad numérica. Las conclusiones obtenidas aportan información valiosa al ámbito académico, proporcionando datos útiles para la resolución y el análisis de circuitos RLC passivos.

Palabras clave: Circuito Eléctrico. Circuito Eléctrico RLC Chaveado. Transformada de Laplace. MATLAB®. LTspice®.

1 INTRODUCTION

In engineering, mathematical modeling plays a fundamental role in representing real systems through equations or systems of equations. These enable the analysis of systems, whether linear or not, as is the case with electrical and electronic circuits ([1]; [2]; [3]; [4]; [5]). These models form the mathematical basis for more detailed investigations into the behavior of different types of systems ([5]; [6]; [7]; [8]; [9]), with RLC circuits being one line of research.

In general, modeling in engineering consists of translating physical, mechanical, electrical, biological, or other phenomena into mathematical representations that describe their behavior over time or in steady state ([10]; [11]; [12]; [13]). This step is essential for understanding, predicting, and optimizing the operation of these systems, allowing engineers to design more efficient solutions, perform more accurate simulations, and validate theoretical hypotheses before practical implementation. Thus, modeling acts as a link between theory and real-world applications, serving as support for analysis, design, control, and decision-making in different areas of engineering ([7]; [13]; [14]; [15]; [16]; [17]).

Modeling RLC circuits is essential to understanding how these circuits behave under different operating conditions. In this scenario, the Laplace Transform becomes an indispensable tool, facilitating the treatment of sets of differential equations, transforming them into algebraic equations ([2]; [14]; [18]; [19]; [20]).

The Laplace Transform is a powerful mathematical technique applied in the analysis of linear systems from the time domain to the frequency domain ([10]; [15]; [21]). Its importance is mainly due to the difficulty in dealing with differential equations in system modeling. Through it, it is possible to clearly separate the input, the output, and the system. Another point of great importance is that the Laplace Transform converts differential equations into algebraic equations, which makes mathematical calculations simpler to perform ([16]; [17]; [18]; [21]; [22]; [23]; [24]; [25]).

The Modeling of Physical Systems - Graphical Simulator of RLC Circuits (SimuRLC) application aims to optimize the graphical construction process associated with the waveforms corresponding to each circuit element, as a form of support for analysis. The application is structured in two tabs: (*i*) circuit topology; (*ii*) waveforms. In tab (*i*), the user must select one of the six available RLC circuit models, which can have one, two or three loops. At this stage, it is possible to define the values of the circuit component, as well as to set the simulation time as desired. In tab (*ii*), the user must initially select the number of graphs to be displayed and then select the electrical quantities to be analyzed from the listed options. Thus, the application constitutes a stable didactic and computational tool, capable of integrating theory and practice in the study of RLC electrical circuits and their analysis through the Laplace Transform.

2 THEORETICAL FOUNDATIONS

2.1 LAPLACE TRANSFORM

The Laplace Transform is a linear operator widely used in systems analysis, applicable to continuous-time functions. Its main objective is to convert a time-dependent function into a function in the frequency domain, which simplifies the process of solving and analyzing the system, transforming it from the time domain to the frequency domain. By definition, the Laplace Transform of a function is expressed as follows ([14]; [26]; [29]):

$$X(s) = \int_{-\infty}^{\infty} x(t)e^{-st}dt \qquad (1)$$

Base on this definition, it is possible to recover the original function using the Inverse Laplace Transform. This operation is represented as follows:

$$x(t) = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} X(s)e^{st}ds \qquad (2)$$

Where:

c represents a real constant that guarantees the convergence of the integral in Equation (1) ([14]; [27]; [29]).

During the application of the Laplace Transform, it is common to use certain properties that make the calculations simpler and avoid extensive mathematical operations. Below, some of the properties used to perform the mathematical development will be shown.

2.1.1 Time shift property

According to this property, if a function has a Laplace Transform, then for any time delay, we obtain ([29]):

$$x(t-t_0) \leftrightarrow X(s)e^{-st_0} \qquad (3)$$

Considering the use of the unit step function, the property can be described as:

$$x(t)u(t) \leftrightarrow X(s)\# \quad (4)$$

And, in case there is a time shift of :t_0

$$x(t-t_0)u(t-t_0) \leftrightarrow X(s)e^{-st_0}\# \quad (5)$$

2.1.2 Time derivative property

According to this property, the Laplace Transform of derivative of a function over time is given by ([29]):

$$\frac{dx(t)}{dt} \leftrightarrow sX(s) - x(0)\# \quad (6)$$

Where:

$x(0)$is the initial condition of the function immediately before $t = 0$. This property can be extended to higher-order derivatives, based on the concept of successive derivatives.

2.1.3 Time integral property

Finally, the Laplace Transform also has a useful property for integrals. If $x(t)$has Laplace Transform , then $X(s)$([29]):

$$\int_0^t x(\tau)\,d\tau \leftrightarrow \frac{X(s)}{s} - \frac{X(0)}{s}\# \quad (7)$$

This property allows transforming integrals into simple algebraic expressions in the domain of , thus facilitating the solution of problems involving the accumulation of signs over time.s

2.1.4 Other properties of laplace transforms

In addition to the transforms presented above, there are other Laplace Transforms that are very useful in Engineering, which will be presented below in the Laplace Transform table (Table 1):

Table 1

Laplace Transforms

$x(t)$	$X(s)$
1	$\frac{1}{s}$
t	$\frac{1}{s^2}$
t^n	$\frac{n!}{s^{n+1}}$
e^{at}	$\frac{1}{s-a}$
$cos\ at$	$\frac{s}{s^2+a^2}$
$sin\ at$	$\frac{s}{s^2-a^2}$
$cosh\ at$	$\frac{s}{s^2-a^2}$
$sinh\ at$	$\frac{a}{s^2-a^2}$

Source: [29].

2.2 INITIAL AND FINAL VALUE THEOREM

2.2.1 Initial value theorem

The Initial Value Theorem establishes a relationship between the initial value of a function in time and its Laplace Transform, being expressed as follows ([28]; [29]):

$$f(0^+) = \lim_{s\to\infty} sF(s) \qquad (8)$$

This theorem allows us to determine the value of the variable immediately after $t = 0$, that is, immediately after the application of an excitation or change in the circuit. The theorem is especially useful in circuits with capacitors and inductors, since the initial value of voltages and currents is associated with the initial conditions of energy stored in these elements

However, the Initial Value Theorem is valid only if does $f(t)$not have infinite impulses or discontinuities at the initial instant ([28]; [29])element.

2.2.2 Final value theorem

The Final Value Theorem allows us to determine the steady-state value of a function $f(t)$, from its Laplace Transform, and is expressed as follows ([29]; [30]):

$$f(\infty) = \lim_{s\to 0} sF(s) \# \qquad (9)$$

This theorem provides the stable (or stationary) value that the variable tends to assume after the end of the transient regime. This analysis is widely applied in circuit response to verify the final behavior of voltages and currents when the system reaches equilibrium.

3 INTERFACE PRESENTATION

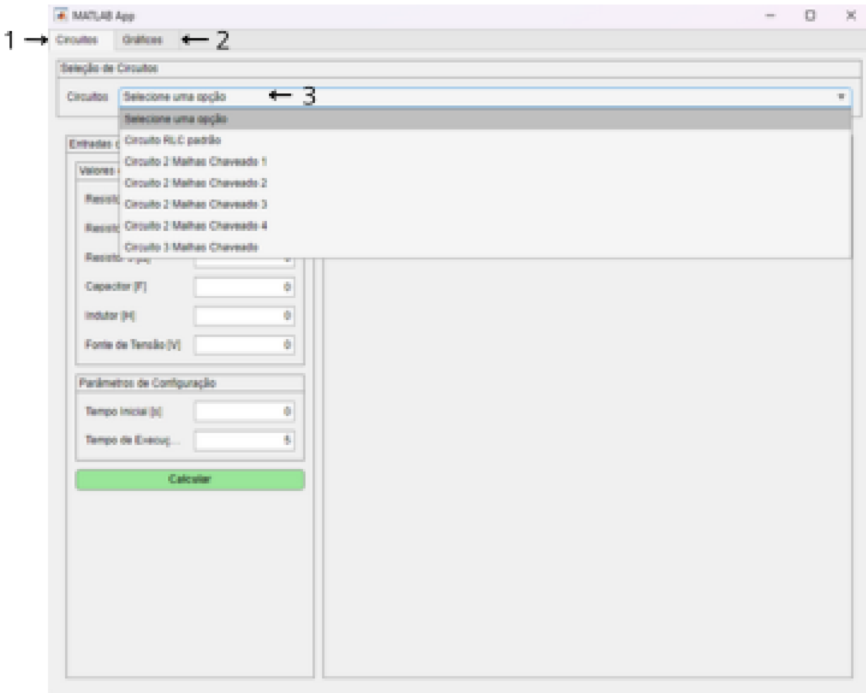
The application installation can be done simply and directly. To do this, the user must acess the project's official page on MATLAB® File Exchange, available at the following link: https://www.mathworks.com/matlabcentral/fileexchange/182482-modelagem-de-sistemas-fisicos-simurlc?s_tid=ta_fx_results. In this repository, you will find the application package, its documentation, and additional information. After acess the link, simply download the file provided and proceed with the installation in MATLAB® through the Add-ons interface.

The application is divided into 2 tabs:

In the "Circuits" tab (Figure 1) we have a selection menu to choose which circuit will be used. As can be seen in the figure, the program was designed to work with 6 different RLC circuits, including one, two and three loops.

Figure 1

Presentation of the Circuits tab



Source: SimuRLC.

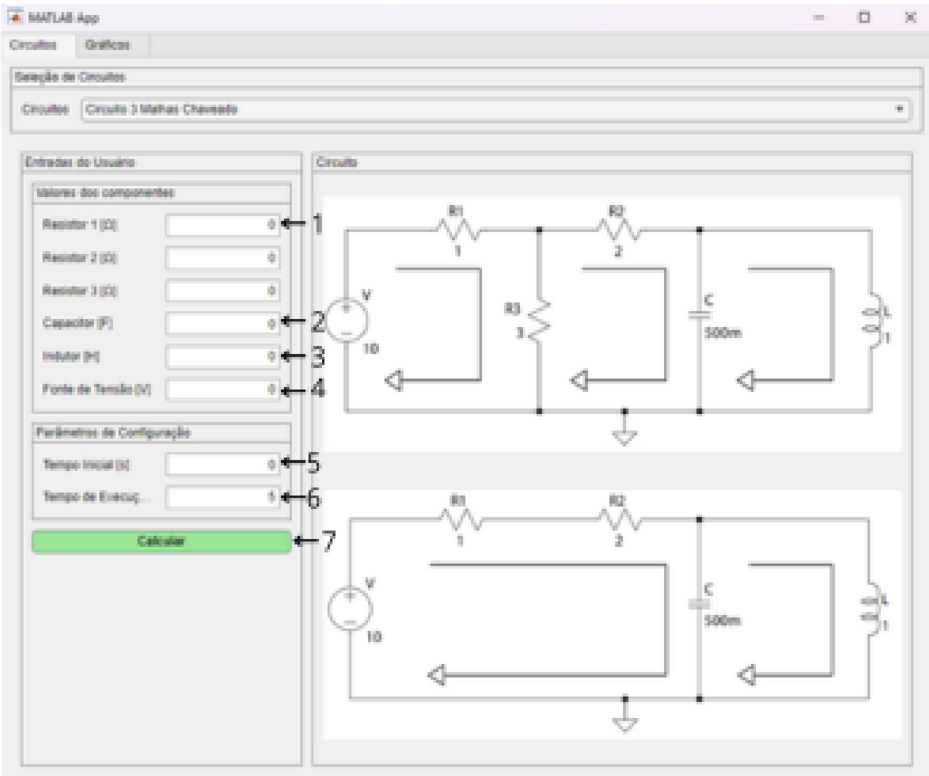
The circuits tab also servers to perform the calculations of current and voltage values in each component (Figure 2).

Following the numerical order, represented in Figure 2, we have:

1) Resistance values, depending on the circuit there may be 1 to 3 resistors, and this box is where their values will be entered.
2) Capacitor value, the capacitor value will be entered here, all circuits have only one capacitor.
3) Inductor value, the inductor value will be entered here, all the circuits have only one inductor .
4) Voltage source value, the voltage value in the circuit will be entered here.
5) Initial simulation value, usually starts at zero, but it is possible to use another initial value.
6) Final simulation value, indicates the time the circuit will operate.
7) Calculate button, clicking on it perform the calculations for the selected circuit.

Figure 2

Presentation of the Circuits tab

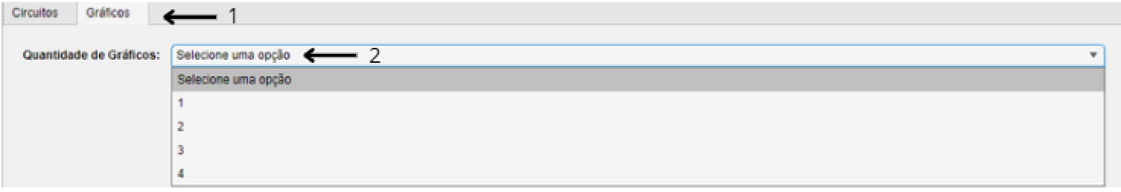


Source: SimuRLC.

In the "Graphs" tab (Figure 3) we have a selection menu to choose how many graphs will be used, with options from 1 to 4 graphs. After choosing the number of graphs, we have the option to choose which graph will appear (Figure 4), with the option of voltage graphs for any of the circuit components and current graphs.

Figure 3

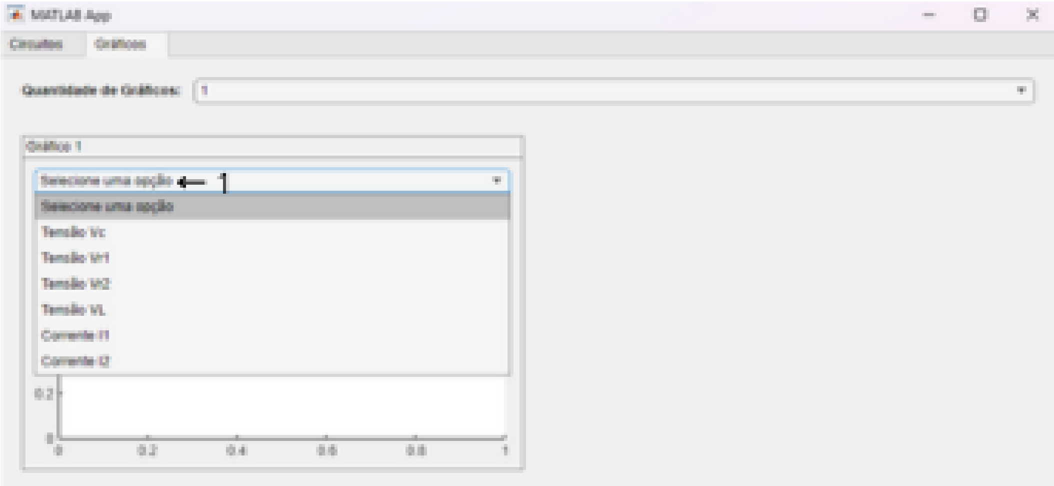
Presentation of the Graphs tab



Source: SimuRLC.

Figure 4

Presentation of the Graphs tab



Source: SimuRLC.

4 CASE STUDY

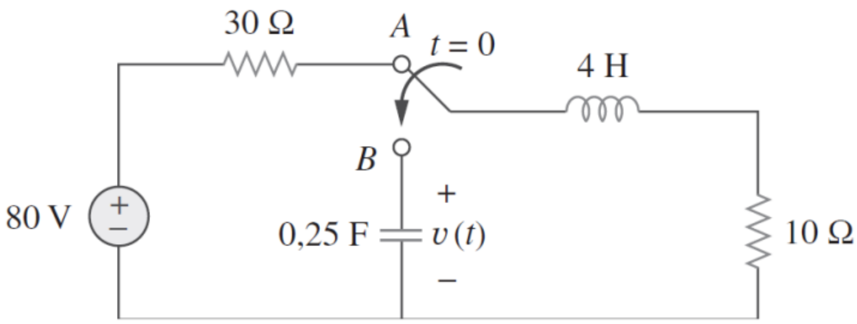
Next, one of the six circuits available in the application will be presented. This case study will analyze how to simulate circuits in the SimuRLC application, and will also show how to perform the circuit calculation.

4.1 1-LOOP SWITCHED CIRCUIT 4

For this case study (Figure 5), the following component values were considered $R_1=30\Omega$, $R_2=10\Omega$, $C=0{,}25F$and $L=4H$, the circuit is powered by a voltage source of $V=80V$.

Figure 5

2-Loop Switched Circuit 4



Source: [30].

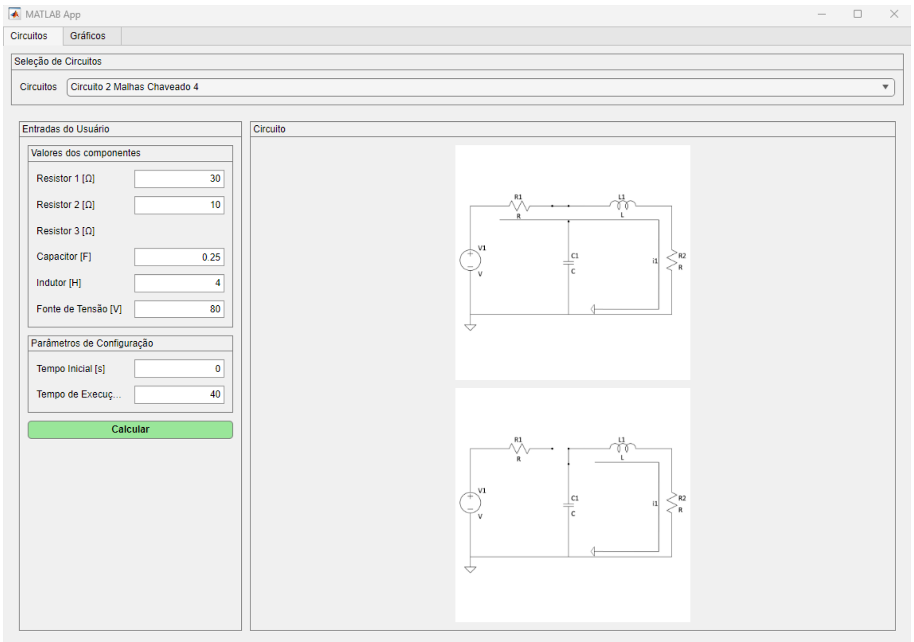
4.1.2 Circuit simulation in the application

First, a step-by-step guide on how to perform the circuit simulation in the application will be shown.

Once the application is open, the first step is to select the circuit to be used, the 2-Loop Switched Circuit 4. Then, the next step is to enter the components values: $R_1 = 30\Omega$, $R_2 = 10\Omega$, $C = 0{,}25F$and , with an input voltage of $L = 4HV = 80V$. With the components values properly configured, the circuit simulation time must be chosen. In this case, the initial time was set to $t_0 = 0s$and the final simulation time to $t_f = 40s$, as shown in Figure 6. Then, simply click the calculate button.

Figure 6

Circuits tab configuration for the case of 2-Loop Switched Circuit 4

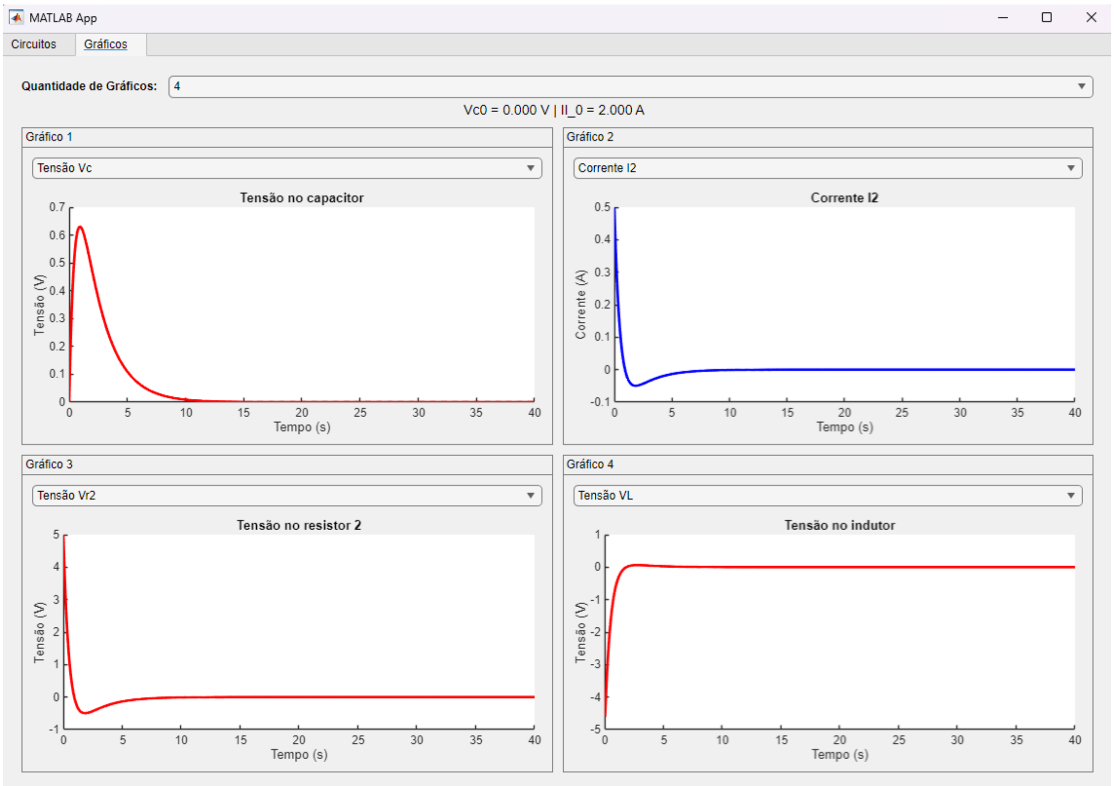


Source: SimuRLC.

By clicking the calculate button, the application will calculate the selected circuit, and the waveforms will be generated. The graphs tab opens, where you first select the desired number of graphs (in this example, 4). The 4 graphs will appear, and in each one, you select which waveform will be displayed. By changing the switch position to point B in Figure 5, the circuit now has only one loop in the second analysis, and finally, there will be 4 waveforms: the voltage across resistor 2, the inductor, the capacitor, and the current I_2. These 4 graphs were selected in the graphs tab, as illustrated in Figure 7.

Figure 7

Graphics tab configuration for the case of 2-Loop Switched Circuits 4



Source: SimuRLC.

4.1.3 Circuit modeling

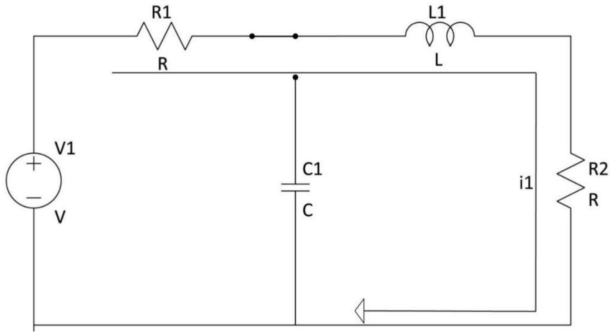
To perform the calculation, it is necessary to divide the circuit (Figure 5) into two parts: (*i*) $t < 0$and (*ii*) $t \geq 0$. Each stage will have a different analysis, because for (*i*), the circuit is in steady state with direct current, where the inductor is a short circuit and the capacitor is an open circuit. For (*ii*), the switch is connected to point B, and the initial voltage and inductor current values determined in stage (*i*) are also available.

4.1.4 Analysis for $t < 0$ (steady state in direct current)

In this phase, the circuit (Figure 8) is in steady state in direct current before any circuit changes. The inductor behaves as a short circuit, while the capacitor behaves as an open circuit. This part of the circuit is analyzed to find the values of the initial conditions.

Figure 8

Circuit for $t < 0$



Source: LTspice®.

4.1.5 Mesh Equation and Laplace Transform Setup

The circuit was analyzed using Kirchhoff's Law, the circuit was modeled, and the equation for when the switch is at point A was found to be:

$$-Eu(t) + R_1 i_1(t) + L\frac{di_1(t)}{dt} + R_2 i_1(t) \ = \ 0\# \qquad (10)$$

The Laplace Transform was applied to Equation (9), in the form:

$$\mathcal{L}\{f(t)\} = F(s)\# \qquad (11)$$

$$\mathcal{L}\left\{\frac{df(t)}{dt}\right\} = \ sF(s) - F(0) \rightarrow \ sF(s)\# \qquad (12)$$

$$\mathcal{L}\ \{\int_0^t f(\tau)d\tau\} \ = \ \frac{F(s)}{s}\# \qquad (13)$$

Equations (10) and (11) were substituted into Equation (10):

$$-\frac{E(s)}{s} + R_1 I_1(s) + LsI_1(s) + R_2 I_1(s) = 0\# \qquad (15)$$

The values of the components $R1 = 30\Omega$, $R2 = 10\Omega$, $L = 4H$and were substituted and Equation (15) was adjusted:$V = 80V$

$$I_1(s)(30 + 4s + 10) = \frac{80}{s} \# \qquad (15)$$

The equation was manipulated in order to determine the current in the frequency domain:

$$I_1(s) = \frac{20}{s(s+10)} \# \qquad (16)$$

To find the value of the current in the time domain, we use the final value theorem:

$$\lim_{t \to \infty} x(t) = \lim_{s \to 0} sX(s) \# \qquad (17)$$

The final value theorem, Equation (17), was applied, which corresponds to the inductor current, i.e., the current I_1, Equation (16), in the form:

$$\lim_{t \to \infty} i_1(t) = \lim_{s \to 0} sI_1(s) = \lim_{s \to 0} s \frac{20}{s(s+10)} = \frac{20}{10}$$
$$\lim_{t \to \infty} i_1(t) = \lim_{s \to 0} sI_1(s) = 2A \# \qquad (17)$$

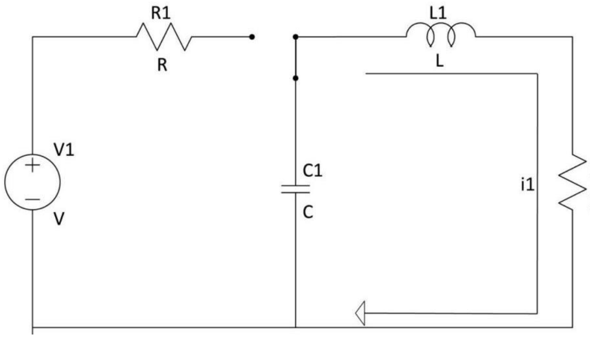
Since the switch is at point A for this first phase of the circuit, the capacitor is in an open circuit, as it is located at point B of the circuit. Therefore, the initial voltage across the capacitor can be defined as zero.

4.1.6 Analysis for $t \geq 0$ (transient regime)

For $t \geq 0$, the circuit (Figure 9) is reconfigured, resulting in a new system with a loop.

Figure 9

Circuit for $t \geq 0$



Source: LTspice®.

4.1.7 Mesh Equation and Laplace Transform Setup

The circuit was modeled using Kirchhoff's Law, for the switch at point B:

$$L\frac{di_1(t)}{dt} + R_2 i_1(t) + \frac{1}{C}\int_0^t i_1(\tau) = 0\# \quad (19)$$

The Laplace Transform was applied to Equation (19), analogous to that done in Equation (10):

$$LsI_1(s) - I_1(0) + R_2 I_2(s) + \frac{1}{C}\frac{I_1(s)}{s} = 0\# \quad (20)$$

The values of the components $R2 = 10\Omega$, $C = 0{,}25F$e $L = 4H$were substituted and Equation (20) was adjusted:

$$I_1(s)(4s + 10 + \frac{4}{s}) = 2\# \quad (21)$$

The current was calculated, and the following result was obtained:

$$I_1(s) = \frac{2}{4s + 10 + \frac{4}{s}} = \frac{2s}{4s^2 + 10s + 4} = \frac{s}{2s^2 + 5s + 2}\# \quad (22)$$

Unlike the first analysis for $t < 0$, where only the current in the inductor and voltage across the capacitor were needed, now it is necessary to obtain all the voltages of each component present in the circuit after the switch is in position B.

Therefore, the voltage equations for all components in the circuit will now be determined.

To calculate the voltage across resistor R_2,Ohm's Law was used, as follows:

$$V_{R_2}(s) = R_2 I_1(s) \# \qquad (23)$$

given $R_2 = 10\Omega$and Equation (22), when substituting into Equation (23), we have:

$$V_{R_2} = 10\frac{s}{2s^2 + 5s + 2} = \frac{10s}{2s^2 + 5s + 2} \# \qquad (24)$$

For capacitor voltage, the concept of impedance in the Laplace domain is used:

$$V_c(s) = \frac{1}{Cs} I_1(s) \# \qquad (25)$$

given $C = 0{,}25F$and Equation (22), substitute into Equation (26):

$$V_c(s) = \frac{1}{0{,}25s}\frac{s}{2s^2 + 5s + 2} = \frac{4s}{2s^3 + 5s^2 + 2s} = \frac{4}{2s^2 + 5s + 2} \# \qquad (26)$$

For the voltage across the inductor, which will be applied as follows:

$$V_L = LsI_1(s) \# \qquad (27)$$

given $L = 4H$and Equation (22), substitute into Equation (27):

$$V_L = 4s\frac{s}{2s^2 + 5s + 2} = \frac{4s^2}{2s^2 + 5s + 2} \# \qquad (28)$$

4.1.8 Time domain analysis (inverse laplace transform)

After finding the voltage and current expressions Equations (23), (25) and (27) in the components present in the circuit, after the switch is opened at time $t \geq 0$, in the frequency domain. In the time domain, to find the expressions, the Inverse Laplace Transform was applied to each of the voltage and current equations, corresponding to Equations (22), (24), (26) and (28).

Applying the Inverse Laplace Transform to Equation (22), we obtained:

$$\mathcal{L}^{-1}\{I_1(s)\} = \mathcal{L}^{-1}\left\{\frac{s}{2s^2+5s+2}\right\} \tag{29}$$

To perform the Inverse Laplace Transform, it is first necessary to factor the denominator, as the manipulation depends on the type of roots:

$$D(s) = 2s^2 + 5s + 2 = (s+2)(2s+1) = 2(s+2)\left(s+\frac{1}{2}\right) \# \tag{30}$$

After factoring the denominator, it was observed that there are two distinct real roots, therefore, the partial fraction expansion became:

$$\frac{s}{2(s+2)(s+\frac{1}{2})} = \frac{A}{(s+2)} + \frac{B}{\left(s+\frac{1}{2}\right)} \# \tag{31}$$

Equation (31) were multiplied by :$2(s+2)\left(s+\frac{1}{2}\right)$

$$\frac{s}{2} = A\left(s+\frac{1}{2}\right) + B(s+2) \# \tag{32}$$

In the next step, distributive multiplication was performed in order to express a polynomial in terms of the complex variable s:

$$\begin{cases} A + B = \frac{1}{2} \\ \frac{A}{2} + 2B = 0 \end{cases} \# \tag{33}$$

Using Equation (33), we obtained:

$$A = \frac{2}{3} \text{ e } B = -\frac{1}{6} \# \tag{34}$$

The residues are substituted into Equation (34):

$$I_1(s) = \frac{2}{3}\frac{1}{(s+2)} - \frac{1}{6}\frac{1}{\left(s+\frac{1}{2}\right)} \# \tag{35}$$

Finally, the Inverse Laplace Transform was applied to the electric current flowing in the circuit after the switch operation, expressed by:

$$i_1(t) = \left(\frac{2}{3}e^{-2t} - \frac{1}{6}e^{-\frac{t}{2}}\right)u(t) \# \tag{36}$$

To find the voltage value across Resistor 2, Ohm's Law will be used, as in Equation (23). Then the Inverse Laplace Transform will be applied.

$$V_{R_2} = \frac{10s}{2s^2+5s+2} = \mathcal{L}^{-1}\left\{\frac{10s}{2s^2+5s+2}\right\} \tag{37}$$

Based on the analysis performed previously, where the current was obtained, the values of the factored denominator, Equation (32), as well as the values of A and B, Equation (34), can be used, and the same steps for the previous transformation are performed, where the following was obtained:

$$v_{R_2} = \left(\frac{20}{3}e^{-2t} - \frac{5}{3}e^{-\frac{t}{2}}\right)u(t) \# \tag{38}$$

To find the voltage across the capacitor using the Inverse Laplace Transform, the capacitor voltage formula, Equation (25), is used, where this result will be transformed from the frequency domain to the time domain, following the same steps as for the other equations found:

$$V_c = \frac{4}{2s^2+5s+2} = \mathcal{L}^{-1}\left\{\frac{4}{2s^2+5s+2}\right\} \tag{39}$$

The Inverse Laplace Transform is applied where the same steps were performed previously:

$$v_c = \left(\frac{8}{3}e^{-2t} - \frac{2}{3}e^{-\frac{t}{2}}\right)u(t)\# \qquad (40)$$

Finally, all that remains is to perform the Inverse Laplace Transform for the voltage across the inductor. To do this, use the inductor voltage formula, which was found in the result in Equation (28). This result will be transformed from the frequency domain, in the same way as for the other voltages:

$$V_L(s) = \frac{4s^2}{2s^2 + 5s + 2} = \mathcal{L}^{-1}\left\{\frac{4s^2}{2s^2 + 5s + 2}\right\} \qquad (41)$$

Based on the analysis performed previously, where the current was obtained, the values of the factored denominator can be used, Equation (32).

With this, it is possible to calculate the values of A and B, since for this voltage, we have a different analysis. As we have in the numerator, that is, we have the same degree in the numerator and denominator, we know that: $4s^2$

$$\frac{-10s - 4}{2(s+2)\left(s + \frac{1}{2}\right)} = \frac{A}{(s+2)} + \frac{B}{\left(s + \frac{1}{2}\right)}\# \qquad (42)$$

The two partial equations were multiplied by the denominator of Equation (42):

$$\frac{-10s - 4}{2} = A\left(s + \frac{1}{2}\right) + B(s+2) \qquad (43)$$

In the next step, distributive multiplication was performed in order to express a polynomial in terms of the complex variable s:

$$\begin{cases} A + B = -5 \\ \frac{A}{2} + 2B = -2 \end{cases}\# \qquad (44)$$

Using Equation (44) we obtained:

$$A = -\frac{16}{3} \text{ e } B = \frac{1}{3} \qquad (45)$$

The obtained values are substituted and the Inverse Laplace Transform is applied:

$$v_L(t) = \left(2\delta(t) - \frac{16}{3}e^{-2t} + \frac{1}{3}e^{-\frac{t}{2}}\right)u(t)\# \qquad (46)$$

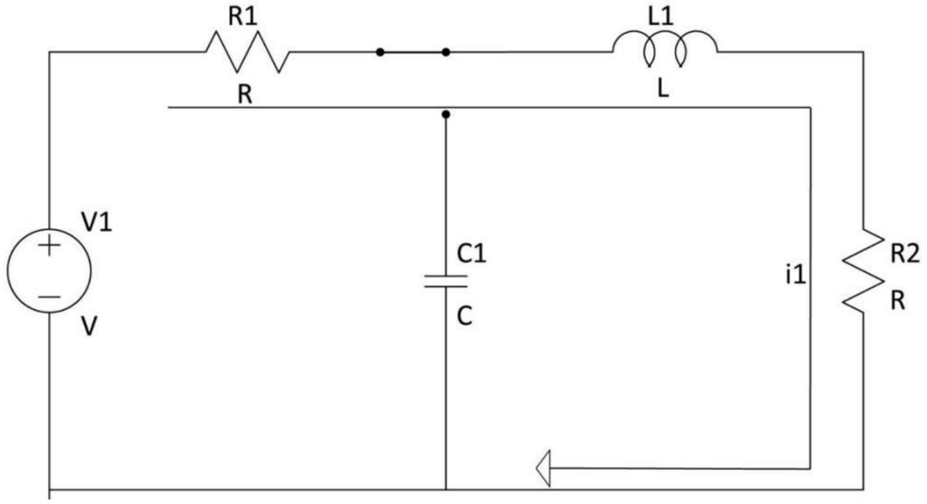
5 SIMULATION IN LTspice®

The waveforms generated by the proposed application were validated, and the simulation was performed in the LTspice® software, where the circuits used in the example corresponding to the previous chapter were simulated.

For the case of the 2-Loop Switched circuit, the circuit was first assembled, where the two operating phases were assembled, pre-switching (Figure 10) and post-switching (Figure 11), resulting in two circuits.

Figure 10

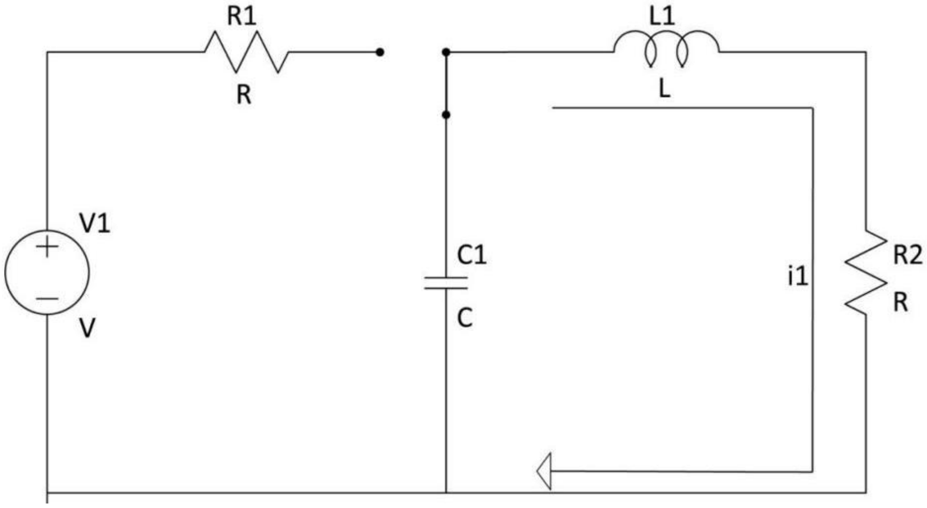
2-Loop Switched Circuit (Pre-switching)



Source: LTspice®.

Figure 11

2-Loop Switched Circuit (Post-switching)



Source: LTspice®.

With the circuits properly assembled, the necessary configuration for performing the simulations is carried out. Initially, the initial conditions of the circuit in the post-switching stage are defined.

This configuration is done in the LTspice® software, using the "SPICE Directive" option, available in the top bar, or by using the shortcut (.). Then, the following command must be entered: *. CI V(C2)=0 I(L2)=2*.

Thus, the capacitor and inductor shown in Figure (21) start the simulation already equal to their initial conditions.

Before running the simulation, it is necessary to configure the transient. To do this, acess the "Configure Analysis" option in the software's top bar, or press the (A) key. In the "Transient" bar, define the analysis time in the "Stop time" field, assigning the value of 15. To finalize this configuration, scroll to the bottom of the window and add the command ".tran 15 uic", ensuring that the simulation of the initial conditions is correctly executed.

At the end of this process, the simulation environment should be similar to that shown in Figure (12).

Figure 12

LTspice® configuration commands

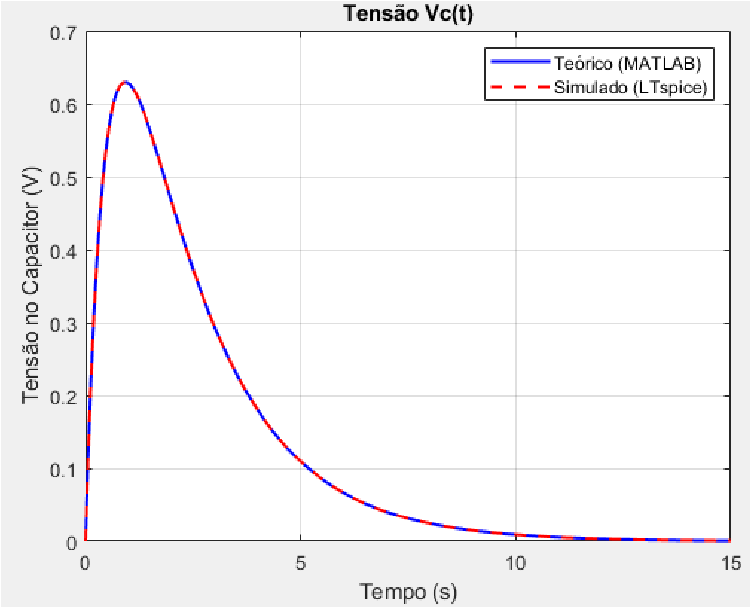
```
.IC V(C2)=0 I(L2)=2
.tran 15 uic
```

Source: LTspice®.

With these settings made, the simulation and verification of the graphs is carried out, as shown in Figures (13)-(14), where comparisons are made between the voltage graphs in the capacitor (Figure 13) and the current in the inductor (Figure 14), where using the MATLAB® software it was possible to overlay both graphs to perform the simulation:

Figure 13

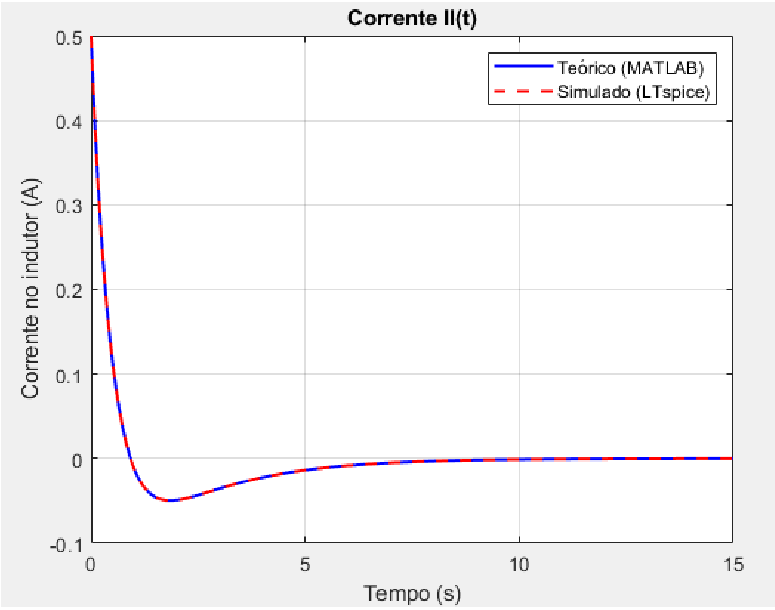
Comparison of graphs from the SimuRLC and LTspiceV_c® applications



Source: MATLAB.®

Figure 14

Comparison of the graphs from the SimuRLC and LTspiceI_L® application



Source: MATLAB.®

This allowed us to determine that the simulation differences were minimal and did not compromise the overall correspondence between the simulations. In all cases, the simulation results from the application (SimuRLC) and the simulation results (LTspice®) were equivalent with an error of less than 0,5%.

6 FINAL CONSIDERATIONS

The development of the Modeling of Physical Systems - Graphical Simulator of RLC Circuits (SimuRLC) application demonstrated the feasibility of combining theoretical concepts of electrical circuit analysis with practical application within the computational environment. Through the integration of the Laplace Transform, mathematical models, and the graphical interface, the application proved to be a valuable and efficient tool for teaching and understanding the behavior of RLC circuits.

The case studies presented confirmed the accuracy of the calculations and simulations performed by the application, showing high agreement between the results obtained in the application and in the LTspice® software, with an error of 0,5%. This correspondence validates both the mathematical method used in the application's modeling and the reliability of the developed environment.

In addition, the application contributes significantly to the learning process, allowing students to visualize the relationship between differential equations and responses in the time and frequency domains, in an interactive and intuitive way. This approach strengthens the understanding of the phenomena of charging, discharging, and electrical transients present in real systems.

Therefore, the project achieved its objectives of providing and accessible, accurate, and effective educational tool capable of assisting in the study of the Laplace Transform applied to electronic engineering.

REFERENCES

1 Abreu, L. de M., Rossini, F. L., & Oliveira, L. F. P. de. (2022). Modelagem cinemática de um robô modelo SCARA e desenvolvimento de aplicativo para análise gráfica. In Anais do XII Seminário de Extensão e Inovação & XXVII Seminário de Iniciação Científica e Tecnológica da UTFPR. Even3. https://doi.org/10.29327/1152426.1-2

2 Alexander, C. K., & Sadiku, M. N. O. (2013). Fundamentos de circuitos eléctricos (5ª ed.). McGraw-Hill Interamericana.

3 Andrade, P. de A., Nanni, M., & Rossini, F. L. (2025). Revisão bibliográfica de métodos de detecção de falhas em motores de indução com aplicação de redes neurais. In Anais do XV Seminário de Extensão e Inovação & XXX Seminário de Iniciação Científica e Tecnológica da UTFPR. Universidade Tecnológica Federal do Paraná - Campus Curitiba.

https://www.even3.com.br/anais/sei-sicite-2025-593680/1278381-revisao-bibliografica-de-metodos-de-deteccao-de-falhas-em-motores-de-inducao-com-aplicacao-de-redes-neurais

4 Andrade, P. de A., Silva, L. E. da C., & Rossini, F. L. (n.d.). Análise de circuito elétrico RLC de três malhas via transformada de Laplace com softwares Matlab® e LTspice®. ResearchGate. https://www.researchgate.net/publication/375924489_Analise_de_circuito_eletrico_RLC_de_tres_malhas_via_transformada_de_Laplace_com_softwares_MatlabR_e_LTspiceR

5 Barbosa, R. F. de S., Garcia, L. R., Cunha, M. R. da, & Rossini, F. L. (2023). Modelagem e simulação da cinemática direta de um robô móvel de três rodas com tração diferencial. In Anais do XIII Seminário de Extensão e Inovação & XXVIII Seminário de Iniciação Científica e Tecnológica da UTFPR. https://seisicite.com.br/storage/seisicite-trabalhos-finais/1103-4319d5d6514993af9a1f90540918b99cd1746e145f6cf690b5e0c0f62ece771c.pdf

6 Barbosa, R. F. de S., Machado, M. F. N., Moraes, A. T. de, & Rossini, F. L. (2024). Modelagem, simulação e planejamento de trajetória de robô móvel de três rodas com acionamento diferencial. In H. C. Brito & F. A. F. Marques Junior (Eds.), Perspectivas da engenharia: Teoria, prática e desafios (pp. 222–235). Amplla Editora. https://doi.org/10.51859/amplla.pet4499-17

7 Barbosa, R. F. de S., Rossini, F. L., Pontim, F. M., Oliveira, J. M. S. de, & Souza, R. E. (2025). Geração de trajetória em um robô manipulador RRR por meio de algoritmo numérico. In Anais do XV Seminário de Extensão e Inovação & XXX Seminário de Iniciação Científica e Tecnológica da UTFPR. Universidade Tecnológica Federal do Paraná - Campus Curitiba. https://www.even3.com.br/anais/sei-sicite-2025-593680/1279530-geracao-de-trajetoria-em-um-robo-manipulador-rrr-por-meio-de-algoritmo-numerico

8 Canham, D. C., Brolin, L. C., & Rossini, F. L. (2022). Aplicação do método do gradiente e do método dos mínimos quadrados recursivo para análise de desempenho do controle adaptativo por modelo de referência. In J. Dallamuta & H. A. Holzmann (Eds.), Engenharia elétrica: Sistemas de energia elétrica e telecomunicações 2 (pp. 91–100). Atena. https://doi.org/10.22533/at.ed.2702211118

9 Carvalho, P. H. C., Brolin, L. C., Rossini, F. L., & Nanni, M. (2025). Modelagem e controle para estabilização de um quadrirotor com um grau de liberdade. In L. De Carvalho Vidal, G. G. de Oliveira, J. R. Monteiro, & W. P. N. dos Reis (Eds.), Tecnologias emergentes em engenharia: Convergência entre automação, robótica, metrologia e energia (pp. 43–67). Editora Científica Digital. https://doi.org/10.37885/250519390

10 Cristofoli, C. B., Rossini, F. L., & Monteiro, A. L. R. (2024). Desenvolvimento de uma estação portátil de crioterapia e hipertermoterapia com o microcontrolador PIC16F874A para controle PID de temperatura. In H. C. Brito (Ed.), Ciência, tecnologia e inovação: Tendências e desafios para o desenvolvimento científico e tecnológico (Vol. 2, pp. 107–122). Amplla. https://doi.org/10.51859/amplla.cti4345-8

11 Donda, R. A., Rossini, F. L., Souza, R. N. de, & Garcia, R. V. (2021). Desenvolvimento do aplicativo Métodos de Matemática Aplicada – Simulador da Série de Fourier (MMA-SSF): Estudo de caso. In Anais do XI Seminário de Extensão e Inovação & XXVI

Seminário de Iniciação Científica e Tecnológica da UTFPR. Universidade Tecnológica Federal do Paraná - Campus Guarapuava. https://eventos.utfpr.edu.br/sei/sei2021/paper/viewFile/8387/4067

12 Ferreira, L. A., Rossini, F. L., & Brolin, L. C. (2024). Modelagem e análise de estabilidade de um drone terrestre de duas rodas com acionamento diferencial. In A. M. T. Soares (Ed.), Tópicos especiais em engenharia: Inovações e avanços tecnológicos (Vol. 11, pp. 24–42). Aya Editora. https://doi.org/10.47573/aya.5379.2.313.2

13 Kaneda, E. K., Berger, G., Pinto, V. H., Pinto, M. F., Ferreira, M., Rossini, F. L., & Lima, J. L. S. de M. (2024). Development of a platform with 2 DoF to assist the cooperation between grounded mobile robots and UAVs in landing operations. In 2024 7th Iberian Robotics Conference (ROBOT) (pp. 1–6). IEEE. https://doi.org/10.1109/ROBOT61475.2024.10797380

14 Lathi, B. P. (2005). Linear systems and signals (2nd ed.). Oxford University Press.

15 Luz, E. de C., Figueiredo, G. C. M., Souza, J. C. de, Thozolino, L. H. dos S., Oliveira, P. H. M., & Rossini, F. L. (2024). Modelagem, simulação e análise por meio da integral de convolução em tempo contínuo de um circuito RLC série. In H. C. Brito & F. A. F. Marques Junior (Eds.), Perspectivas da engenharia: Teoria, prática e desafios (pp. 236–251). Amplla Editora. https://doi.org/10.51859/amplla.pet4499-18

16 Luz, E. de C., & Rossini, F. L. (2023). Modelagem, solução e análise de circuito RLC paralelo via transformada de Laplace e uso dos softwares Matlab® e LTspice®. In Anais do XIII Seminário de Extensão e Inovação & XXVIII Seminário de Iniciação Científica e Tecnológica da UTFPR. https://seisicite.com.br/storage/seisicite-trabalhos-finais/1378-62571b21cf94861b1535847e22286c433bfddd7073015dfa8d932782d128a7b9.pdf

17 Nakashima, A. S., Siqueira, M. F., Yamao, V. H. S., & Rossini, F. L. (2016). Modelagem, simulação e análise de sistema massa-mola-amortecedor com não linearidade. In III Simpósio de Tecnologia e Engenharia Eletrônica - III SIMTEEL.

18 Nise, N. S. (2013). Control systems engineering. John Wiley & Sons.

19 Pontim, F. M., Oliveira, J. M. S. de, & Rossini, F. L. (2025). Modelagem da cinemática direta de robô com quatro graus de liberdade e simulação no software MATLAB® via Robotics Toolbox. In R. N. Pagani (Ed.), Cidades inteligentes e práticas sustentáveis (pp. 65–78). Aya Editora. https://doi.org/10.47573/aya.5379.2.450.4

20 Pontim, F. M., Rossini, F. L., Rossini, G. P., Oliveira, J. M. S. de, & Souza, R. E. (2025). Geração de trajetória em um robô manipulador RRR por meio de algoritmo numérico. In Anais do XV Seminário de Extensão e Inovação & XXX Seminário de Iniciação Científica e Tecnológica da UTFPR. Universidade Tecnológica Federal do Paraná - Campus Curitiba.

21 Pradela, W. G. L., Maran, M. E. dos S., & Rossini, F. L. (2023). Estimação de parâmetros em tempo real aplicado a um sistema em tempo discreto. In F. C. Barbosa (Ed.), Engenharia: A máquina que constrói o futuro (17ª ed.). Editora Conhecimento Livre. https://doi.org/10.37423/231208520

22 Rossini, F. L. (n.d.). Transformada de Laplace: Aplicação [Notas de aula]. Moodle.

23 Rossini, F. L., Pawelski, L., & Silva Junior, P. R. M. (2022). Desenvolvimento do aplicativo métodos de matemática aplicada - simulador de entrada-saída periódica de circuito elétrico RLC série (MMA-SESPC). In F. L. Rossini, L. Pawelski, & P. R. M. Silva Junior (Eds.), Open science research II (pp. 1350–1359). Editora Científica Digital. https://doi.org/10.37885/220207739

24 Rossini, F. L., & Silva Junior, P. R. M., & Alcantara, C. V. B. de. (2023). Modelagem dinâmica e simulação do sistema de controle não linear do robô manipulador SCARA RH-3FRHR35 com fixação superior, fabricante Mitsubishi. In F. C. Barbosa (Ed.), Engenharia: A máquina que constrói o futuro (17ª ed., pp. 173–194). Editora Conhecimento Livre. https://doi.org/10.37423/231208504

25 Rossini, G. P., Santos, O. A. de P. dos, & Rossini, F. L. (2025). Cinemática direta e inversa e geração de trajetória do robô ABB IRB 1010. In L. De Carvalho Vidal, G. G. de Oliveira, J. R. Monteiro, & W. P. N. dos Reis (Eds.), Tecnologias emergentes em engenharia: Convergência entre automação, robótica, metrologia e energia (pp. 68–94). Editora Científica Digital. https://doi.org/10.37885/250619554

26 Santos, O. A. de P. dos, Bezerra, M. dos S., & Rossini, F. L. (2023). Modelagem no domínio do tempo, solução via transformada de Laplace e análise das formas de onda de circuito elétrico RLC chaveado. In Anais do XIII Seminário de Extensão e Inovação & XXVIII Seminário de Iniciação Científica e Tecnológica da UTFPR. https://seisicite.com.br/storage/seisicite-trabalhos-finais/1119-273fdd50d70f957c2049c4cb733bbfbc3a3ac140015f5ccc37511e31b541e501.pdf

27 Silva, V. A. da, Oliveira, L., Seifert, N., Oliveira, J. M. S. de, Pontim, F. M., & Rossini, F. L. (2023). Modelagem no domínio do tempo e aplicação da transformada de Laplace na solução e análise de um circuitos RLC com três malhas. In I. L. Fontgalland (Ed.), Cidades inteligentes e novos modelos industriais (Vol. 2, pp. 62–84). Amplla Editora. https://doi.org/10.51859/amplla.cin3224-5

28 Silva, V. A. da, Rossini, F. L., Pontim, F. M., Oliveira, J. M. S. de, & Oliveira, L. (n.d.). Aplicação da transformada de Laplace para modelagem e análise de um circuito RLC de três malhas. ResearchGate. https://www.researchgate.net/publication/376071485_Aplicacao_da_Transformada_de_Laplace_para_Modelagem_a_Analise_de_um_Circuito_RLC_de_Tres_Malhas

29 Souza, E. D. de, Rossini, F. L., & Oliveira, L. F. P. de. (2023). Desenvolvimento de um aplicativo no ambiente App Designer do software Matlab® para planejamento de trajetória do robô Puma 560. In L. C. Freitas (Ed.), Engenharia elétrica e de computação: Docência, pesquisa e inovação tecnológica (pp. 87–109). Atena. https://doi.org/10.22533/at.ed.4652316018

30 Takemoto, V. S., Rossini, F. L., & Correa, W. J. (2022). Modelagem de um sistema caixa-cinza por meio do método dos mínimos quadrados a partir de identificação ARX. In Anais do XII Seminário de Extensão e Inovação & XXVII Seminário de Iniciação Científica e Tecnológica da UTFPR. https://www.even3.com.br/anais/seisicite2022/547687-modelagem-de-um-sistema-caixa-cinza-por-meio-do-metodo-dos-minimos-quadrados-a-partir-de-identificacao-arx/