The Electrical Circuits Education using Computer Algebra Systems on Raspberry Pi

Vladimir Mladenović, Sergey Makov, Yigang Cen, Viacheslav Voronin, Živadin Micić

***Abstract*— In this paper, the new method and the methodology are presented for the education of students of electrical engineering at low-cost computers and open-source software as computer algebra system (CAS). These manner and method contribute to students for solving electrical circuits in transient regimes, especially if they have a poor knowledge in the field of mathematics. CAS helps in the formation of equations relating to a circuit and it is not necessary to know the field of differential equations. The obtained solutions are symbolic expressions, which indicate the transient response in closed-form expressions. Such expressions can be used further for manipulation and processing. In this way, students are exempted from long-term learning of mathematics.**

***Keywords*—Computer algebra system , education, Raspberry pi, Electrical engineering**

I. Introduction

DESIGNING and implementing a computer simulation requires skills in electronic circuits, digital signal processing and software engineering, fields which are familiar to many electrical engineers. The students of electrical engineering must learn in various fields of mathematic in parallel to the fields of electrical engineering for acquiring certain knowledge for analysis and synthesis, and it does not always guarantee accurate results in practice. One of the major problems in dealing with the transient response of electrical circuits is a good knowledge differential equations and determination of the initial conditions. The numerical-based software tools can only give responses but cannot help the students to understand and comprehend transient processes. This paper introduces the computer simulation of electrical circuits based on an educatively approach for deeper understanding and fast acquiring simulation skills of transient response. It is illustrated throughout by examples taken from the simulation of electrical circuits without special knowledge level in the field of mathematic. This procedure has a few contributions. First, no need expert's knowledge in the field of mathematics, particularly in the field of differential equations. Secondly, there are no possibility wrong solutions of complex transient response. Third, all solutions are in close form and can be analyzed during transient response. Fourth, there is the possibility for post-manipulation and post-processing obtained close form solutions. And finally, the student quickly reaches the level of feeling good skills for the analysis of electrical circuits in transient response.

This paper is organized as follow. In the section II the related works are presented according to observed approach. Section III defines, describes and explains the method of complex solving of transient response. Finally, section IV provides the final conclusion.

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II. Literature review

Today, there are numerous mathematical software tools such as Matlab and Mathematica, which students and engineers in computer science can be used to solve complex mathematical problems [1], [2], [3]. Relying on the classical approach in learning and applying mathematical tools in engineering sciences, distinguished four stages in learning methodology [4], [5]. In this sense, a variant of low cost computers, named Raspberry Pi [6], are appeared on the market, recently. Its performance satisfies the characteristics of a medium PC and allows access to each person to use. The open-source software is installed, and to the software package Mathematica which is one of the best programming language for symbolic computation, named Wolfram language [2]. To analyze the properties of the elements or system, mathematical models are used often. Modeling is the process of presenting a physical elements or system in a manner that enables the use of mathematical expressions [7]. Simplification of the model is carried out by adopting a number of assumptions that do not affect the essential properties of the element, a single analysis gives good results that show the essence and the most important features [8]. This paper introduces a presented approach in solving of electrical circuits with transient response using mathematical models, which are based on current changes. In practice, these changes gradually changed from one value to another [9].

III. Problem statement

For example, let us consider a specific case, to solve the transient regime in the circuit shown in Figure. 1.

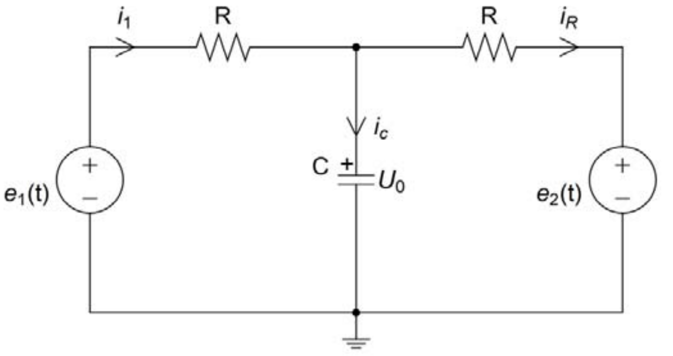

Fig. 1. Complex electrical circuit for studing of theory electrical engineering theory of circuits in transient response

Let electrical circuit is composed of two resistors of the same value in a label R, the two generator whose excitation different denoted $e_1(t)=E_0\cdot h(t-\tau_1)$ and $e_2(t)=E_0\cdot e^{-a\cdot t}\cdot h(t-\tau_2)$ where E_0 is the voltage amplitude, a is a constant of attenuation, and $h(t)$ is the unit step function. The τ_1 and τ_2 are delays on generators both, respectively. There is one capacitor when the voltage U_0 is already present. It is necessary to calculate the transient response of voltage and current through the capacitor.

This, seemingly, simple example is not so easy to solve. The principle of superposition is only way to resolve it. The equations are written for the three cases where each part of the circuit is analyzed by the influence of a generator, where the other generators are in short circuits. Deeper analysis announces writing certain moments, such as $t(0^-)$ and $t(0^+)$, when the electrical parameters change in a circuit. For those cases, the differential equations are written and the final form is obtained by a complex voltage function. The more complex form is obtained if we look for a function of current.

For such a calculation in closed form can not be used the traditional numerical methods. They would give us a graphical interpretation of the transient regime without being able to observe processes analytically. All these explanations are valid if they are not present delays in the electrical circuit, i.e. when $\tau_1=\tau_2=\tau_3=0$, where the τ_3 is delay on capacitor. However, the analytical form of the transient regime is almost not possible to get in closed form by introducing delays.

In our approach is not necessary to know to solve the differential equations. The main advantage is that we immediately write the system of equations by the Kirchhoff rules, using mesh current method or node-voltage analysis. The initial conditions set immediately and software tool provides the solution for a few seconds without any errors. Obtained analytic functions of current and voltage on the capacitor can still be used to manipulate if necessary.

After the deriving of all the terms we illustrate further manipulation (post-manipulation and post-processing) on this way that we involve the delay in each of the excitation voltage marked with τ_1 and τ_2.

In the following Figure 2. the analysis is illustrated when the delay is present on one generator, and on both.

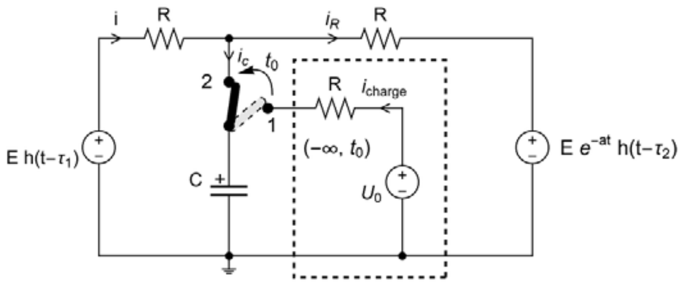

Fig. 2. Modeling of the transient regime from moment of $t(0^-)$ (which indicates the period from $-\infty$ to the moment t_0) to the moment of $t(0^+)$

Also, it is possible to analyze changes in current and voltage on the capacitor when the initial voltage is present on capacitor, and this analysis can be controlled over a time constant τ_3, but it is not involved in this paper.

IV. WOLFRAM LANGUAGE

In the engineering sciences, the first step for much problem solving is to understand various engineering fields, such as the processes and systems. The next step is the knowledge transfer into the corresponding software, which commonly uses procedures for solving the given problems. The best-known language to encapsulate expert knowledge in software is Wolfram language. It allows some computations to be performed quite simply. It possesses many built-in functions that can be used for term rewriting. Also, it enables us to build, program and execute many processes, and to understand as everything-expressed structures. Using simplification rules of the Wolfram language, or by rearranging expressions, it is very easy to check that this automated derivation generates the same result. Calculation of the previously presented expressions is often very arduous and complex; sometimes there is no output solution. In these cases, the special functions used to obtain a closer solution are applied, so that we can carry out the necessary assessments. The basic idea is to prepare examples for users who are used as an exemplary document or software for analysis, simulation or processing [10].

V. SOLVING TRANSIENT RESPONSE

Let us start to write the system of the differential equations based on Kirchhoff rules with Wolfram language. So,

```
equ=
{c*Uc'[t]+iR==i1,
E0*UnitStep[t-delay1]==r*i1+Uc[t],
E0*Exp[-a*t]*UnitStep[t-delay2]-Uc[t]==-r*iR};
```

Fig. 3. The system of equations written by Kirchhoff rules

This is the basic setting for solving of the transient response of the electrical circuit. There is needed to eliminate currents `i1` and `iR` in two branches in order to manipulate with one differential equation where voltage of capacitor is present only as unknown. The command that performs it is `Eliminate[]`.

```
sol1=Eliminate[equ,{i1,iR}];
2 Uc[t]-e^-at E0 UnitStep[-delay2+t]+
c r Uc'[t]==E0 UnitStep[-delay1+t]
```

Fig. 4. Reducing the equation to an unknown value

Now, we have the differential equation prepared to solve solution observed. The command `DSolve[]` addresses to calculation transient response in closed-form expression. So,

```
solution=DSolve[{sol1,Uc[0]==
U0*UnitStep[t-delay3]},Uc[t],t];
Uc=Uc[t]/. solution[[1]][[1]]
  // TraditionalForm
```

Fig. 5. Solving of the differential equation of transient response

The second line simplifies view of obtained solution, and it is presented on figure 6.

The resulting expression is a general solution for the voltage on the capacitor in the transitional regime. The expression is very complex and includes all the elements necessary to explain and present all the details of the processes that take place during the transitional regime. From the engineering viewpoint, it is possible to carry out a complete review at any moment during the transition process, and therefore the possibility of modeling the voltage and current characteristics of the capacitor because there are delay parameters (generators and the initial voltage on the capacitor) in the expression. From the education aspect, this expression is almost impossible to get using a numerical software tool and even less by hand.

$$
\begin{aligned}
&\frac{1}{2\,(a\,C\,R-2)}\,e^{-\frac{2\,t}{C\,R}-a(\tau_2+2)-a(t+\tau_2+2)-a(2\,t+\tau_2+1)}\\
&\Big(-2\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)+\frac{2}{C\,R}}\,e_0\,\theta(1-\tau_1)+\\
&\quad 2\,e^{\frac{2\,\tau_1}{C\,R}+a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)}\,e_0\,\theta(1-\tau_1)+\\
&\quad a\,C\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)+\frac{2}{C\,R}}\,R\,e_0\,\theta(1-\tau_1)-\\
&\quad a\,C\,e^{\frac{2\,\tau_1}{C\,R}+a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)}\,R\,e_0\,\theta(1-\tau_1)+\\
&\quad 2\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)+\frac{2}{C\,R}}\,e_0\,\theta(1-t)\,\theta(1-\tau_1)-\\
&\quad 2\,e^{\frac{2\,\tau_1}{C\,R}+a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)}\,e_0\,\theta(1-t)\,\theta(1-\tau_1)-\\
&\quad a\,C\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)+\frac{2}{C\,R}}\,R\,e_0\,\theta(1-t)\\
&\quad \ldots\\
&\quad 2\,e^{2\,a\,t+a\,\tau_2+a(\tau_2+2)+a(t+\tau_2+2)+\frac{2}{C\,R}}\,e_0\,\theta(t-1)\,\theta(1-\tau_2)\\
&\qquad \theta(t-\tau_2)-2\,e^{2\,t\,a+(\tau_2+2)\,a+(t+\tau_2+2)\,a+a+\frac{2\,\tau_2}{C\,R}}\\
&\qquad e_0\,\theta(t-1)\,\theta(1-\tau_2)\,\theta(t-\tau_2)+\\
&\quad 2\,e^{\tau_2\,a+(t+\tau_2+2)\,a+(2\,t+\tau_2+1)\,a+2\,a}\,e_0\,\theta(1-\tau_2)\,\theta(-\tau_2)-\\
&\quad 2\,e^{(t+\tau_2+2)\,a+(2\,t+\tau_2+1)\,a+2\,a+\frac{2\,\tau_2}{C\,R}}\,e_0\,\theta(1-\tau_2)\,\theta(-\tau_2)-\\
&\quad 4\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)}\,U_0\,\theta(t-\tau_3)+\\
&\quad 2\,a\,C\,e^{a(\tau_2+2)+a(t+\tau_2+2)+a(2\,t+\tau_2+1)}\,R\,U_0\,\theta(t-\tau_3)\Big)
\end{aligned}
$$

Fig. 6. Close form expression of transient response in electrical circuit for observed case

Based on the obtained expression, it is no longer difficult to get a graphic interpretation of the shape of the curve as responses. Thus, figure 7 shows the response of the voltage on the capacitor in the transitional regime for different values of the inclusion excitation voltage generator.

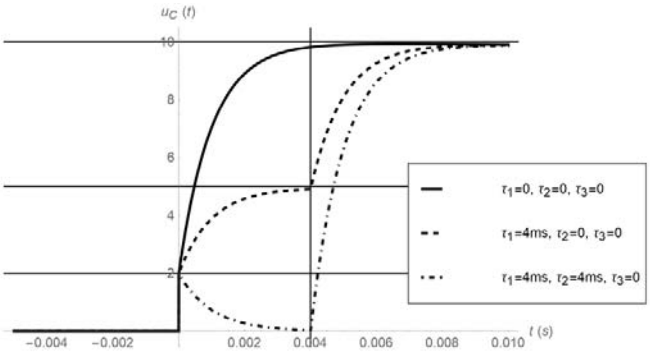

Fig. 7. The voltage on the capacitor in the transitional regime for different values of the activation of the excitation voltage generators setting by time constants delays

Similarly, as in the previous figure, Figure 8 shows current's responses through the capacitor for different values for different values of turning on of the excitation voltage generator.

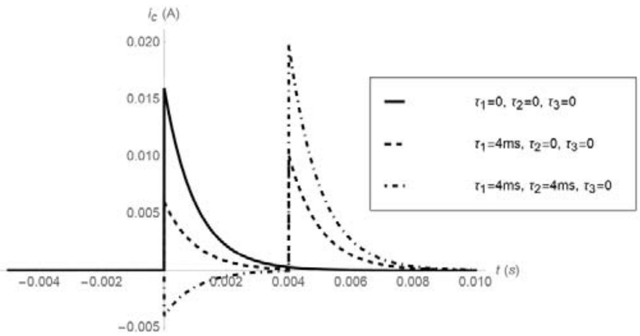

Fig. 8. The currents through the capacitor in the transitional regime for different values of the activation of the excitation voltage generator setting by time constants delays

Thus obtained solutions allow the engineers to better model the transient processes, and students to have a better insight into process behavior of voltage and current through the passive components on which place transitional regime. It should be noted that in this way it is possible to analyze each electrical circuit, even more complex. Also, one should not ignore the fact that in a similar way we can describe processes in the transition response when a coil is present in the circuit.

Of course, all of this analysis conducted are and tested on Raspberry Pi computers with Raspbian operating system and with the open-source Wolfram Mathematica to write program code.

VI. Conclusion

The presented approach for analysis and education of students of electrical circuits is presented. Obtained solutions are in close form expression where engineers can model transient response, and student can have better insight into transient regime. Obtained expressions can be used for further manipulation and processing. This procedure has a few advantages. First, the future engineer does not need to know too much the field of differential equations, their types and ways of solving them. Second, there is no possibility of a wrong solution transient regime. Third, all the solutions are obtained in a closed form so can be analyzed during the transient regime. Fourth, there is the possibility of further use of the obtained expression for post processing and post manipulation.

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Abstract

U ovom radu, prikazana je nova metoda i metodologija za obrazovanje studenata elektrotehnike na jeftinim računarima i besplatnom softveru kao što je računarski algebarski system (CAS). Dobijena rešenja su simbolički izrazi koji indiciraju prolazno režime u zatvorenom obliku. Takvi izrazi mogu se dalje koristiti za manipulaciju i obradu.

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