Using Excel Spreadsheets to simulate the Electric Circuits of Alternating Current

Ionel Grigore¹²

(1) Faculty of Physics, University of Bucharest, Bucharest-Magurele, Romania
(2) "Lazăr Edeleanu’’ Technical College, Ploiești, Romania
E-mail: grigore_nl@yahoo.com

Abstract
This paper presents an instrument used to simulate the RLC series circuit of alternating current utilizing Excel spreadsheets. There are highlighted the facilities offered by spreadsheets both for the calculus of measures specific for the alternating current, and for the graphic representations. There is a detailed presentation of the design of the instrument with the aid of the functions placed at disposal by the program Microsoft Excel. The instrument is useful both in teaching and learning, and it can easily be adapted in other situations.

Keywords: Spreadsheet, Excel, Alternating Current, RLC circuit, Physics.

1. Introduction
The results of tests applied in a series of countries have shown that students possess certain erroneous conceptions when it comes to interpreting measures and phenomena connected to electric circuits (Shipstonet et al. 1988; Sencar, 2004).

A study guided by the constructivist theory that focused on students’ understanding of the electric circuits has been carried out by D. P. Shepardson and Elizabeth B. Moje. At the end of a training unit, after the interviews taken to each student from a tested batch, the conclusion was that electric circuits have been understood more easily from a technical point of view, but there have been some major difficulties in the correct scientific understanding of the electric current. Consequently, it has been stated that for an effective teaching process, and, respectively, an objective assessment, a restructuring of acquisitions is imposed (Shepardson, 1994). Also, it frequently happens for students to have some wrong conceptions even after the instruction, a concrete example being the confusions between current, voltage and electric resistance (Engelhardt, 2004).

Following the direction of the constructivist approach, the spreadsheet can represent both an efficient modeling and a simulation instrument for the study of electric circuits, and any teacher can apply diverse models of tabular calculus for simulation (Silva, 1994); at the same time, the spreadsheet can be used to help students learn about the electric circuit (Kellog, 1993).

The advantages of spreadsheets, from the simple user-friendly interface, to the rapid feedback when changing data and the large number of functions at the user’s disposal, have been presented in a series of papers (Cooke, 1997; Subedi, 2007) and need no further emphasis.

It needs to be noted that modern spreadsheets contain a macro language that allows users to include programs specific for their operation, such as Visual Basic for Application (VBA) for Microsoft Excel. In this respect, M. Aliane’s article describes how Microsoft Excel can be used as an alternative platform for the development of interactive learning instruments in the educational field (Aliane, 2008).
The present paper develops an instrument for the simulation of the RLC series circuit of alternating current with the aid of the Excel 2010 spreadsheets. There are exploited both the calculation capacities in Excel, and the graphic facilities offered by this program. Thus, with the help of the input data, we obtain two categories of results, on the one hand constant measures connected to the electric circuit, and on the other, variations of measures according to time, visualized through associated graphic representations.

2. Theoretical background

The RLC series circuit consists of a grouping made up of a resistor with electrical resistance R, an inductor with inductance L and a capacitor with capacitance C, all connected in series to the terminals of the AC voltage source. We consider that the inductor and the capacitor are ideal, meaning lacking electric resistance.

By applying a sinusoidal alternating voltage, $u(t)$, to the grouping, in the form:

$$u(t) = U_m \sin \omega t$$

the current through the circuit, $i(t)$, in a permanent state is also sinusoidal, so that we can write:

$$i(t) = I_m \sin (\omega t - \phi_0)$$

where $\omega$ represents the angular frequency of the voltage applied, $U_m$, $I_m$ the maximal values of the voltage, respectively of the sinusoidal current, $\phi_0$ the phase angle between voltage and current, $t$ the time variable.

The angular frequency is connected to the period, $T$, and the physical frequency, $f$, by the relation:

$$\omega = \frac{2\pi}{T} = 2\pi f$$

The link between $U_m$ and $I_m$ is:

$$I_m = \frac{U_m}{Z}$$

where $Z$ represents the impedance of the RLC series circuit, function of parameters $R$, $L$, $C$ of the circuit and the angular frequency $\omega$:

$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C} - \frac{1}{\omega L}\right)^2}$$

The measures:

$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C}$$

represent the inductive reactance, respectively the capacitive reactance of the RLC series circuit.

The phase angle between the voltage applied to the terminals of the grouping and the current through the circuit, $\phi_0$, is given by the equation:

$$\tan \phi_0 = \frac{X_L - X_C}{R}$$

According to the values of the two reactances we have the following three situations:

- $X_L > X_C$: we obtain $\phi_0 > 0$. In this case the inductive reactance prevails and the current through the circuit is phased as a consequence of the voltage applied to the terminals of the grouping;
- $X_L = X_C$: we obtain $\phi_0 = 0$. In this case the inductive reactance and the capacitive reactance compensate each other and the circuit has a purely resistive behavior, thus resulting the resonance phenomenon;
• $X_L < X_C$ we obtain $\varphi_0 < 0$. In this case the capacitive reactance prevails and the current through the circuit is phased before the voltage applied to the terminals of the grouping.

The resonance frequency, $f_0$, is immediately obtained from the equality of the inductive and capacitive reactances:

$$[9] \quad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

At the resonance, the impedance of the circuit becomes minimum, equal to the resistance of the circuit, $Z = R$, and the electric current through the circuit, $I_{\text{rm}}$, becomes maximal (Nicula et al. 1982):

$$[10] \quad I_{\text{rm}} = \frac{U_m}{R}$$

The quality factor, $Q$, of the circuit is:

$$[11] \quad Q = \frac{1}{\frac{R}{C}}$$

From an energetic point of view, we can characterize the alternating current circuit through several types of powers. For the following ones, we only state the types of powers, specifying the corresponding calculus relations. We have:

• Instantaneous power, $p(t)$

$$[12] \quad p(t) = u(t) \cdot i(t)$$

• Active power, $P_a$

$$[13] \quad P_a = \frac{1}{2} U_m I_{\text{m}} \cos \varphi_0$$

• Reactive power, $P_r$

$$[14] \quad P_r = \frac{1}{2} U_m I_{\text{m}} \sin \varphi_0$$

• Apparent power, $S$

$$[15] \quad S = \frac{1}{2} U_m I_{\text{m}} = \sqrt{P_a^2 + P_r^2}$$

The significance of the measures that intervene in the equations [12]-[15] is that of the previous formula [1]-[8].

The current-voltage diagram phasor, the physical interpretation and other observations connected to powers are presented in any introductory course of Physics that treats the circuits of alternating current and need no further emphasis (Nicula et al. 1982; Purcell 2013).

3. The “RLC Simulation” Instrument

With the aid of the “RLC Simulation” instrument we can simulate the behavior of an RLC series circuit of alternating current. Knowing the maximum voltage applied to the terminals of the circuit, the physical frequency of the voltage applied and the parameters of the circuit, the resistance of the resistor, the inductance of the inductor and the capacity of the capacitor, we can determine the maximum current through the circuit, the phase angle voltage-current, as well as other measures, but, at the same time, visualize the voltage, current and instantaneous power curbs, according to time, observing how they are phased in relation to one another. Both the inductor and the capacitor are considered ideal, therefore lacking electric resistance.

The instrument is made up of the main calculation spreadsheet rendered in figure 1 with the sections “Data Input” and “Results”, plus a secondary spreadsheet that contains the source table for the charts placed in the main spreadsheet next to the two sections.
The section “Data Input” comprises two subsections, namely, one connected to the measures characteristic to the source, entitles “AC voltage source”, and a second one connected to the elements of the circuit exterior to the source, entitles “Parameters of the RLC circuit”. In the first subsection the following data are introduced: physical frequency of the voltage applied, \(f\), expressed in Hertz (Hz) and the maximum voltage, \(U_{m}\), applied to the terminals of the grouping, expressed in Volts (V). In the second subsection the following data are introduced: the resistance of the resistor, \(R\), expressed in Ohms (\(\Omega\)), inductance of the inductor, \(L\), expressed in miliHenries (mH) and the capacity of the capacitor, \(C\), expressed in microFarads (\(\mu\)F).

In the section “Results” we obtain the calculated values, according to the data introduced in the first section, for: inductive reactance, \(X_L\), in Ohms, capacitive reactance \(X_C\), in Ohms, impedance of the circuit, \(Z\), in Ohms, maximum current in the circuit, \(I_{m}\), in Amperes, the phase angle between voltage and current, \(\phi_0\), in degrees, the active \(P_a\), reactive, \(P_r\), and apparent, \(S\), powers in Watts, the resonance frequency of the circuit, \(f_0\), in Hertz, the quality factor of the circuit, \(Q\), the current through the circuit at resonance, \(I_{m}\), in Amperes. Under the table of calculated values, in an extended cell, it is displayed the type of regime in which the circuit works, namely inductive or capacitive regime or resonance regime according to the entry data.

In order to make the calculation more comfortable in Excel and intervene more easily in the case of errors, we name the cells where the data are introduced together with some cells, in which the results are displayed, also constituting, in their turn, data in the calculation of other measures, in conformity with the table below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Cell</th>
<th>Name</th>
<th>No.</th>
<th>Cell</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B5</td>
<td>Frequency</td>
<td>6</td>
<td>B13</td>
<td>Reactance L</td>
</tr>
<tr>
<td>2</td>
<td>B6</td>
<td>Voltage Max</td>
<td>7</td>
<td>B14</td>
<td>Reactance C</td>
</tr>
<tr>
<td>3</td>
<td>B8</td>
<td>Resistance</td>
<td>8</td>
<td>B15</td>
<td>Impedance</td>
</tr>
<tr>
<td>4</td>
<td>B9</td>
<td>Inductance</td>
<td>9</td>
<td>B16</td>
<td>Current Max</td>
</tr>
<tr>
<td>5</td>
<td>B10</td>
<td>Capacitance</td>
<td>10</td>
<td>B17</td>
<td>Phase_angle</td>
</tr>
</tbody>
</table>

*Table 1. Names of cells in the main spreadsheet*
Next, with the notations we introduced, taking into account the equations [4]-[15], we have rendered the transcription in Excel for the calculus of the following measures:

- **Inductive reactance,** $X_L$, in cell B13:
  
  $$=2\pi f L \times 10^{-3}$$, where we multiplied $10^{-3}$ to transform from mH to H;

- **Capacitive reactance,** $X_C$, in cell B14:
  
  $$=\frac{1}{2\pi f C \times 10^{-6}}$$, where we multiplied $10^{-6}$ to transform from $\mu F$ to F;

- **Impedance, Z**, in cell B15:
  
  $$=\sqrt{R^2 + (X_L - X_C)^2}$$

- **Maximum current,** $I_m$, in cell B16:
  
  $$=\frac{V_{max}}{Z}$$

- **Phase angle between voltage-current,** $\phi_0$, in cell B17:
  
  $$=\text{DEGREES}(\text{ATAN}((X_L - X_C)/R))$$

- **Active power,** $P_a$, in cell B18:
  
  $$=\frac{1}{2}V_{max}I_{max}\cos(\text{RADIANS}(\phi_0))$$

- ** Reactive power,** $P_r$, in cell B19:
  
  $$=\frac{1}{2}V_{max}I_{max}\sin(\text{RADIANS}(\phi_0))$$

- **Apparent power,** $S$, in cell B20:
  
  $$=\frac{1}{2}V_{max}I_{max}$$

- **Resonance frequency,** $f_0$, in cell B21:
  
  $$=\frac{1}{2\pi \sqrt{L C \times 10^{-6}}(10^{-3})^2}$$

- **Quality factor,** $Q$, in cell B22:
  
  $$=(1/R)\sqrt{L/C \times 1000}$$, where we multiplied with 1000 taking into account that the inductance is expressed in mH and the capacity in $\mu F$;

- **Current at resonance,** $I_{m0}$, in cell B23:
  
  $$=\frac{V_{max}}{R}$$

To display the type of regime in cell A24 we will write the Excel formula:

$$=\text{CONCATENATE}(\text{IF}(X_L=X_C;"RESONANCE";\text{IF}(X_L>X_C;"INDUCTIVE";"CAPACITIVE"));"";"";""))$$

In the previous formula we have used twice the logical function IF taking into account the three types of regime in which the circuit can function, namely, inductive, capacitive and of resonance. Also, we have utilized the function CONCATENATE that operates on a series of characters to write the word “Regime” in the same cell with the result obtained for the type of regime following the application of the logical function IF.

To obtain the charts that render the time dependencies of the voltage, current and instantaneous power, we build the source table in the secondary worksheet of the file. As it can be observed in figure 2, along the column B we generate increasingly the values of the moments in time starting from $t=0$, and in the columns C, D and F, according to the values in B, we calculate the voltage $u(t)$, current $i(t)$ and the momentary power, $p(t)$.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Source table for curves of voltage, current and instantaneous power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>n</td>
<td>$t[g]$</td>
<td>$u(t)[V]$</td>
<td>$i(t)[A]$</td>
<td>$</td>
<td>i(t)</td>
<td>[100A]$</td>
<td>$p(t)[W]$</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.0000</td>
<td>0.00</td>
<td>-0.59</td>
<td>-40.98</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.0002</td>
<td>7.85</td>
<td>-0.88</td>
<td>-82.85</td>
<td>-6.24</td>
<td>-62.40</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>0.0004</td>
<td>15.78</td>
<td>-0.79</td>
<td>-75.28</td>
<td>-11.52</td>
<td>-115.20</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>0.0006</td>
<td>22.58</td>
<td>-0.56</td>
<td>-87.25</td>
<td>-16.16</td>
<td>-161.60</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>0.0008</td>
<td>29.94</td>
<td>-0.59</td>
<td>-93.24</td>
<td>-17.89</td>
<td>-178.90</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2. Secondary spreadsheet with the source table for charts*
The generation of the time moments in column B is done with the help of a time quantum equal to the 100th part of the period of voltage applied and using the increasing series noted with “n”, with the unit step starting from n=0, from the column A. Thus, in the cell B4 the start value is generated according to the Excel formula “=A4*(1/(Frequency*100))”, and the rest of the values up to n=225, corresponding to the line 229, are obtained through the propagation of the formula from B4 along the column B. We have chosen n=225 to visualize the curbs in a time interval equal to 2T+(T/4) measured from t=0, when u=0, where T is the period of voltage u(t), obviously equal to the period of current i(t) and the instantaneous power, p(t).

For the calculation of the values from the columns C, D and F we transpose in Excel the relations [1], [2], [12]. Thus, in the cells C4, D4 and F4 we write the formulas:

- C4: “=Voltage_Max*SIN(2*PI()*Frequency*B4)”;
- D4: “=Current_Max*SIN(2*PI()*Frequency*B4-RADIANS(Phase_angle))”;
- F4: “=C4*D4”.

By propagating the previous formulas along the columns C, D, and F up to the last line of the table, corresponding to n=225, we obtain the values of the voltage, current and instantaneous power according to time. In figure 2 there are rendered the first five values of these measures from the 4th line to the 8th line of the secondary spreadsheet.

For a better visualization of the charts of the three measures according to time within the same diagram, considering that the first point of interest is the way in which the respective measures are phased, we have utilized the values from columns B, C, E and G, where in column E there are the values of the current from the column D multiplied by a factor 100, and in the column G the values of the power from column F multiplied with a factor 10.

The chart that renders the instantaneous power according to time using the entry data from figure 1, overlapped on the voltage and current charts is presented in figure 3.

By modifying the entry data we can track the changes in results and in the corresponding diagrams. With the help of the “freeze panel” command, from the menu “Window”, we can bring any of the two diagrams exactly near the table with the entry data so that we can rapidly observe the feedback on the charts when the data are changed.
4. Conclusions
The “Simulation RLC” instrument can be used within an interactive lesson about the electric alternating current, firstly facilitating the acquisition of knowledge regarding the RLC series circuit of alternating current. Through its design, it can be adapted or particularized also for the simulation of other types of circuits. Thus, by correspondingly modifying the calculation formula, we can transform the instrument so that we simulate the RLC parallel circuit, or, in particular, to obtain the simulation of the RL, RC, LC series or parallel of alternating current circuits.

With the help of this instrument, by changing the entry data, different particular cases can be analyzed, immediately obtaining feedback in results and in the associated diagrams. It becomes more efficient in both the teaching and learning of alternating current, and, thus, students can more easily understand this chapter of Physics.

5. References

Books:

Journal Articles:

Computer Programs:
Microsoft Excel 2010.