Computing in Circuits and Systems

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Professor Mousavinezhad was EE/EECS Department Chair, 2007-2013 and teaches classes in circuits & systems, digital signal processing and communication systems. Before joining Idaho State University in 2007, Dr. Mousavinezhad served as Electrical/Computer Engineering Department Chair and Professor at Western Michigan University, Kalamazoo, Michigan. He has been an invited keynote speaker for national and international conferences. He has been a Program Evaluator for ABET Electrical/Computer Engineering, Computer Science and Engineering programs in the US and for international programs.

COMPUTING in CIRCUITS and SYSTEMS

Abstract. Many engineering and computing programs offer an introductory course on electric circuits analysis. Typically this is a three (3) credit hours lecture course, in some schools accompanied by a 1 credit laboratory section. In our school the first circuit course is offered without a laboratory section. It is therefore helpful for student learning to incorporate into the course practical examples where students can use computer software packages like Matlab, Mathcad or PSpice to solve circuit problems. Several textbooks are available that include examples introducing students to use these computing and information technology tools. For some majors the circuits course is followed by a course in Signals & Systems where circuits are seen again as examples of systems.

Introduction. Authors have taught introductory circuits classes as well as signals & systems, sensors, and digital signal processing courses where the use of information technology tools have helped students, especially when dealing with abstract concepts such as circuit analysis techniques, first-order, second-order circuits, filters, frequency response, impedance matching, transfer function, transforms, and signal to noise ratio. With widespread use of the software packages it becomes important for engineering educators to consider using these powerful packages at the right place, right time. Circuits are usually taken by engineering majors or some computer science students as their first engineering course after calculus. Some programs (e.g., computer science, computer engineering or electrical engineering) include a digital (logic) circuits class as the first engineering course. Software packages are available in computer laboratories so students can access them for problem solutions, graphing and analyzing more complex circuits/systems where they may be solving systems of equations with several circuit unknowns and variables.

Some students have introductory familiarity with these computing tools, for example they have seen Matlab examples before, also the text has brief tutorial and examples of using software tool (mostly Matlab). In class we briefly introduce also the Mathcad where it is easier, for example, to enter mathematical expressions, functions and obtain graphs and manipulate/format them on the worksheet. Mathcad is a symbolic programming language where mathematical expressions are entered as they are written naturally on a paper. It is a valuable problem-solving tool for students of mathematics, science, engineering and computing. Of course other software systems are also available as computer-aided analysis/design tools, they include Maple, Mathematica (in our universities all students, faculty and staff can access the software), as well as WFilter. WFilter is used in design of analog and digital filters and also includes specifications of the PSpice circuit elements to implement these filters in real-time; it is more useful in upper-division design classes and in elective courses. In an introductory course it is good to use one or maybe two such software packages for simulation. In this paper emphasis will be on using Mathcad and Matlab examples for enhancing student learning of difficult engineering concepts and abstractions.

Circuits course topics. There are excellent textbooks available in this subject area, for example [1], [2], [3]. Course starts by introducing basic concepts in electric circuits, voltage, current, charge, power/energy; international system of units (SI) as well as how to state/formulate engineering problems. Circuit laws are introduced next in addition to conservation principles

(charge & energy.) In addition to circuit (system) elements (components) like resistors, voltage/current sources, the course also has an introduction to operational amplifiers (Op-Amps) which are useful for topics considered in other courses such as active filters and electronics. One place to introduce software packages is where Kirchhoff's laws are used (KVL, KCL) to derive systems of linear equations: circuit analysis methods known as nodal & mesh analyses. First part of course resistive circuits are analyzed, then (after Op-Amp) we cover energy storage elements: capacitors and inductors. This will lead into discussion of first-order and second-order circuits which of course are represented by differential equations. The circuits class in our schools is taken by EE majors as well as ME & NE students. It is also noted that successful completion of the circuits class for majors is a good indication of academic success [4]. The circuits class is one of the subjects where students encounter seemingly abstract concepts (for example see [5]), therefore it is important to use computer tools at the right time, right place to help student learning. A review of literature shows that use of simulation can be a bridge between theory and reality, see for example [6]. Next we show some examples from class problems using the IT tools, more examples, data will be shown during the presentation at the conference.

Example 1. As a first example consider the following problem (homework problem, circuit drawn in "Lab Notebook"), students are asked to compute node voltages V_1 and V_2 then verify the principle of conservation of energy (power.)
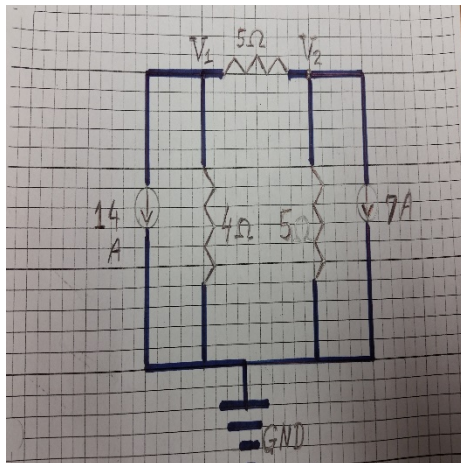
Solution. Working with KCLs at nodes 1 and 2 equations are written as:

$$14 + V_1 / 4\Omega + (V_1 - V_2) / 5\Omega = 0$$

$$(V_1 - V_2) / 5\Omega = V_2 / 5\Omega + 7$$

These 2 equations are put in standard form:

$$9V_1 - 4V_2 = -280$$
$$V_1 - 2 V_2 = 35$$

With solutions obtained as $V_1 = -50$ V , $V_2 = -42.5$ V .

At this time it is pointed out that the system of equations above can be put in matrix form AX = B and solved, for example, using Matlab:

```
>> % Nodal Analysis, Spring 2017
>> A=[9 -4;1 -2];
>> B=[-280;35];
>> inv(A)*B
ans =

 -50.0000
 -42.5000
>>
```

Once node voltages are computed, students can check the balance of power:

Absorbed powers:

$P_{5\Omega} = 11.25$ W (this is the 5Ω between nodes 1 and 2)

$P'_{5\Omega} = 361.25$ W (the 5Ω resistor between node 2 and the ground)

$P_{4\Omega} = 625$ W

$\Sigma\ P_{abs.} = 997.5$ W

$P_{14A} = (-14)(-50) = 700$ W

$P_{7A} = (-7)(-42.5) = 297.5$ W

Conclusion is that power equation is balanced : $(700 + 297.5)W = 997.5$ W or $\Sigma\ P_{del.} = \Sigma\ P_{abs.}$.

There are special cases of nodal analysis, for example in the above example a voltage source can be placed in place of the 5Ω resistor between nodes 1 and 2. As a numerical example suppose there is a voltage of 5V between nodes 1 and 2 where "+" polarity is at node 1. In this case students are reminded of the constraint and super-node equations:

$V_1 - V_2 = 5$ (constraint)

$14 + V_1 / 4\Omega + V_2 / 5\Omega + 7 = 0$ or $5V_1 + 4V_2 = -420$ (super-node)

These equations can be solved with Matlab as well:

>> A=[1 -1;5 4];

>> B=[5;-420];

>> inv(A)*B

ans =

  -44.4444
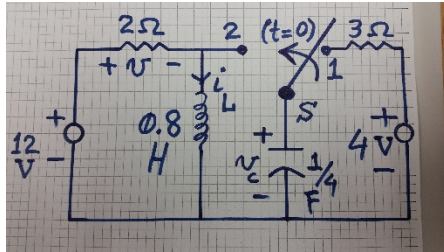
  -49.4444

>>

So $V_1 = -44.44$ V and $V_2 = -49.44$ V (approximately).

This time the power calculations show about 982.59 W total absorbed power and 982.69 W delivered which is close since we approximated V_1 and V_2 to 2 decimal places.

Example 2. In this example we show a second-order system (circuit) described by second-order differential equation. The system is in steady-state for $t < 0$, at $t = 0$ the switch S is moved from

position 1 to 2. Student solve this problem beginning with determination of initial conditions (ICs) which are calculated as:

$v_c(0) = V_0 = 4$ V   and $i_L(0) = I_0 = 12$ V/ $2\Omega = 6$ A. It is noted that because of DC sources these conditions are computed by opening the capacitor and shorting the

inductor. Then for the $t > 0$ the circuit consists of the RLC + DC source (12 V source.) At this point they can either write the differential equation for solving for voltages or currents in the circuit or recognizing that the natural response of the circuit for positive time is that of the parallel RLC system. There are 2 parameters needed to find this response:

$\alpha_p = 1/(2RC) = 1$ 1/sec.

$\omega_0 = 1/(LC)^{1/2} = \sqrt{5}$ rad./sec.

So the response is under-damped. If we select capacitor's voltage as the main unknown we have:

$$v_c(t) = A \exp(-t) \cos(2t) + B \exp(-t) \sin(2t) + v_f$$

where A & B are constant coefficients to be determined from initial conditions, v_f is forced response which is zero in this case (capacitor is in parallel with inductor which is shorted as $t \to \infty$). Also we used roots of characteristic equation involving α_p and ω_0 computed earlier. Students have difficulty finding the second initial condition, dv_c/dt at $t = 0$. This can be found by looking at circuit for $t = 0+$ and noting that the current from 12 V source is:

$(12 - 4)$ V / $2\Omega = 4$ Amp. Then apply Kirchhoff's Current Law to get:

$4 = 6 + 0.25 \, dv_c/dt \, |_{t = 0}$, we find that $dv_c/dt \, |_{t = 0} = -8$ V/sec.

We finally apply initial conditions to get constants A & B:

$A = 4$, $B = -2$

Capacitor's voltage (a key variable) is then given as:

$v_c(t) = 4 \exp(-t) \cos(2t) - 2 \exp(-t) \sin(2t)$ V , $t \geq 0$.

We now calculate the voltage across the 2Ω resistor shown on the circuit as:

$v(t) = 12 - 4 \exp(-t) \cos(2t) + 2 \exp(-t) \sin(2t)$ V , $t \geq 0$.

In discussion about second-order circuits, it is mentioned that the response [e.g., v(t) shown above] will reach steady-state value as $t \to \infty$, because natural response was underdamped, there

will be a peak value of the voltage before it settles down. We illustrate this using Mathcad software next.

RLC Circuit Response with DC Source
Spring 2017

$$t := 0, 0.1 .. 10$$

$$v(t) := 12 - 4 \cdot \exp(-t) \cdot \cos(2 \cdot t) + 2 \cdot \exp(-t) \cdot \sin(2 \cdot t)$$

DC RLC CIRCUIT UNDERDAMPED RESPONSE
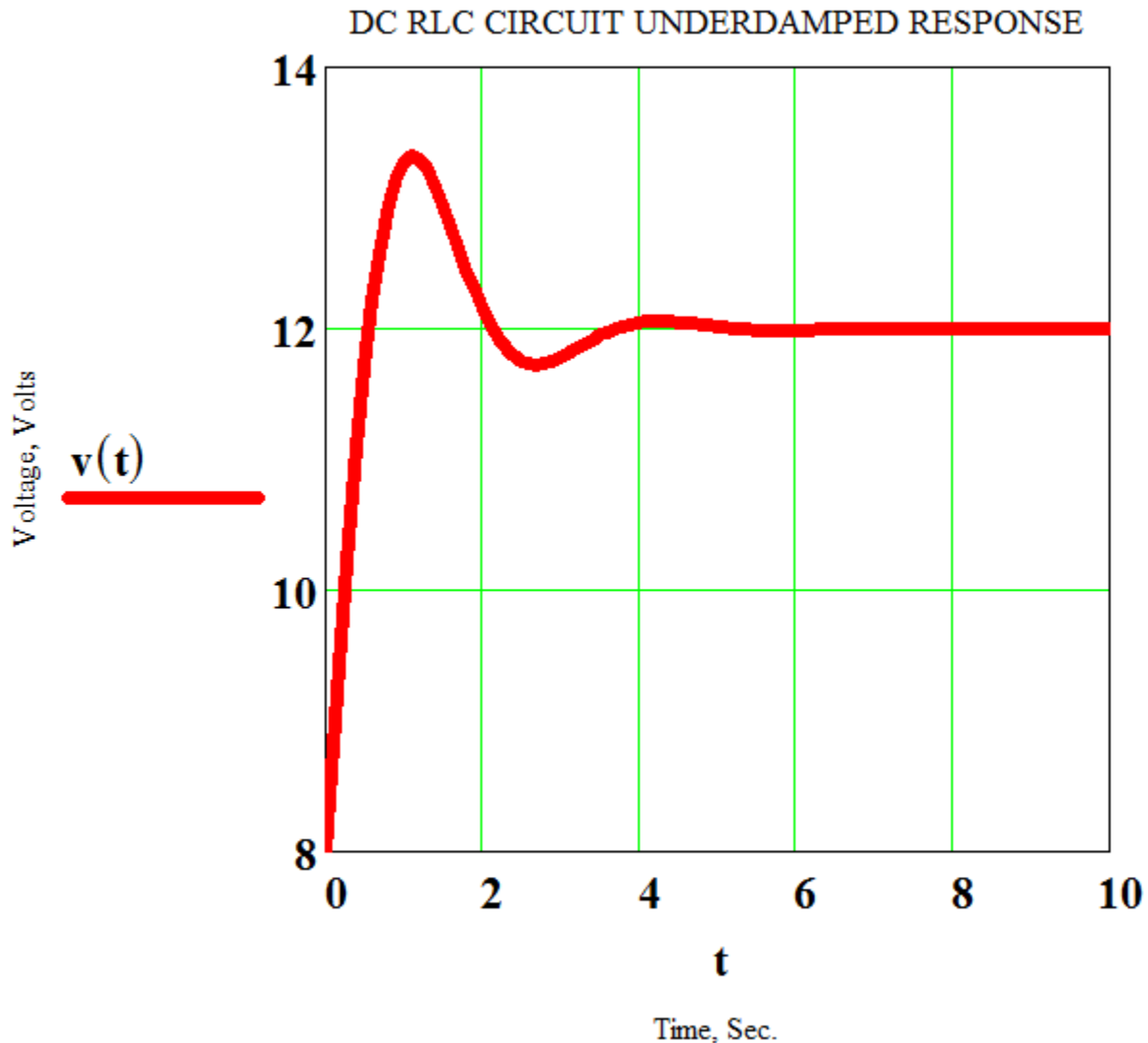
Conclusions. We have introduced use of computing and information technology tools in engineering circuits analysis course. This course is foundation for later courses in signals and systems and other electrical, mechanical, nuclear, and computer engineering courses. Included are a couple of examples where students use these tools to check their results, obtain graphical

representation and do simulations. Because this is an engineering fundamentals course one has to be careful to introduce the use of software packages after students have mastered basic laws such as Ohm's Law and Kirchhoff's Laws and also have an appreciation of basic physical principles including conservation laws (charge and energy.) Student response has been positive when they use these tools to aid in their visualization and understanding of some abstract concepts. Student Outcomes (see [7]) covered by the course are outcomes (a) and (e) (an ability to apply knowledge of mathematics, science, and engineering; an ability to identify, formulate, and solve engineering problems.) Because the first circuits course is offered to majors as well as non-majors, we introduce students gradually to these IT tools, some for example will have full programming class in Matlab, in their programs. EE majors will see more circuit applications also use more advanced Matlab programming methods (e.g., functions, m-files) as well as PSpice. In EE there is an elective course where students use Wfilter ([8]), a tool for designing analog filter circuits and digital filters. There will be more examples presented during the conference as well as student outcomes assessment data.

R E F E R E N C E S

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[4]. Investigating Student Motivation and Performance in Electrical Engineering and Its Sub-Disciplines, by Foley, Daly, Lenaway and Phillips, IEEE Transactions on Education, November 2016.

[5]. Conceptual Gaps in Circuits Textbooks: A Comparative Study, by Sangam and Jesiek, IEEE Transactions on Education, August 2015.

[6]. Simulation – a bridge between theory and reality: the case of electric circuits, by Ronen and Eliahu, Journal of Computer Assisted Learning, 2000.

[7]. Engineering Accreditation Criteria, http://www.abet.org/accreditation/accreditation-criteria/.

[8]. Practical Analog and Digital Filter Design, by Les Thede, Artech House, 2005.