SECTION C

A Concept Diagram for Transient Circuit Analysis Instruction

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ABSTRACT

Transient circuit analysis is a particularly challenging topic in introductory circuit analysis courses. In illustrating the solution of transient analysis problems, many textbooks emphasize the procedure of problem solving. While such focus provides valuable training for students, we believe an in-depth understanding of critical concepts in transient process is crucial and needs to be emphasized in classroom instruction. In this paper, a concept diagram is presented that focuses on three critical time instants for transient analysis. Important concepts for each time instant are clearly presented by this simple diagram, which integrates all relevant concepts in an organized manner. The diagram is an effective tool for outlining and reviewing transient analysis concepts.

Background and Motivation

This paper addresses the instruction of an important subject in introductory electrical engineering (EE) courses, transient circuit analysis. It is well known that most engineering students, including both EE and non-EE majors, find transient analysis challenging and hard to grasp. In fact, based on our teaching experience, non-EE students consider transient analysis the most difficult topic in introductory circuit analysis courses.

When there is a switch in the circuit, the change in the switch position results in a sudden change in the circuit structure. If there is a capacitor or an inductor in the circuit, a transient process will begin as the circuit rebalances itself toward a new steady state. Since capacitor voltage and inductor current cannot change suddenly to achieve a new steady state value, transient analysis is very important when we want to study how the circuit parameters, such as voltages and currents, evolve with time. Practical examples include charging a camera flashlight, shutting off a motor while avoiding a sudden voltage change to destroy the motor, etc. The major challenge students face when learning transient analysis is to establish fundamental connections between key concepts in differential equations and in transient process. This subject not only requires solid foundation in first and second order ordinary differential equations, but also the ability to describe and analyze a physical process with mathematical equations, a critical skill to be developed for engineering students.

Many textbooks provide a comprehensive coverage of materials necessary for transient analysis, and illustrate the problem solving process through various example problems (e.g., Hambley, 2007; Kerns & Irwin, 2004; Rizzoni, 2007 & 2009). The presentation often focuses on the procedure of problem solving, such as identifying the initial and final conditions, establishing the differential equations, and determining the parameters in the general-form solution of differential equations. While such presentation provides valuable training for students to follow certain standard solution procedure, a coherent insight into critical concepts in transient process is crucial and needs to be emphasized in classroom instruction. Otherwise, students can easily lose the view of "big picture" when trying to solve problems using the standard procedure.

It is our belief that a unified framework is needed to present essential transient process concepts in a succinct and logical manner. This will help students acquire an organic system of knowledge on this subject. For such a purpose, a concept diagram is proposed in this paper for effective instruction of transient analysis. The diagram concisely presents key concepts in transient analysis and illustrates their logical connections. These include: steady-state equivalent models for capacitors and inductors, continuity of V_C (voltage across capacitor) and I_L (current across inductor), initial and final conditions identification, and differential equations describing transient processes using KCL (Kirchhoff's Current Law) or KVL (Kirchhoff's Voltage Law).

The Concept Diagram

Figure 1 is the concept diagram developed to facilitate the instruction of transient analysis. The focus is on three critical time instants essential to the solution of transient circuits: $t = 0-$, the instant before the switch changes position; $t = 0+$, the instant immediately after the switch changes position; and $t \rightarrow \infty$, after the switch has been changed for a long period of time.

Steady State 1	Switch Changes	Initial Condition	Transient Process	Steady State 2
$t = 0-$	$\longrightarrow$	$t = 0+$	$\longrightarrow$	$t \rightarrow \infty$
C: open	$V_C(0-) = V_C(0+)$	$V_C(0+)$	Diff. Equation by	C: open
L: short	$I_L(0-) = I_L(0+)$	$I_L(0+)$	KCL or KVL	L: short

Figure 1. Concept diagram for transient analysis

As can be seen, key information at each time instant is provided in the diagram. Also, the transitions between time instants are clearly described.

Explanation of the Concept Diagram

1) $t = 0-$, the instant before the switch changes position

This time instant is important because it is useful in determining the initial condition needed to solve a transient circuit problem. At this instant, circuit is in a steady state, i.e., voltages and currents are not varying with time (assuming DC sources). Therefore, there is no current across capacitors and no voltage across inductors. As a result, capacitors are considered open circuits, and inductors are considered short circuits. The two equivalent models allow us to solve for $V_C(0-)$ or $I_L(0-)$ conveniently.

2) $t = 0+$, the instant immediately after the switch changes position

This time instant is important because it is the starting point of the transient process, i.e., the initial condition for the differential equation corresponding to the transient process. The value of $V_C(0+)$ or $I_L(0+)$ needs to be obtained for the solution of the differential equation. In the case of second order transient circuits, $dV_C/dt(0+)$ or $dI_L/dt(0+)$ is also needed.

3) The transition from $t = 0-$ to $t = 0+$

The common problem for many textbooks is the lack of emphasis on distinguishing between $t = 0-$ and $t = 0+$. It is true that from the perspective of problem solving, $V_C(0+)$ equals to $V_C(0-)$, and $I_L(0+)$ equals to $I_L(0-)$. However, understanding the difference between the two time instants and their connection is essential to transient analysis. The sudden change in the switch position causes a change in the circuit structure, which forces the circuit to rebalance itself and establish a new steady state through the transient process, during which voltages and currents evolve towards their new stabilized values. Since the quantities that cannot change suddenly are V_C and I_L, we can easily get the value of the initial condition $V_C(0+)$ or $I_L(0+)$, which is identical to $V_C(0-)$ or $I_L(0-)$. For this very reason, we always establish differential equations in terms of V_C or I_L. The continuity of these two quantities makes it possible for us to determine the initial conditions. In the case of second-order circuits, $dV_C/dt(0+)$ or $dI_L/dt(0+)$ also needs to be obtained from $I_C(0+)$ or $V_L(0+)$, which can be solved through KCL or KVL equations at $t = 0+$.

4) $t \rightarrow \infty$, after the switch has been changed for a very long period of time

This is the new steady state called "final condition." Like the first steady state, all voltages and currents are again stabilized (assuming DC sources), so capacitors are considered open circuits, and inductors are considered short circuits. The value of V_C or I_L at $t \rightarrow \infty$ can be easily obtained by simple circuit analysis. It is worth mentioning that the final condition is embedded in the differential equation also. In fact, by letting the derivative terms go to zero, the final condition can be determined conveniently from the differential equation.

5) The transient process: from $t = 0+$ to $t \rightarrow \infty$

The evolution of the current and voltage quantities during the transient process is described by differential equations. Since KCL and KVL are always valid, they are often used to establish these differential equations. For parallel circuits, KCL is used; and for series circuits, KVL is used. In establishing the differential equations, it is important to focus on the desired variable (either V_C or I_L) and express other voltages and currents appearing in KCL or KVL in terms of V_C or I_L.

Instruction Methodology of Transient Analysis

Here we present our suggested methodology for the instruction of transient analysis:

1) It is highly beneficial to first review key concepts in first and second order differential equations and the general forms of their solutions. In particular, the importance of initial and final conditions, and how they are used to determine constants in general-form solutions need to be emphasized. This review refreshes students' memory about differential equations they have previously learned about.
2) The concept diagram is presented, as explained in the previous section.
3) Example transient problems are solved to illustrate the determination of constants in general-form solutions for first and second order transient circuits. For example, in first order networks, the general-form solution of V_C or I_L is: $x(t) = K_1 + K_2 e^{-t/\tau}$, where: $x(t)$ is either V_C or I_L; K_1 is a constant that is equal to the final condition; K_2 is another constant equal to the difference between the initial and final conditions, i.e., $x(0)-x(\infty)$; τ is the time constant. There is no need to list the differential equation to determine τ, only the equivalent resistance R_{TH} (with L or C considered as the load)

is needed. For RL network, $\tau=L/R_{TH}$; for RC first order network, $\tau=R_{TH}C$. For second order networks, the standard procedure to solve a second order differential equation needs to be followed. The most challenging part here is the identification of the second initial condition, i.e., $dV_C/dt(0+)$ or $dI_L/dt(0+)$. This involves applying KCL or KVL at $t = 0+$ to solve for $I_C(0+)$ or $V_L(0+)$.

4) Transient responses for sample circuits are plotted in MATLAB windows. It is important for students to see dynamic evolution of transient responses, and see the solution as a combination of forced and natural responses.
5) During the final review of transient analysis at the end of the semester, the concept diagram is again presented to outline key concepts and ensure students' grasp of the "whole picture."

Assessment questions can be designed at each stage to evaluate the effectiveness of this teaching practice. In particular, drawing the concept diagram as a quiz or one-minute paper is a good assessment tool. Also, asking students to explain the concept diagram to each other as a think-pair-share activity is also a valuable exercise.

Based on our experience, students respond very positively to the introduction of the concept diagram. After learning the concept diagram, many students indicated that they had a clear mental picture of transient process and expressed appreciation to us. We are currently planning to conduct a formal survey for assessment purpose in the near future. The survey questions are under preparation.

Conclusions

In this paper, a concept diagram is introduced to assist the instruction of transient analysis, a challenging topic in introductory electric circuit courses. The concept diagram clearly illustrates three important instants that are essential to the solution of transient circuit problems, and helps students establish a clear picture of the dynamic evolution of voltages and currents during the transient process. Combined with relevant example problems and assessment activities, the concept diagram is a highly effective tool for teaching and reviewing critical concepts in transient analysis.

References

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SECTION D

All I Ever Needed to Know About Economics, I Found at the Bottom of a Wine Glass!

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ABSTRACT

Teaching economics is typically an exercise in finding stimulating examples, games, and case studies to engage students in active learning. Students at Embry Riddle Aeronautical University, Andrews Air Force Campus, are the nontraditional adult students often earning their college degrees after hours while on active military duty. With an attention grabber like "Back to My Wine Glass," the students' interest gets piqued and they engage to apply the theories and tools covered in lectures. Crawling to the bottom of a wineglass in the classroom involves a series of classroom exercises and small case studies designed for use throughout introductory Macroeconomics and Microeconomics courses. Students are also encouraged to engage in critical thinking and to include interdisciplinary concepts in the classroom. This author has found a unique way to sneak in economic antioxidants in an unobtrusive manner with a little fun involved.

Introduction

Teaching economics is typically an exercise in finding stimulating examples, games, and case studies to engage students in active learning. In short, instructors need a pretty good song and dance! Students at Embry Riddle Aeronautical University, Andrews Air Force Campus, are the nontraditional adult students ranging in age from their mid 20s to the mid 40s, often earning their college degrees after hours while on active military duty. To further constrain full engagement of the student, this instructor's class meets for nine sequential Fridays, from five o'clock to ten o'clock p.m. Many of these students have been on duty all day, or worse, they attend class before going to work the night shift. Keeping these students engaged in classroom activities requires the effort of an off-Broadway show and dance routine. Instructors with nontraditional students need to use nontraditional methods. With the attention grabber "Back to My Wine Glass" phrase, the students' interest was piqued and they were engaged in applying the theories and tools covered in lectures.

Methods

Classroom Strategy. Crawling to the bottom of a wineglass in the classroom involved a series of classroom exercises and small case studies designed for use in both introductory Macroeconomics and Microeconomics classes. Throughout both courses, students used current supply and demand market data, labor and production costs, regulatory environment, pricing, elasticity measures, trade issues, and tax information to apply economic concepts to Virginia's wine industry. During the term of the courses, Virginia was the fourth largest state for wine production. Both courses required a term paper that encouraged most students to perform current economic analysis and prescribe actions the vintner may consider given the current economic climate. The class culminated with a virtual classroom visit by a local master vintner to discuss students' lessons and prescriptions for the vintners.

The inspiration for this idea came directly from three presentations at the Economics Teaching Conference at Robert Morris University. King (2009) used a popular television show *The Apprentice* to involve students in the application of economic theory. Jones and Wilson (2009) presented the economics of a rock concert with genuine stories and great visual supplements for lectures, drawing in the interest of students who probably have experience at rock concerts. And finally, Clark & Wolcutt (2009) presented a short skit where students took various roles, the audience participated, and the history and mechanics of the financial crisis was presented in a digestible manner. All three presentations had a common thread. Students who engage in interesting, fun, and familiar teaching activities retain more information and may even be inspired to learn more. At a local wine tasting and education seminar, this instructor realized that wine making had all the elements for a semester long example to deliver economic principles.

Integrating Wine into the Syllabus. The syllabus for each Macroeconomics and Microeconomics course was developed in a fairly traditional manner. Learning outcomes and a timeline for covering the theory were developed. The class must deliver the content no matter what subject was at the heart of the semester long example. At every point in a lecture after speaking of theory, the instructor would break into a wine example by saying, "Come Join Me at My Wine Glass" while holding up a red stained goblet as a visual prop. This physical cue served as a shift in instructional strategy to indicate to students to change their focus and in some cases, start paying attention. A portion of each week's homework assignment challenged students to explore the wine industry. The instructor noted that this consistent semester-long example backfired in a good way. Instead of the wine industry, some students translated the lessons of the semester-long economic application example to apply to their own life interests, i.e., hunting, aviation, apartment rentals, etc. While not necessarily applying work to the wine example, they were actively engaged in critical thinking in their own topics of interest. In any case, this consistent semester-long example grounded them into seeing how economics applies in the everyday world around them. In subsequent lectures, students kept the wine example at the ready and started to predict how topics of theory and lecture would be reflected in wine. As this instructor finished the theory portion of lecture, some students would ask a question that specifically related to the wine example. Essentially, students transitioned themselves into the next agenda item for the class time rather than having the instructor manage it. In short, they were actively thinking ahead.

Examples of the discussions in our classroom and basis for homework questions were adopted from the current economic news. The instructor was responsible for assimilating this into the syllabus and some examples and their uses follow.

Basic supply and demand analysis as well as elasticity examples were easily constructed using the wine industry. Virginia has state controlled commerce; the state awards wholesalers the rights to sell in Virginia. Neighboring District of Columbia (DC) does not have these restrictions. This disparity led to many examples of theoretical supply shifts and resulting price effects as well as discussions on competition. With wine production at high levels globally, students were able to track wine price levels and predict future prices. On the demand side of the equation, Gallup's annual survey of American drinking habits indicated a 15 year trend of wine gaining market share of all beverage consumption. For the first time ever, in 2005, wine edged out beer as the most popular beverage.

Tarara Winery had also embarked in creating a small futures market in wine that students were able to experience. The limited production of Tarara's Commonwealth series wine, sold only through a futures order, illustrated to students how a producer can harness modern financial strategies on a small scale to expand its capabilities in production. The revenue received from customers' futures orders allowed the winery to expand its capital equipment required to produce their wine without incurring debt or risk. Whether or not the wine produced was good, consumers had already paid for the bottle and the productive capacity of the winery expanded permanently on the risk-free money provided by the customers.

Virginia wineries, including Tarara, had won many awards at the London International Wine Fair in recent years. Complementary businesses have burgeoned in Fairfax and Loudoun counties as wine tourism has grown into a cottage industry and increased real economic activity in the area. Many macroeconomic fundamentals were covered using data in the immediate locale of the students. Just one example was the addition of bed and breakfast establishments offering winery tour packages. This has increased local employment and services that ultimately have added to the tax revenue base of Loudoun County. Students worked on problems where they would predict the economic multiplier effects of new, unplanned investment in the local economy.

During the instruction of this class, our students were academically blessed with a recession and all the real time data that can provide for instruction of an introductory class. Students used the winery to study business cycles and learned that the wine industry has some recession-proof characteristics to it. Jordan Harris, vintner at Tarara Winery, reasoned that a bottle of wine to share on a picnic, a home-cooked dinner, or a tasting visit to a winery was a relatively cheap form of entertainment and explained why the local wineries experienced higher customer traffic during the recession that started in 2008. Students were quick to point out this illustrated consumer behavior theory where consumers substitute lower cost goods in an effort to maximize their utility or satisfaction.

Foreign exchange effects were demonstrated through the emergence of foreign wines in the domestic market. For example, the dollar had remained strong against the Argentinean peso. This dollar strength along with strong consortium efforts in promoting South American wine has stimulated the growth of Malbec wine. In 2002, the government decoupled the Argentinean peso to the dollar and fueled an export boom in excess of 40% growth per year until 2008.

And finally, what is a Microeconomics class without discussion of cost curves? The instructor dreamt up many illustrations of shifting cost curves and changing market pressures with the local winery. The student's favorite example was the effect of technological advancement as more wineries shift to screw top closures instead of corks and how that affects costs as well as production as spoilage dramatically falls. Screw top wine is now the smart economic choice for producers because it decreases spoilage by up to 5 to 10% and is cheaper in production. However, the mass transfer to screw top technology for wine producers use is slow to be adopted as consumers' attitude toward new screw top technology is changing at the pace of glacial creep.

Conclusion

Unfortunately, for this instructor's students, a sponsored winery visit for the class would have been easily arranged; however, legalities prohibited such an activity. The author is currently working on the constraints to arrange an acceptable visit for her future series of introductory courses. Many students had taken time on their own to visit the area's wineries as part of their research for their term project. Students were encouraged to engage in critical thinking and to include interdisciplinary concepts in the classroom by combining economic principles with accounting, marketing, and management principles.

By far, this instructor has found this example as one of the most effective attention grabbers that excited students and kept them engaged throughout both courses at least through purely qualitative evidence. It seemed that students were just more attentive and invested in classroom activities and the recognition of economic principles in the outside world. Since the population of students was so small and there were a minimal number of comparison activities in relation to the previously taught course without the semester-long wine example, no statistical tests on grades or activities were run. In the larger application, from the instructor's perception it appeared that using one example through the course was a better experience for students than a number of disconnected examples presented in a typical course. This instructor intends to use a semester long example in the redeveloped of Managerial Economics course. When this series of introductory courses are taught again, this instructor intends to structure the syllabus so that there are a number of measures that can be used for statistical comparisons. This author has found an easy way to sneak in economic antioxidants in an unobtrusive manner!

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