2006-1335: INFORMATION VISUALIZATION APPLIED IN PRESENTING SOME FUNDAMENTAL POWER SYSTEMS TOPICS

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Information Visualization Applied in Presenting some Fundamental Power Systems Topics

Abstract

Visualization methods are widely credited for simplifying presentation of difficult subjects as well as aiding cognition. Its use in the power engineering industry and education is enjoying significant growth. However, developing visualization systems for fundamental power system topics is a time-consuming task. This paper presents a series of student-created applications of visualization concepts in teaching a number of power system topics. The simple visualization schemes emanating from students' perspectives serve to both aid understanding of concepts as well as enable the instructor to systematically integrate the valuable inputs into instruction delivery.

1. Introduction

The methods and patterns of presentation of traditional topics and concepts in power engineering have stabilized and remained largely intact, and until recently have survived the deluge of changes brought about by the digital revolution. This may be attributed to a variety of factors -- refining pedagogy to better adapt undergraduate power engineering classes to the needs of the times presents much demand on time and limits time commitment to non-pedagogic research and other scholarly activities. Also, textbooks that have made some attempts to recast presentation methods are few.

Significant strides in information visualization have been documented in research and application literatures over the past decade. With its wider acceptance as an alternative to studying complex problems defined by multidimensional and large data sets, many visualization software development systems have been deployed and are finding applications in power engineering. The profusion of visual displays of information without an educated guide to meanings discerned from the information has led to a groundswell of movements seeking to develop metrics and quantifiable quality measures.

Amar and Stasko[1] discuss a framework for design and evaluation of information visualization systems. It suggests that exposing uncertainty, concretizing relationships, and formulating cause and effect would lead to more effective information visualization techniques. Burkhard[2] highlights the differences between information visualization (exploring abstract data to amplify cognition) and knowledge visualization, indicating the necessity to customize the information to recipient's cognitive background. It draws a parallel between information visualization and the work of an architect; showing how the visual representations by an architect transfer knowledge. Chaomei and Chen[3] list ten high priority unsolved information visualization problems compiled by a panel of experts at an IEEE Visualization Conference in 2004. Viewer background, aesthetics, intrinsic quality measures, and usability ranked high on the list. In exploring a most effective means of visualizing high dimension data, Keim[4] focuses on the number of variables or dimensionality of the data, a need for geometric transformation and display style - iconic, dense pixel, or stacked displays.

Information visualization is finding increasing application in both business and technical fields. Mackinlay[5] predicts that advances in 3-D computing graphics and the high bandwidth access to information over the Internet will provide the medium necessary to push information visualization into the mainstream for use in the business plans of many corporations. The electric power systems field has intensely focused on visual representation of information in a variety of domains as a means capturing the essence of typically large data sets. The value in power engineering education is also well recognized [6-11] as a way of teaching difficult non-intuitive concepts.

The students read and evaluated a number of published articles relating to various aspects of visualization. This served as a basis for the development of the individual student projects. The publications approached the use of visualization from many different aspects. The students gained insight and various perspectives on the subject for these articles.

This paper presents applications of visualization in teaching a number of power system topics and concepts in the undergraduate curriculum. It is well known that it is time-consuming to develop visualization systems and expensive to acquire appropriate tools for constructing schemes with the sophistication that takes into consideration all the ‘good’ practices in the emerging field of visual cognition. With due recognition of these limitations, students were given the challenge to develop visual learning tools that address some learning needs in the power system course in which they were enrolled. This would be accomplished by using computer tools and a programming environment that they were already familiar with. Students proposed visualization projects in areas of their interest and incorporated the knowledge gained from the articles which they reviewed.

2. Visualization applied in various power system topics

In the power system analysis course a series of information visualization tasks were assigned to students who were challenged to develop visual cognition systems that would aid them and their fellow students in better understanding and retaining core concepts of the course material. For the purpose of the visualization projects, information visualization is defined as the use of visual aides, such as computer graphics, to organize and display data in such a way that facilitates successful decision-making and analysis. When done properly it would allow the student to better gain insight into the concept being studied.

The summary of the visualization schemes that were developed are presented in this section.

2.1. Case 1: Visualization of synchronous machine performance (MATLAB)

The synchronous motor is a complex electro-mechanical energy conversion device. The interaction between armature current drawn from the three-phase source, dc field current supplied and power-factor is often visualized through 2D machine v-curves. The v-curves most significantly highlight the transition from lagging to a leading machine power-factor. The performance visualization display in Figure 1 allows values of power-factor to be determined from the graph in addition to armature and field current quantities. The panning and zooming function available in MATLAB plot environment makes it possible to interactively translate the plot to view different portions.

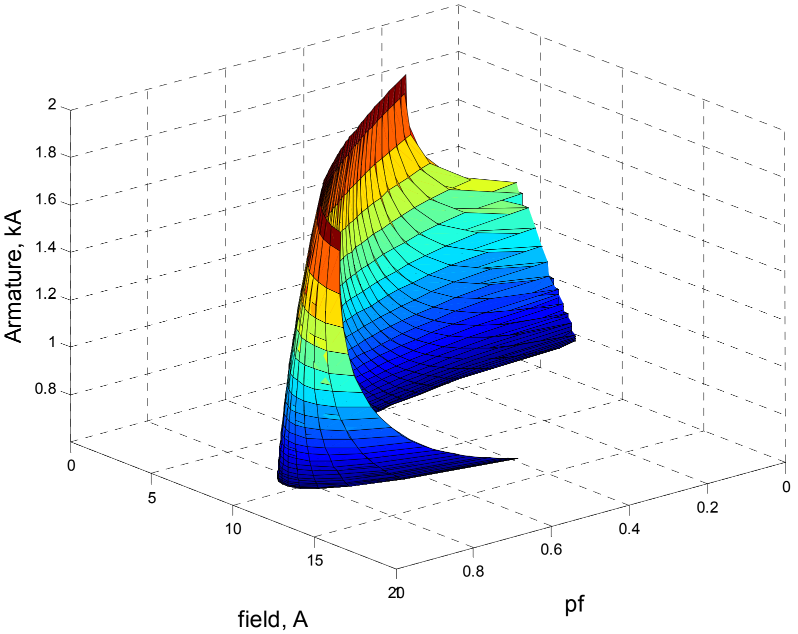


Figure 1. Visualization of Induction machine performance (MATLAB)

2.2. Case 2: Visualization of transmission line sag (MATLAB)

Thermal expansion of the 345-kV Hanna-Juniper line and the subsequent tree-to-line contacts (line sag) were among various reasons cited in the cascading sequence of events leading to the large scale power outage of August 2003 in the northeastern US and Canada [14]. The presentation of this outage summary in class motivated this visualization tool. Several parameters are typically involved in the complex relationships that determine the transmission line sag profile. The goal of the 2D visualization in Figure 2 is to create an interactive environment for studying the effect of the input parameters on sag profile using the IEEE Standard 738-1993.

The inputs to the 2D display includes: conductor diameter, resistance at low temperature, resistance at high temperature, emissivity, solar absortivity, coefficient of linear expansion, AC current frequency, air temperature, air density, wind speed, span distance, tower height (to conductor), and conductor arc length. The output quantities includes: final conductor temperature, expansion due to heat, sag profile and distance from ground.

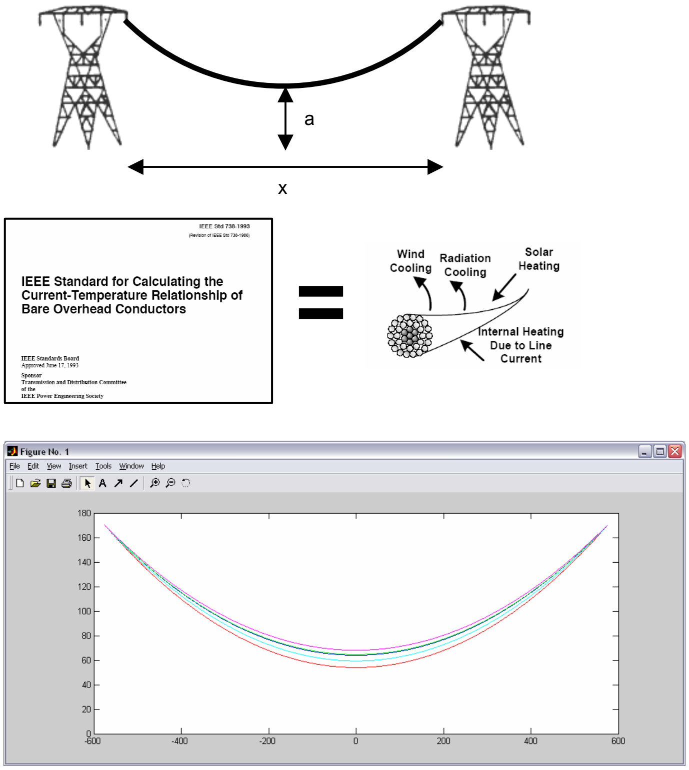


Figure 2. Visualization of transmission line sag (MATLAB)

2.3. Case 3: Visualization of Symmetrical Components (Microsoft PowerPoint)

The method of symmetrical components is introduced in preparation for the study and analysis of the unbalanced three-phase power systems. Traditionally, it is convenient and tidy to simply state the transformation matrix, mapping system variables from a-b-c to 0-1-2 sequence. This, however, does not enable students to quickly conceptualize the relationship between the two domains. The 2D visualization of Figure 3 is designed to help students to recognize this mapping before introducing it mathematically. The display is implemented in Microsoft PowerPoint. Color schemes and animations are used in demonstrating how a composite system of three-phase phasors is developed from individual sequence components.

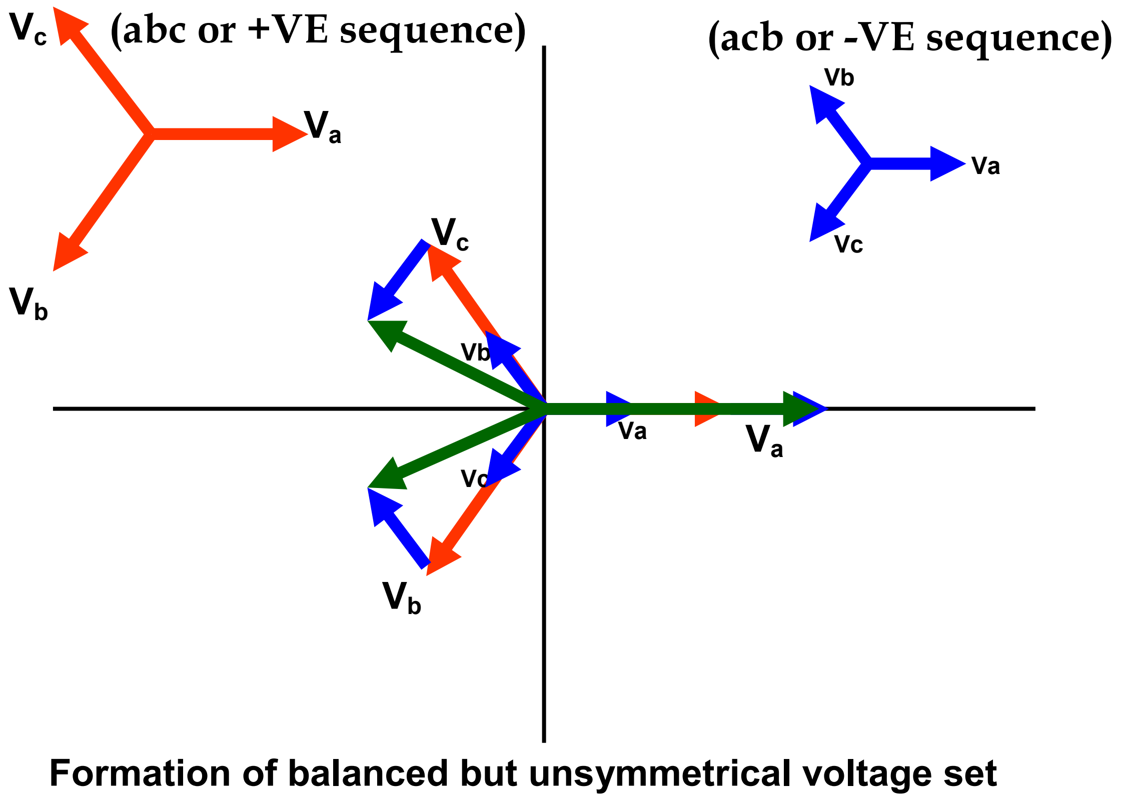


Figure 3. Visualization of Symmetrical Components (Microsoft PowerPoint)

2.4. Case 4: Visualization of line flow data (LabVIEW)

The National Instruments – LabVIEW, Laboratory Virtual Instrumentation Engineering Workbench, was used to design an interface to a power system simulation program to display per unit values, voltages, currents, phase angles, generated voltage and synchronous machine load angle on a polar chart. As shown in Figure 4a, the purpose is to visualize the relationship between rotor angle and stator magnetic field in a synchronous machine. The polar attributes allow the user to configure the chart and easily view the magnitudes and phase angles of the voltages. Since LabVIEW can run continuously, students can view the changes to magnitude and phase angle instantly in response to changes on the grid, such as load demand or power factor. LabVIEW is not limited to one conceptual visualization, as can be seen in Figure 4b, establishing the phase relationship of generated voltage in response to load. This graphic is displayed simultaneously with the previous example. Beyond the graphic is the ability to display the change in generator emf voltage and generator terminal voltage in response, not only to load, but also to transmission line changes. The added capability of LabVIEW for real time data acquisition makes the program valuable for both static presentations and dynamic evaluations.

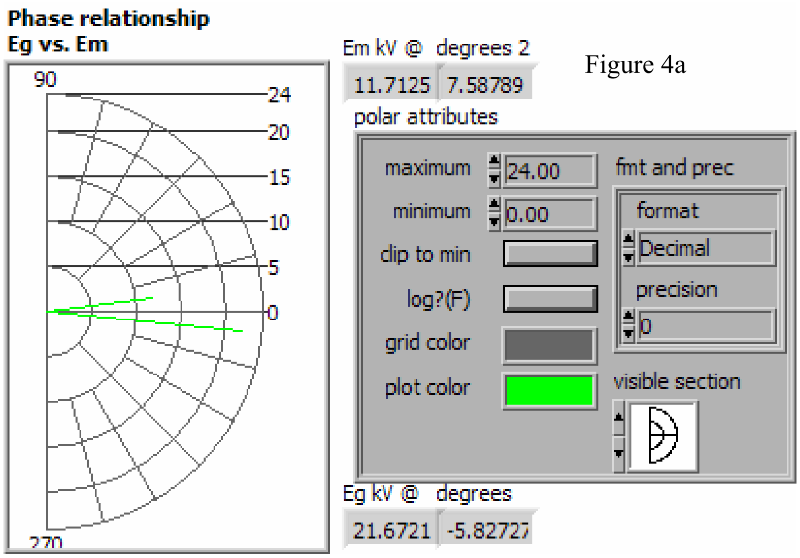


Figure 4a

Phase relationship
Eg vs. Em

Em kV @ degrees 2: 11.7125 | 7.58789

polar attributes

- maximum: 24.00
- minimum: 0.00
- clip to min
- log?(F)
- grid color
- plot color
- fmt and prec: format Decimal; precision 0
- visible section

Eg kV @ degrees: 21.6721 | -5.82727

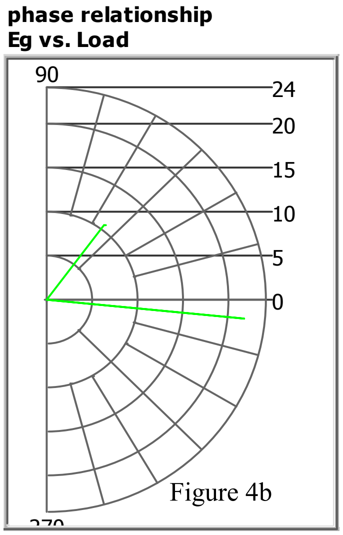
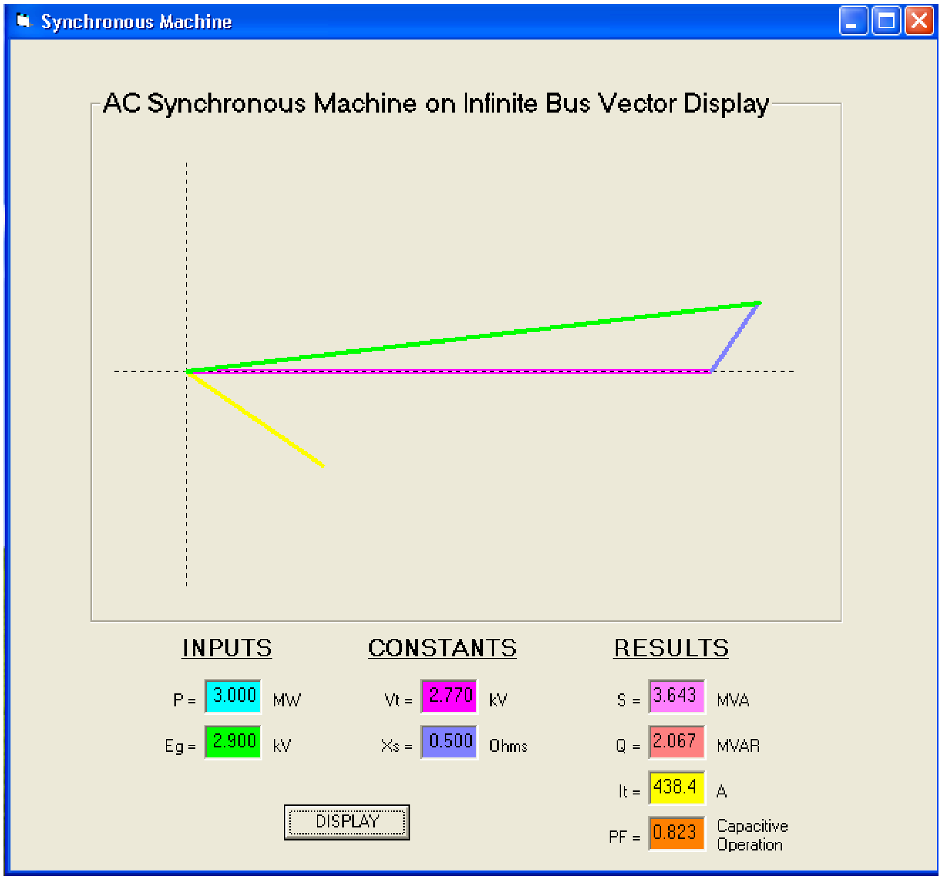


Figure 4b

Figure 4. Visualization of line flow data (LabVIEW)

2.5. Case 5: Visualization of synchronous AC machine load angle (Visual Basic)

The relationship between an infinite bus voltage, generated voltage, load-angle and power-factor is often unclear and confusing to the student. The 2D visualization tool shown in Figure 5 is implemented in Visual Basic. It generates a dynamic graphical display of vectors representing machine terminal voltage, line current, reactance voltage drop and excitation voltage. It highlights for the student a distinction between the angles and how the infinite bus voltage is maintained with changing load current. Inputs to the visualization tool include: prime mover input power and excitation voltage. The output information includes: machine apparent power, reactive power, line current and power factor. The program allows for various values to be entered and dynamically displays the resulting vectors. The classical way of presenting this information to students is with blackboard diagrams or illustrations within the textbook. The program allows for an interactive means to illustrate the interactions of the parameters which are adjusted on a synchronous machine.



P = 3.000 MW

Eg = 2.900 kV

Vt = 2.770 kV

Xs = 0.500 Ohms

S = 3.643 MVA

Q = 2.067 MVAR

It = 438.4 A

PF = 0.823 Capacitive Operation

Figure 5. Visualization of synchronous AC machine load angle (Visual Basic)

2.6. Case 6: Visualization of electric energy production and use (Microsoft Excel)

The objective of this visualization tool is to give students an exposure to data on electric energy production and use in the United States, and to study electric energy generation and consumption patterns. The total installed generating capacity; total electric power consumption and the population of each state are presented in visual form to aid in establishing patterns not readily discernible from numerical data tables. The chart (Figure 6) readily identifies net energy producers, industrial centers among others in the union.

Microsoft Excel ScreenTips shows detailed information on each bar on the chart; this feature is used by viewer to see exact values and data on the chart. As the user rests the pointer over the bar, data values and the region associated with it shows up on the ScreenTips display box.

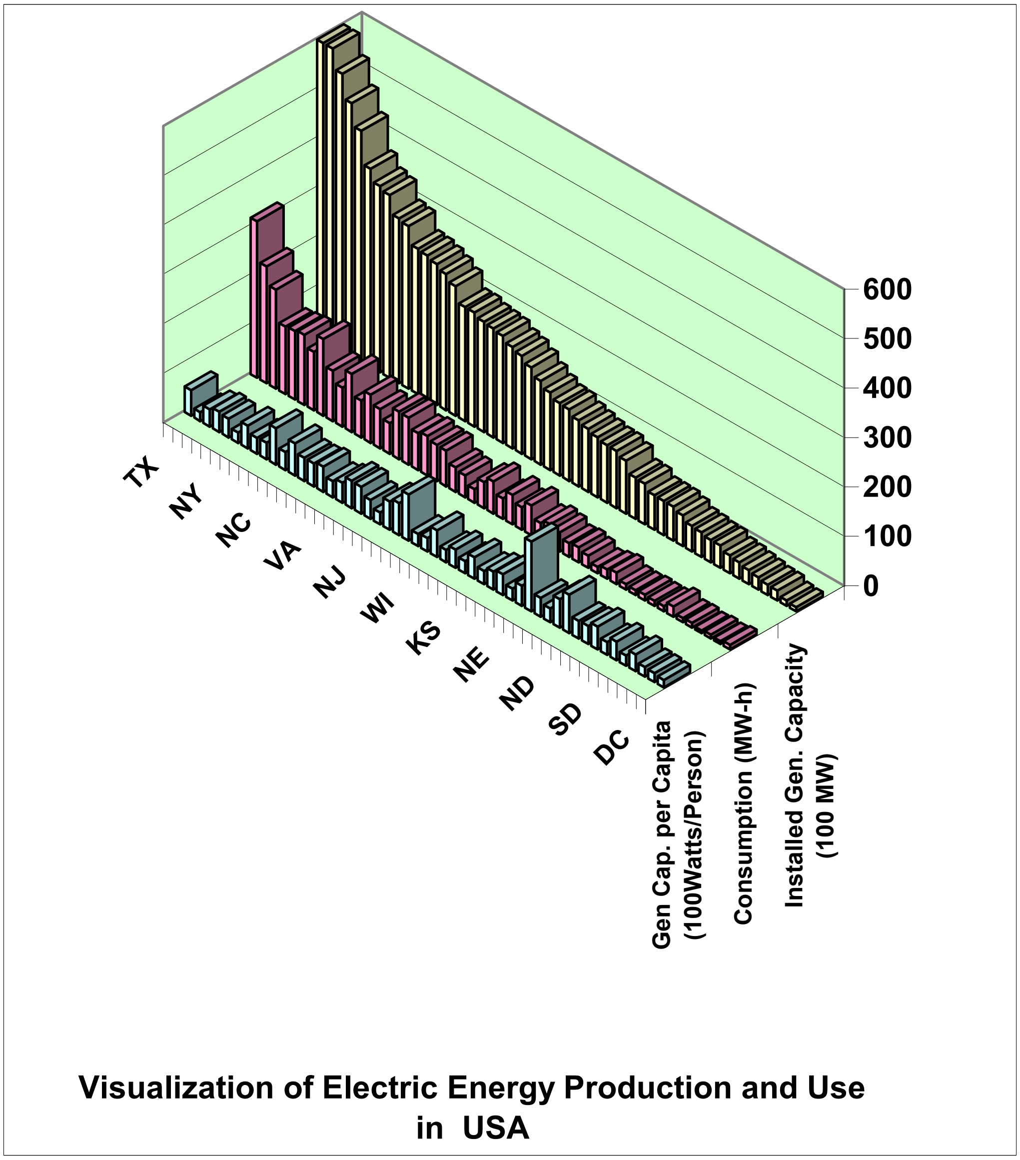


Figure 6. Visualization of electric energy production and use (Microsoft Excel)

2.7. Case 7: Visualization of AC DC resistance in copper and aluminum conductors (Scilab)

The visualization task is to highlight for the student the variation of AC and DC resistance with respect to the length, conductor cross-sectional area, frequency, conductor property (resistivity) and temperature. The 2D visual display in Figure 7 is implemented in Scilab[15] – a free scientific software development system. It enables students to visually arrive at some very basic conclusions such as: (a) at constant length, the resistance of the conductor decreases with the increase in the radius of the conductor; (b) a short and thick conductor will have less resistance than a long and thin conductor; (c) the resistance of the conductor depends on the material of the conductor; (d) the resistance of the conductor changes with the temperature, etc.

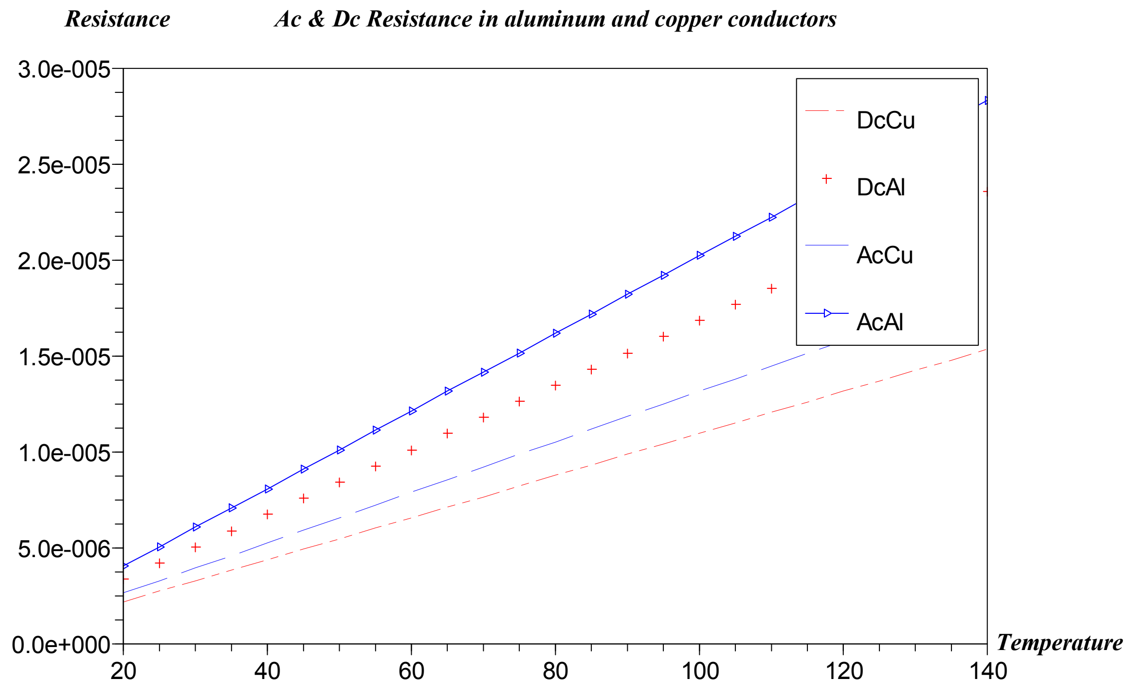


Figure 7. Visualization of AC DC resistance in copper and aluminum conductors (Scilab)

3. Conclusion

A series of visual learning tools were developed by students and instructor over a 16-week semester. These assignments were integrated into the power system analysis course where the objective was to learn to model power system components and to analyze the interconnected system represented in per-unit form. The learning tools complemented the presentations from course instructor and textbook specified for the course by providing added insights to topics in the course. Since students were directly involved in the design of the visualization schemes it assures that their individual perspectives and cognitive patterns are accommodated in the delivery of the course materials. The visualization systems were developed with tools that are readily available and do not require very expensive development systems. Although the students had limited skills in developing sophisticated visualization software they were able to grasp the concept and creatively adapt a familiar programming environment to the design problem. It is anticipated that students will develop a complete visual presentation of all major topics in the course over a few years repeating the visualization assignment. The database of visual presentation will be an asset to both students and instructor in fostering a more engaging learning environment. Feedback from students is favorable; they consider the tools beneficial in grasping the concepts. Some of the comments from students are as follows (Case 5):

"*It (the graphical display) gave me a better understanding of the relationship between the current in the stator and the line voltage. This made clearer the relationship between excitation and power factor*."

"*Being able to see the vectors change on the screen when values were adjusted helped me understand the synchronous machines operation much better that the three vector illustrations in the text book*."

"*I noted that the horizontal component of the current, that component that was in phase with the voltage, did not change in magnitude. This shows that the true power generated remains the same with a change in excitation, while directly affecting the line current and power factor*."

The visual learning tools are accessible through the following URL - http://home.pct.edu/~sneuhard/Web%20pages/Masters/LabVIEW%20download%20and%20demonstration.htm

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