Increasing Student Interest and Comprehension in Power Engineering Education at the Graduate and Undergraduate Levels

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Abstract

This paper reports on new efforts in the modernization of the basic undergraduate courses and a graduate curriculum in electric power engineering. The main focus of the paper is the modernization of the way power engineering is portrayed to students. The motivation is the recognition of the new deregulated and restructured environment in power engineering and the broadening of the area in general. At the undergraduate level, a multimedia approach is described in which renovation of the curriculum is done in such a way as to allow broadening of the subject material. At the graduate level, new efforts in power electronics and electric power quality are described. The implementation of changes as those reported here were made at several universities including Arizona State University.

Keywords: *education; power electronics; energy conversion*

1. Introduction

Declining student interest in electric power engineering has resulted in the reduction of the number of power courses and student-credit hours taught in this area at many universities in the USA. The typical American university teaches a one-semester, three credit course on energy conversion. This basic course, often mandatory for all electrical engineering students, deals with transformers, motors, generators and basic parameters of transmission lines. In addition, AC circuit theory is reviewed and phasors are regularly used for problem solving. At Arizona State University, about 65% of the graduating BSEE students enrolled in the energy conversion course during their undergraduate program. In addition the curriculum contains elective courses such as power system analysis, power electronics and drives, advanced electric machinery, and power plant systems.

The difficulties observed in the undergraduate program, namely low student interest, and the narrow focus of traditional power engineering, are the result of complex interacting factors. Compounding the negative way some students perceive power engineering is the

deregulation and restructuring of the electric utility industry in the United States: this has resulted in far fewer new hires per year in the electric utility industry. However, new industries that were not traditionally in power engineering have entered the arena; computer applications and software development firms now hire power engineers to serve the industry; and a host of auxiliary industries such as automotive, environmental, alternate energy sources, and instrumentation industries are employing power engineers. Potentially the largest and greatest impact in the long term is the power electronics industry. This area has the potential of radical and major changes in power engineering. Each of these new elements in the career paths of our students have their on requirement, and it is clear that the focus of power engineering education needs to be broadened considerably to accommodate these needs.

At the graduate level research needs, more advanced application areas, and university hiring have added impact the doctoral program. At the masters level, there is a special need in the *electric power quality* area: this is a subject that relates to maintaining the sinusoidal voltage waveshape at all load buses. Increasing reliability and selling power quality related services as unbundled services are specialized niche needs in industry. Equipment manufacturers have also entered the commercial sector in the marketing of new power system components for power quality enhancement. Power quality has special importance in an educational program because it teaches modeling and interactions of large scale systems. Measurement and instrumentation also come into play. Power quality issues are relatively new in power education programs because of commercial interest in these areas and because the advent of high power electronic switched loads have resulted in power quality degradation in some cases.

Advanced power electronics also is a real need in industry today. Power electronics is an engineering and research area that has arisen from the confluence of availability of 100 kVA class solid state switches and needs to control power flow.

In recent years, special scrutiny has been focused on efficiency, and power electronic switches are needed to implement high efficiency designs in lighting, machine speed control, and a wide range of industrial loads. Graduates at all levels, especially at the masters and doctoral levels, are in demand in the area of power electronics. It appears that as new silicon, GaN, and InN switches become available, the applications of power electronics will accelerate, and needs for engineers in this area will also accelerate.

2. Modification of course content

The indicated influences on the needs of American industry suggest that the curricula in the undergraduate and graduate programs should be thoroughly modernized and brought into line with industry needs. With this in mind, the United States National Science Foundation has funded a series of projects targeted at the innovative use of modern materials in power engineering [1-3]. The impact of these projects is not yet clear, but the projects have fostered an ongoing dialog on the power curriculum, the exchange of course materials via the Internet, and coalitions of several universities to exchange course materials. Perhaps the most important element of this modernization is the broadening of topic areas. One element common to several of these NSF projects as well as other power engineering course modernization is the revamping of presentation techniques to make the courses attractive to the students through the use of computer equipped classrooms, interactive problem solving and multimedia presentation. These methods improve teaching efficiency and increase student interest.

The basic, one semester electrical energy conversion course deals with variety of subjects: transformers, synchronous, induction motors, DC machines and transmission lines and network calculation. The obvious time constraint requires the concentration on operation principles, calculation of operation parameters using equivalent circuits and a brief description of the hardware. In many cases, details may be neglected or deemphasized. As an example the students might be asked to calculate magnetic flux, DC excitation current and induced voltage in a synchronous machine, taking into account air gaps only. The problems related to saturation around slots may be mentioned but should not be emphasized at this level. This way the students will understand the concept of calculation. The volume of the material presented in the basic energy conversion course should be reduced: but the students have to be able to use basic material for problem solving. The reduction of the material volume comes at a price: many professors find it difficult to delete or compress their favorite material. The compression itself requires course development time. And textbooks that cover traditional materials need to be reevaluated and replaced as needed. It is clear that in order to accommodate new material and new techniques, something has to be deleted.

One place to find room for compression is the long mathematical derivation of equations. The professor should outline the method of derivation and refer to the textbook or suitable references. As an example the derivation of a rotating magnetic field in an AC machine requires tedious trigonometric manipulations. The students probably are unable to remember the long details – and in some cases the details are not applicable to other areas. As an alternative, the three flux equations (A, B C phases) are shown, and the equations of the rotating field are also shown. However, immediately after the presentation of the equations, the students solve a numerical example, calculate and plot the field using some standard mathematical symbolic manipulation package such as MathCad. In this way they will understand the concept of the rotating field without the mathematical details, and they will have a ‘feel’ for the way results should unfold. Selecting some examples related to advanced technology enhances student interest. Typical examples are the motor used in a computer hard drive, a generator used in an aircraft power system, a distribution network of a space station, and a transformer used in an audio amplifier.

Thus, one basic philosophy in the undergraduate power curriculum is the deletion of lengthy details of some applications. The savings in time resulting from this approach is compounded by a multimedia classroom presentation technique described below.

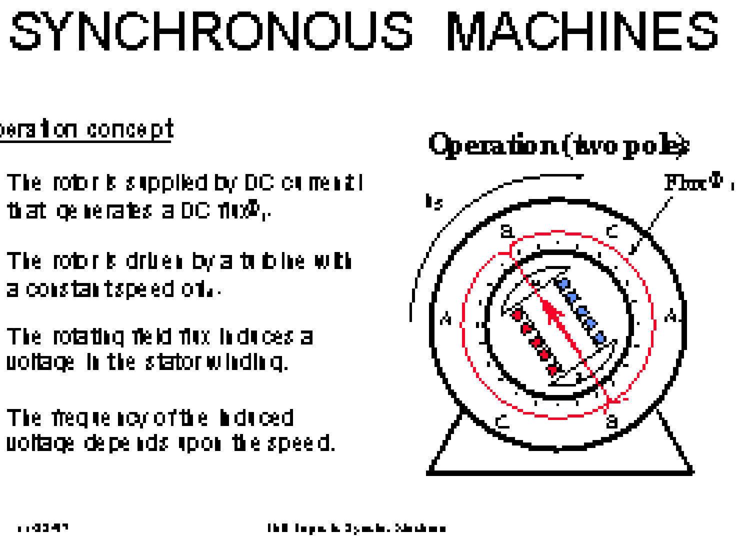
3. Multimedia presentation technique

An important distinctive feature of the newly developed basic undergraduate power course is the classroom itself: the course is presented in a computerized classroom where every two students have a computer which is networked. The professor’s computer is equipped with video and digital slide projector capability, Internet and web access and e-mail. The effective use of this classroom requires familiarity with basic computer applications. Typical American engineering students are familiar with word processors (e.g., MSWord or Word Perfect), spread sheet software (Excel), electric circuit calculation software (SPICE) and one of the general mathematics program such as MathCad, Mathematica or Matlab. If the student is unfamiliar with these packages, the first few weeks of the new course solve this problem: virtually every aspect of the course involves the use of the cited software. To assure easy access to the material and assignments we place the lecture material, calculation exercises and homework assignments on the professor's web home page.

4. Lectures

The lectures follow a selected textbook that is purchased by the students. The lecture material is summarized in the form of slides and placed on the web home page. The students download the material and study it before the lecture. The lecture is presented using the digital slides. This eliminates the need for detailed lecture notes. Admittedly this results in less comprehension of the many details of the applications discussed, and this is most apparent for the less serious students; however, the students do see the results of operation of all main power system components and they are acquainted with where to find the missing details. Figure 1 shows a typical slide that explains the synchronous machine operation. Similar slides are used to present derivations, develop equivalent circuits, and to illustrate applications. Selected key derivations are repeated on the blackboard. As an example, the development of transformer equivalent circuit requires the combination of the primary and secondary loop equations. Experience shows that repetition of slides and blackboard material enhances understanding of key material. The judicious selection of which developments are key and which are not requires some care. This presentation philosophy reduces presentation time, it eliminates the need for taking detailed notes, and it is found to improve student interest and learning. The lecture takes about 30-40 minutes of the 75 minute class two times per week (in a semester system of 15 weeks).

Short videos and digitized colored slides, obtained from industry, present technological aspects and describe hardware used in the electric power industry. The zoom feature of a digital projector permits study of construction details. Figures 2 and 3 illustrate this method: the students study the general arrangement shown in Figure 2 and the details are studied by zooming in on a selected detail as shown in Figure 3.



SYNCHRONOUS MACHINES

Operation concept

- The rotor is supplied by DC current I that generates a DC flux Φ_r.
- The rotor is driven by a turbine with a constant speed of n_s.
- The rotating field flux induces a voltage in the stator winding.
- The frequency of the induced voltage depends upon the speed.

Operation (two poles)

Figure 1. Typical lecture slide: synchronous machine operation

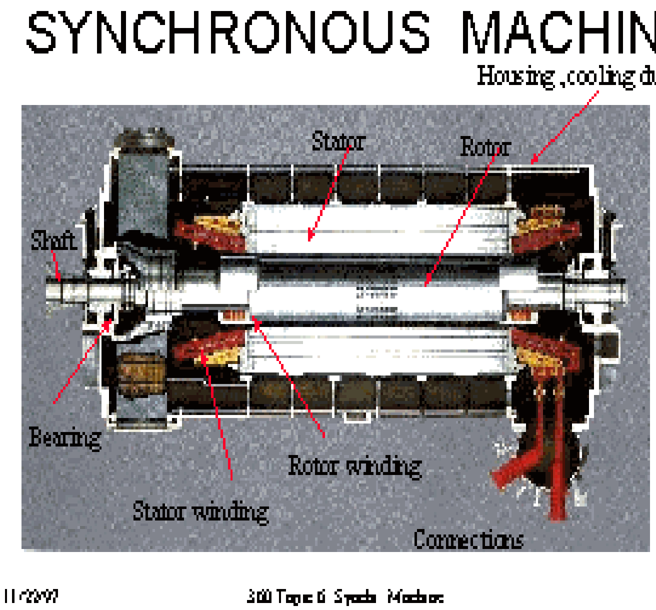


Figure 2 Construction of synchronous generator

Animation of motor and generator operation was introduced to improve student understanding of the physics of motor / generator operation. Four animation programs have been developed:

- Generator operation concept, a loop rotating in magnetic field
- Synchronous generator operation
- Rotating magnetic field generation
- Induction motor operation.

Figure 4 shows a frame from the animation of a three-phase salient pole generator as an example. In addition, the animations of Liu [8] developed for the NSF curriculum development program shall be integrated into the course. These animations include:

- Pulse bounce phenomena in transmission lines
- Breakdown in transformers due to lightning
- RLC circuit response to AC signals.

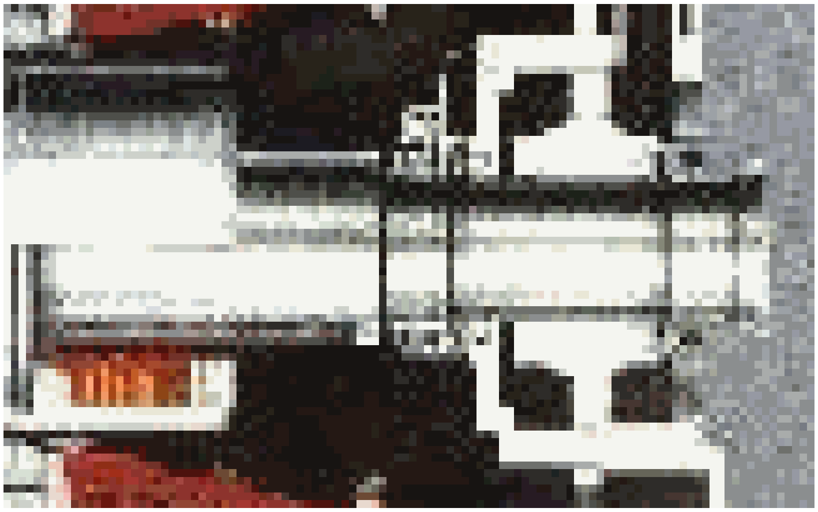


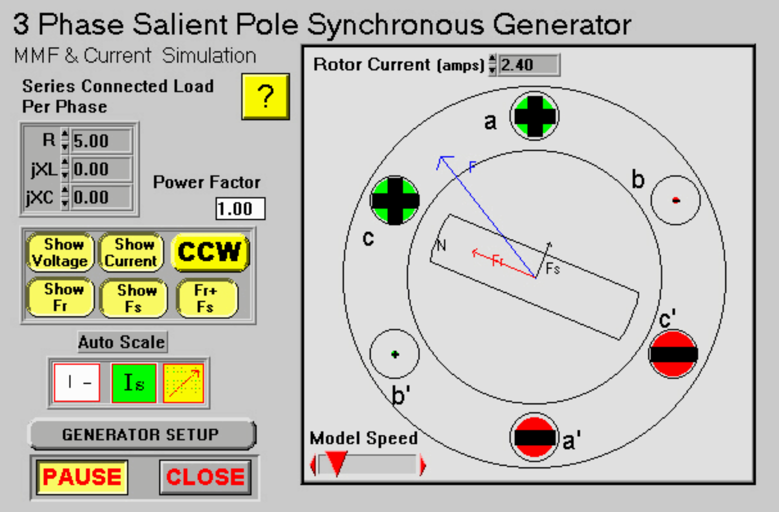
Figure 3 Enlarged bearing of a generator

The animations are used to introduce the concepts of *device operation*. As an example, the teaching of the three phase salient pole generator starts with the brief description of the generator shown in Figure 1. Subsequently, the animation program is used to depict rotor generated flux and induced voltage and current in the three phase stator winding. The load impedance and rotor current are varied and the animation shows the change in load current, voltage and phase angle. The students are requested to work with the animation and determine the effect of different parameters. We found that the animation increases the student understanding significantly and because they have seen pictorially how operation occurs, they seem to recall the material better.

5. Undergraduate student effort

After typical lectures, students form groups and solve numerical problems which are assigned in class or in the lecture notes. The problems are solved using MathCad or SPICE software. The instructor discusses the steps of the problem solution and the student groups attempt to solve the first step using the computers in the advanced classroom. After an appropriate amount of time, the instructor solves the first part of the problem using a computer and discusses typical mistakes. One or two typical problems are solved at each lecture. The circuit software package SPICE can solve many transmission line problems needed at this level. The method of solution is the companion circuit method [4] in which input circuit data is resolved into resistors and inductors or capacitors. The latter two circuit elements are converted to resistors and parallel correction currents. Subsequently SPICE solves the purely resistive circuit with iterative correction on the correction currents. It has been found that the main problems in working with the companion circuit method in class are:

- The need for a ground tie because the resistive circuit assumes a ground reference node.
- Some difficulty in selecting step sizes and solution duration to capture all desired phenomena
- Diagnostic errors in SPICE syntax
- Accommodating all the versions of SPICE (and PSPICE) seen in class.



Rotor Current (amps) 2.40

R 5.00
jXL 0.00
jXC 0.00

Power Factor 1.00

Figure 4 Animation of a three-phase salient pole generator

Ten laboratory exercises are found to improve practical knowledge. The laboratory exercises use real motors and transformers with digital data acquisition systems. Is it important that the students assemble the circuits to obtain hands-on experience. The computer simulated motors are useful economical tools to teach concepts; however, the student should see and handle the hardware that he or she tests. We found that old fashioned 5 – 20 hp rotating machines cause students disquiet, and they convey a message of obsolescence. Therefore the laboratory used in this educational program was assembled using commercially available small motors, transformers and related electronics. Machines with electronic drives are also used. Digital and analog meters are being eliminated entirely, and *digital data acquisition* systems are being used throughout for all instrumentation. We are developing a LabView based system, but other hardware / software combinations may be used to interface primary sensors with palm-top computers, PCs, and base station computers in the lab.

Digital techniques permit more elaborate tests and collection of data. It should be recognized that the content of laboratory exercises have to be upgraded to utilize the advantages of digital data acquisition Some software may be provided to the students to accomplish more complex calculations and tests.

Two design projects relating to a transformer application and a transmission line design aim to teach basic design concepts. For these projects the students are provided catalogs and other materials and they have to use government, IEEE, and industry guides and standards such as the National Electric Safety Code. Three or four students form a team to prepare the project. Each team elects a team leader, who distributes and coordinates the work. The introduction of the teamwork generates problems with some of the best students who like to work alone and with others who prefer not to participate. The professor has to teach team effort. To measure individual participation, at the end of the project each students submit a confidential evaluation of the teammate's effort. Biweekly homework has to be solved using MathCad or SPICE programs. Included in selected subjects are open-ended problems which can not be solved without computer. These problems show that some engineering problems have more than one solution.

6. Graduate program renovation

At the graduate level, knowledge compression is more an influence (see Figure (5)). The relegation of the more traditional topics selected from electric machines, grounding, transmission and distribution engineering, and power system analysis to reading and textbook references must be done in order to allow time for new material. The main new materials to be included are selected from advanced power electronics and electric power quality. In the area of power electronics, the main subject matter included is listed in Table (1). The course is found to attract a few students from the solid state area as well as power engineers. Laboratory exercises (e.g., design and build a simple buck-boost converter) help the students understand the waveforms involved without investing too much time in the process. Interesting effects that result from the use of non-ideal elements (e.g., parasitic elements, losses) are also easily illustrated by laboratory exercises. Early in the introduction of an advanced power electronics course into the masters level program, it became apparent that students who were unable to find employment in the electric utility industry could generally readily find employment in the power electronics industry, and this course was an excellent introduction and preparation for that employment.

Electric power quality has assumed a considerable level of interest in industry because of the proliferation of digital controls (and their accompanying vulnerability to distribution supply quality) and the high level of use of power electronic switches (and their nonsinusoidal load currents). From an educational point of view, power quality offers a number of pedagogical opportunities to teach modeling theory, instrumentation, signal processing, and applied mathematics. The course content of a suitable course in this area is listed in Table (2).

Table (1) Advanced power electronics subjects in a graduate course

Topic	Expected impact
High power electronic devices	This area forms a bridge to solid state engineering, and it allows the introduction of limits to designs
DC / DC converters	This subject is basic to power electronics
Pulse width modulation techniques	PWM is an important area of machine drives and other power flow control applications
Snubbers and other practical circuit designs	Practical circuit design is important for comprehension of non-ideal characteristics of electronic devices
Zero current and zero voltage switching	
Applications	Applications enhance student interest

Table (2) Power quality subjects for a graduate course

Topic	Expected impact
Power quality indices	This area teaches a good deal on engineering indices and the interface between capturing desired phenomena and measurement limitations
Instrumentation	This is a basic area that includes sensors and advanced physical analysis
Grounding	Grounding is a practical subject that is a specialized type of modeling analysis. This gives a good opportunity to combine physics, industry standards, and engineering.
Modeling	These are basic subjects that enhance the students' capabilities in applied mathematics, signal processing, and applying advanced methods to solve engineering problems.
Analysis	
Harmonics in power systems	
Power conditioners	Power conditioning and uninterruptable power supplies are specialized niche engineering areas with unique challenges. The topic increases student interest and provides useful information.
Filters	Filter design, especially for power engineering applications, is a specialized area of circuit analysis. With modern circuit analysis software, the students can do designs in depth with realistic limitations included.

7. The value of advanced modeling in the graduate program

The role of modeling in power quality assessment and analysis is crucial. For this reason, modeling is a focus of the graduate level power quality course. Table (3) shows some of the topics in modeling considered in the course. In addition to the topics indicated, the students are asked to examine advanced methods and innovative techniques. As an example, the Lorenz system [9] is considered,

$$\begin{aligned} \dot{x} &= a(y-x) \\ \dot{y} &= x(r-z)-y \\ \dot{z} &= xy-bz \end{aligned}$$

This is a nonlinear system in which the state trajectory starting from (x_O, y_O, z_O) is highly dependent on the values of x_O, y_O, z_O. Infinitesimal changes in initial condition result in diverging trajectories. Figure (5) illustrates the point. Basic properties of chaotic systems are discussed, and the connection is made with highly varying currents in an electric arc [5]. Figure (6) is an example of the load current of an electric arc furnace, and the use of chaotic systems in modeling such loads is described. This kind of application is an ideal application for power quality indices, and these are discussed as well. Table (4) shows some of the well known power quality indices.

Table (3) Topics in modeling in a graduate course on power quality

Topic	Highlight
Measuring transfer functions	Bandwidth, sensors, measurement techniques
Modeling instrumentation systems	Preprocessing, postprocessing [6]

Periodic steady state analysis	Several advanced methods of finding the periodic steady state solution of systems
Nonstandard transforms	Hartley transforms and Walsh transforms
Adaptive models	Advanced adaptive methods including the use of artificial intelligence methods

The use of power quality indices in connection with IEEE and other standards gives students an appreciation not only for engineering procedures, but also for the difficulties and practicalities of instrumentation. Topics such as sensor bandwidth and dynamic range are discussed. As an example, the relationship between channel capacity *C* and bandwidth *BW* is given by

$$C = BW \log_2 (1 + S/N)$$

Where S/N is the signal to noise ratio. This is applied to find practical limitations of existing instrumentation systems. Practical application of a standard like IEEE 519 [7] is used as an illustration.

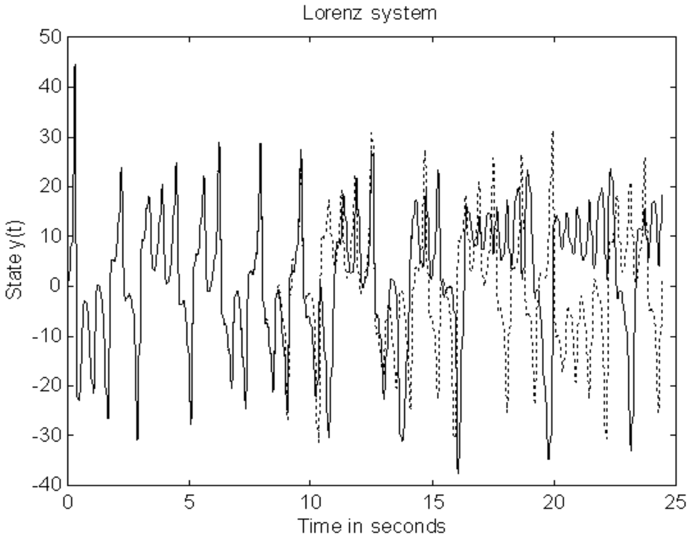


Figure (5) Sensitivity to initial condition of the Lorenz system (state *y(t)* shown for two different nearby initial conditions)

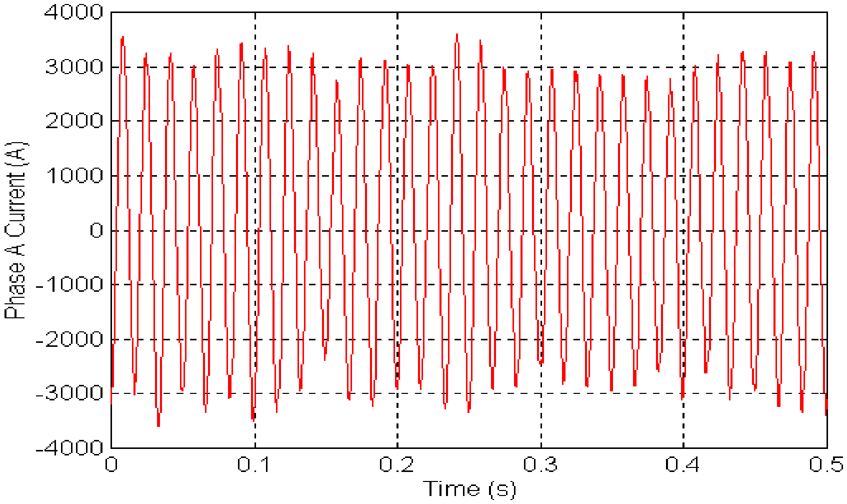


Figure (6) Measured current in a 60 MVA ac electric arc furnace

A popular class topic is the unbundling of power quality services for customers. In this area, the economics of customer service is integrated with sensor and software capability to develop diagnostic and other services that might be offered to customers. The students are interested in the economic aspects of this exercise. Overall, the power quality course brings together several areas and disciplines in a way that is informative and motivational to the students.

Table (4) Common power quality indices

Index	Definition	Main applications
Total harmonic distortion	$\left(\sqrt{\sum_{i=2}^{\infty} I_i}\right) / I_1$	General purpose; standards
Power factor	$P_{tot} / \lvert V_{rms} \rvert \lvert I_{rms} \rvert$	Potentially in revenue metering, losses
Telephone influence factor	$\left(\sqrt{\sum_{i=2}^{\infty} w_i^2 I_i}\right) / I_{rms}$	Audio circuit interference
C message index	$\left(\sqrt{\sum_{i=2}^{\infty} c_i^2 I_i}\right) / I_{rms}$	Communications interference
IT product	$\sqrt{\sum_{i=1}^{\infty} w_i^2 I_i^2}$	Audio circuit interference; shunt capacitor stress
VT product	$\sqrt{\sum_{i=1}^{\infty} w_i^2 V_i^2}$	Voltage distortion index
K factor	$\left(\sum_{k=1}^{\infty} h^2 I_k^2\right) / \sum_{k=1}^{\infty} I_k^2$	Transformer derating
Crest factor	V_{peak} / V_{rms}	Dielectric stress
Unbalance factor	$\lvert V_- \rvert / \lvert V_+ \rvert$	Three phase circuit balance
Flicker factor	$\Delta V / \lvert V \rvert$	Incandescent lamp operation; bus voltage regulation; sufficiency of short circuit capacity

8. Conclusions and final remarks

It is believed that the application of multimedia and the extensive use of computer for problem solving changes student attitudes towards electric power. Further, the broadening and modernization of the subject matter will make the students better prepared for modern industry. In the undergraduate program, a policy of compressing some presented material, and highlighting others is used to make room for new technologies. The approach has improved the image of the power area at the undergraduate level.

At the graduate level, the integration of certain technologies such as signal processing, economics, advanced applied mathematics and control helps the student appreciate those areas as well as become more competent and more competitive in electric power engineering. The inclusion of a course in electric power quality and one in advanced power electronics helps accomplish these goals.

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Biographies

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Gerald Heydt holds the Ph.D. from Purdue University. He spent approximately 25 years as a faculty member at Purdue, and recently he took the position at Arizona State University. He is a Fellow of the IEEE, a member of the National Academy of Engineering, and recipient of the 1995 Power Engineering Society "Power Engineering Educator of the Year" award.