Power Systems Curriculum and Course Structure in Electrical Engineering Technology Program

Ilya Grinberg
State University of New York, College at Buffalo

1. Introduction

Recent years have witnessed an extraordinary increase in the fields of microelectronics, computers, telecommunications, and other so-called hi-tech disciplines.
Because of this significant shift to new technologies, the shortage of electrical engineers, engineering technologists, and technicians with adequate knowledge of power systems theory and practice has now reached a critical point. Electrical power systems curriculum is facing a challenge of changes to make it more attractive to the potential student population and not to lose the essential components of the discipline.

Power/Machines option of Electrical Engineering Technology program had been offered at Buffalo State College since 1971. During the last six years, curriculum in this option is continuously undergoing a number of programmatic and pedagogical changes necessary to meet student's increasing demand as well as expectations from the industry hiring our graduates.

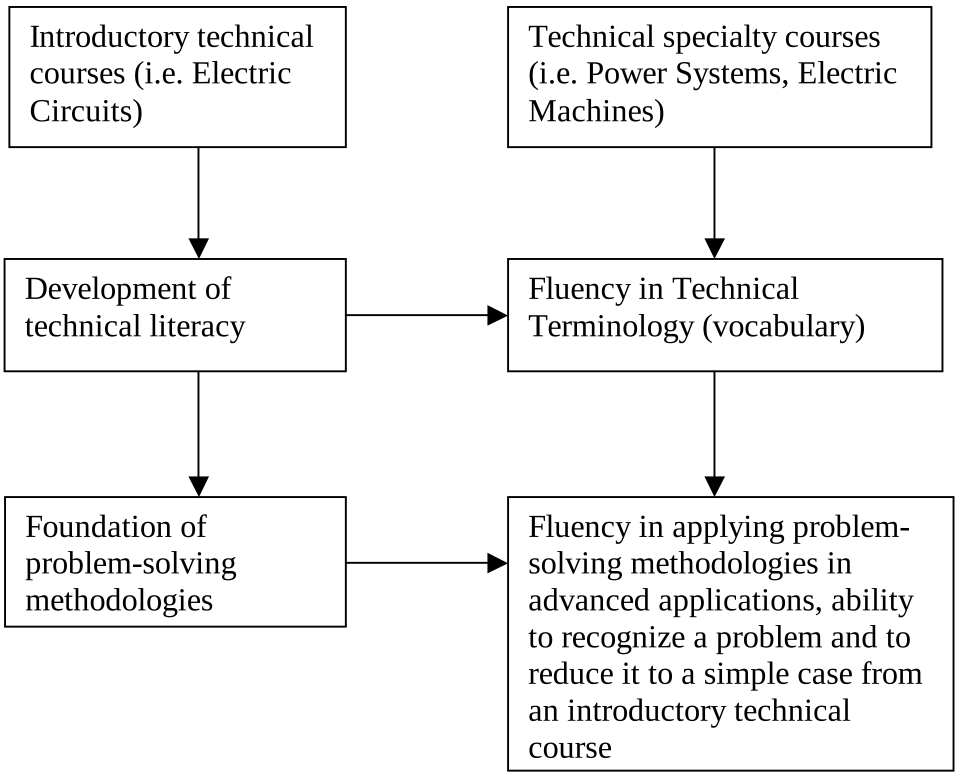
Curriculum is structured based on a systems approach[1, 2, and 3] and recognizes two different levels: introductory technical courses (e.g. electric circuits) and advanced technical specialty courses (e.g. power systems, electric machines, and power electronics). While the first level courses deal primarily with elements, devices, and circuits, the second level courses deal with their advanced applications, as well as with systems.

This paper discusses curriculum structure, topical outlines, methods of delivery, pedagogical strategies (collaborative learning, individual and team projects, off-site industrial laboratories among others), industry collaboration, including industrial advisory committee, and evaluation and assessment techniques, among others. Samples of student work and their involvement in research and creative activities are presented.

2. Curriculum Objectives and Structure

Power/machines option curriculum is structured based on the objectives of the program. To develop technical vocabulary and lay the foundation for problem-solving methodologies is the objective of introductory circuit analysis courses. The objectives of the advanced courses are to extend proficiency in technical terminology and for the students to be able to recognize simple circuit problems in advanced technical applications. In other words, nine out of ten complex problems are solved by application of Ohm's Law. "Resist the urge to astound people by labeling the problem with some high-falutin' name. Simplify! Reduce the complicated circuitry in your mind to a simple series circuit with a voltage source pushing a current through load impedance in series with the impedance of the source. Then you are on your way to a solution!"[4]. Interrelations between introductory and advanced courses objectives are presented in Table 1.

Table 1.Curriculum objectives and their interrelations



To achieve the objectives of the introductory courses the following structure is used:

1. Simple problems from the textbook – but let the students choose numeric values. This provides for the sense of their ownership for the problem and allows to follow solutions from the book
2. More complicated problems. One problem covers one or more topics
3. Laboratory experiments: hands-on experience with the concepts learned, exposure to traditional and state-of-the art instrumentation and measurement techniques. Mistakes (such as blown fuses, burned resistors) are OK! The only condition: explain what happened and never repeat them again
4. Computer simulation of the same problems. Easy way to examine what will happen if…
5. Discussion and comparison of results.

This structure provides activities for different learning styles.

The objectives for the advanced technical courses are met through the following structure:

1. Establishing and enhancing technical vocabulary: definitions, illustrations, samples of equipment, and industrial tours
2. Familiarity with current technical periodicals and standards is a must
3. Application-oriented problems that give sense of a real assignment; PE exam-type problems
4. Laboratory sessions at industrial locations; internships
5. Senior design project. Utilization of gained knowledge in a team-oriented real-life assignment
6. Presentation of results

3. Topical Outlines

Power Systems 1 and 2 are chosen as an example to represent topical outlines in advanced technical courses of the program. These courses are sequenced in two semesters and are both three-credit hour courses.

At the beginning of the first semester students are exposed to the history and basic elements of power systems including such topics as development of power systems, impact of industry deregulation, and systems approach to power systems study. Systems concepts, such as requirements, functional analysis, synthesis, testing, and communications are introduced [2,3]. This introductory lecture lays the foundation for appreciation of the power systems scale and unique features that require special tools for their design and analysis.

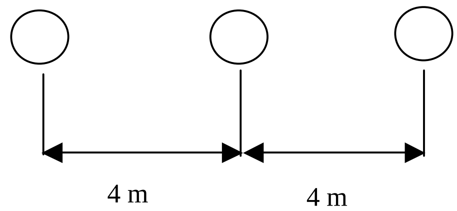
Next topic, which is traditionally covered in all textbooks, is three-phase circuit analysis. It is vitally important for further studies, as power systems are predominantly three-phase.

This is followed by power factor correction and its application in power distribution systems. Such topics as voltage drop and voltage rise, voltage regulation, as well as series and parallel (shunt) capacitors applications are discussed. The emphasis is on loss reduction and savings due to the power factor correction.

The next topic deals with transmission line configuration and impedance. Definitions of DC and AC resistance are introduced. Inductive and capacitive reactances of a single conductor and three-phase line are derived through the extensive use of calculus. The concept of line modeling is presented.

These topics are followed by an exam. The major idea behind exams in this course is integration of topics and realism of practical applications. The following problem is offered for the first exam:

1. Draw electrical network model of the transmission line represented as:



Provide electrical network analysis based on the following data:

Diameter of each conductor d= 17.1 mm
Distance between conductors D= 4 m
Length of the line l= 20 km
Resistance per unit length r = 19.8 Ohms/100 km
Voltage at the receiving end V_r *= 115kV*
Power factor of the load pf = 0.75
Resistance of the load R_{load} *= 150 Ohms*

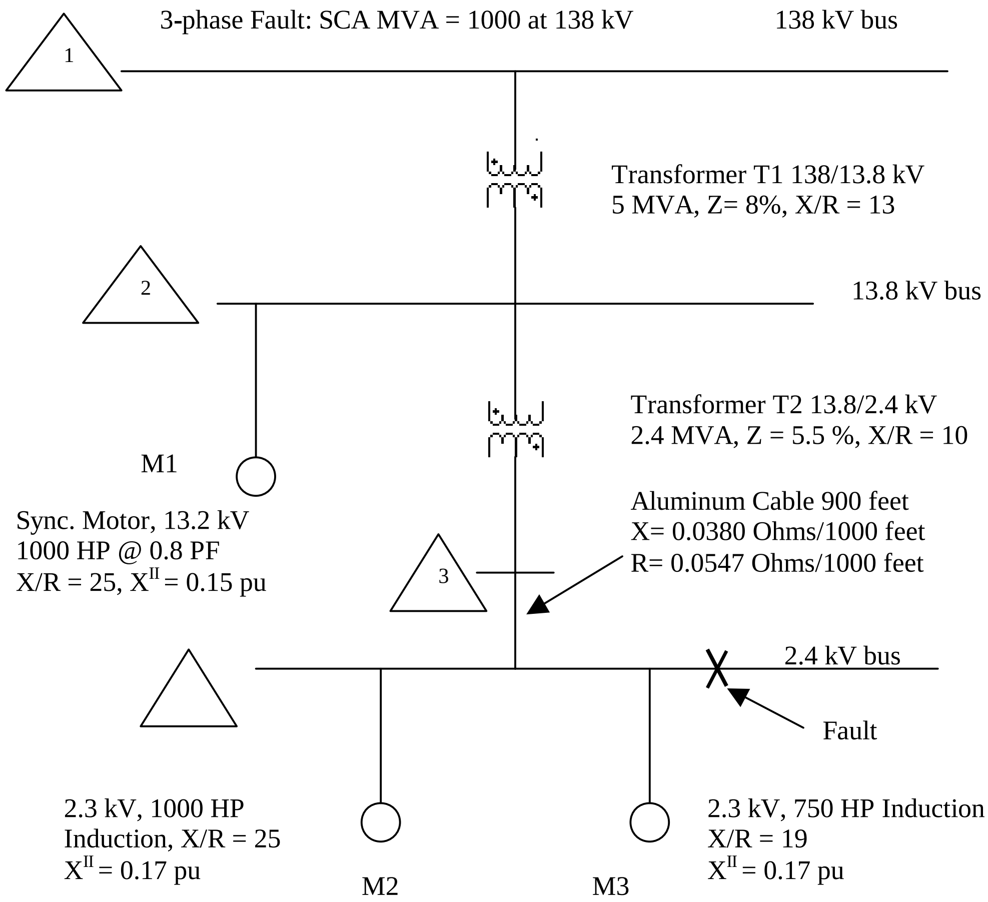
Calculate line reactance (15%), load impedance (5%), draw equivalent diagram (5%), and determine voltage at the sending end (15%).

2. Based on the results of the previous question calculate savings from the improvement of the pf from 0.75 to 0.95 (15%). Note that the load factor is 0.7, there are 8760 hours in a year, and energy costs are $0.07 per kWhr. What would be the voltage at the sending end now (15%)? Draw the network model for this case (10%).

3. Compare results of both cases and make conclusions (10%).

The next topic deals with transformers, autotransformers, and taps and their applications in power distribution systems. Three-phase transformer configurations are introduced and thirty degrees phase shift is discussed. This is followed by a per unit system discussion with an emphasis on adjusting a device's own per unit parameters to the system base. Fault analysis is discussed, covering three-phase-to-ground symmetrical faults. This material is based on the IEEE Red Book: *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants.*[5] The software package that accompanies *Power Systems Design and Analysis* text by Glover and Sarma [6] is used to calculate fault currents for a number of cases. The second exam follows and requires the following calculations:

1. 30% Prepare data for fault analysis of the system (see figure below). Recommended base MVA is 10 MVA.



2. 10% Draw impedance diagram for this network with all per unit resistances and reactances near their respective elements

3. 50% Calculate symmetrical rms short circuit current for the fault at bus 4. Use only first cycle data.

Load flow analysis is presented next and is based on Gauss-Seidel and Newton-Raphson methods. The concept of iterative solution is introduced and the formulas for a simple three-bus system and derived.
The above mentioned software package is used to provide load-flow analysis for a multi-bus system. A fragment of the local utility company network is used for this purpose. It provides a sense of community involvement for the students as they see familiar names of the stations and substations.

The series of lectures and discussions on distribution economics are next and they deal with methods of economical evaluation of several variants. Present worth and future worth analysis are introduced. Relevant examples reinforce the concepts learned.

The final exam integrates the last several topics and requires performing of the following analysis:

1. 45% The distribution network is shown below (Fig.1). The manager asks you to determine if it would be economically justified to shut down one of the transformers on weekend days with the load being 30% of that on the regular weekdays. There are 52 weeks a year, 2 weekend days a week, 24 hours transformer being under load. The proposed configuration with one transformer in action is shown on Fig. 2.

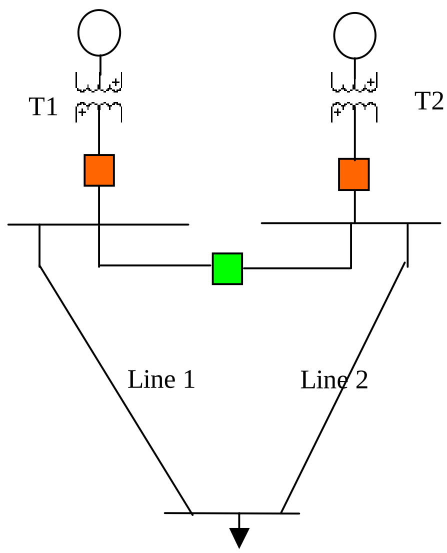


Figure 1

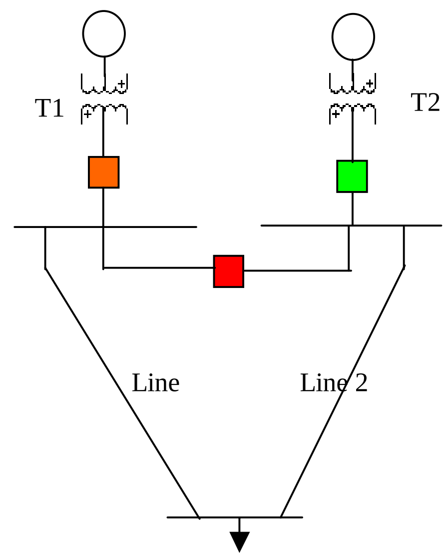


Figure 2

Breaker closed   Breaker open

Incoming data for calculations:

Load

P = 5000 kW

Q = 3000 kVAR

$S = \sqrt{P^2 + Q^2} = 5831 kVAR$

LD(Load Factor) = 0.85

$S = S_1 * LD$*, kVA = 5831 * 0.85 = 4956 kVA*

Transformer

S_{trans} *= (S * 100)/140 = (4956*100)/140 = 3540 kVA*

The nearest standard transformer is rated 3750 kVA

The voltage rating of the transformer is 115/13.8 kV

Lines

Each line carries 1/2 of the load's current, thus

$I_{line} = I_{load}/2 = (5831/2)\ kVA/1.73*13.8kV = 122.12\ A$

We will choose AWG #6 copper conductor with ampacity of 130 A

$R_{Line} = 2.21$ *Ohm/mile*

$X_{Line} = 0.628$ *Ohm/mile*

The length of lines is 30 km each.

The length of the tie between buses 1 and 2 is 50 m. This line is the same as principle lines.

Economical data

Interest Rate is 12%

Transformer's life is 20 years

Energy cost is $ 0.05 per kWhr

2. *50%* *Utilizing load flow analysis find the voltages* V_1, V_2, *and* V_3 *at buses 1, 2, and 3 respectively for the network using data below.*

Bus	*Type*	*Voltage Magnitude, pu*	*Voltage Angle, Degrees*	*Net P, pu*	*Net Q, pu*
1		*1.05*	*0*	*-*	*-*
2		*1.03*	*-*	*1.05 of calculated P at bus 3 (in pu)*	*-*
3		*-*	*-*	*calculated*	*calculated*

3. *5%* *Determine types of buses, and fill in the blank area in the table.*

4. As usual, make conclusions.

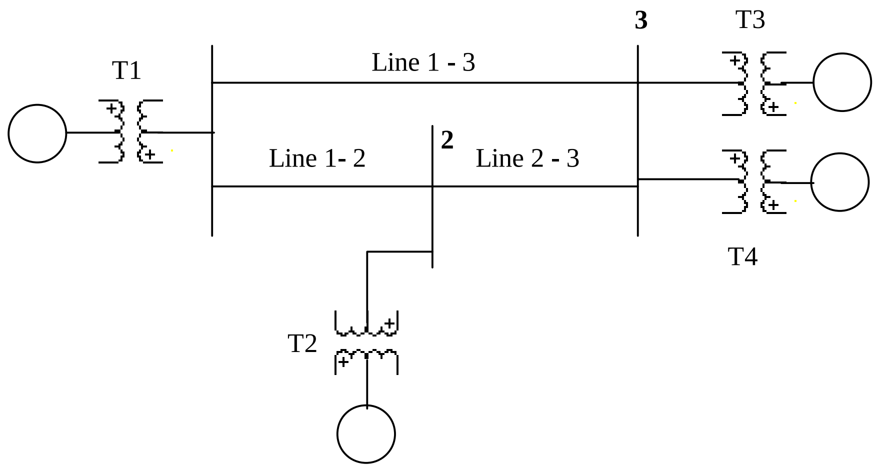
Every exam includes one more question about the technical article in the most recent professional publications. The answer is expected in the form a memorandum to their supervisor. Students should be current in their specialty from the beginning of their careers, right here, at the College. Development of their communications skills is also a target.

At the beginning of the semester students are assigned a library research project. They can choose topics freely as long as they are related to electrical engineering/electrical engineering technology field. The structure of the project should reflect the following:

1. Why did I choose this topic
2. What did I know before I started my research
3. What did I learn
4. What is the future development in the field of my research project

At the end of the semester students present their papers (no less than 10 – 15 pages) to the class and to the members of the industrial advisory committee. Presentations are performed in a professional manner and are videotaped.

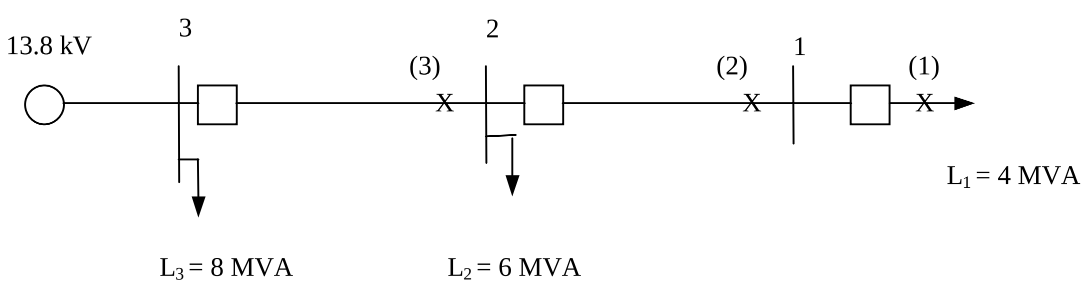
The second semester starts with discussions on demand calculations. Various methods of load analysis are introduced with an emphasis on residential and industrial customers. The following section deals with the method of symmetrical components and unsymmetrical faults. Software simulation program that accompanies Glover/Sarma text [6] is used to verify the results of hand calculations. In addition, the "Fault Tutor" software from the University of Main and Basler Electric is used to illustrate the concept. This program allows excellent visualization of complicated concepts and makes the topic clearer for students. Students are assigned a semester project to perform fault analysis for a power system as illustrated below:



A written report with the results of hand calculations of all possible faults at a specified point is supplemented with the software simulation.

The next section deals with protective relaying. Protection concepts are introduced as well as principles of electromechanical relays operations. Discussions continue with the study of elements and system protection, such as feeder overcurrent protection, transformer protection, and distance protection, among others. Exam that follows requires selection of the feeder overcurrent protection as shown:

Consider 13.8 kV radial feeder shown below:



Fault currents are assumed to be as follows:

$I_{sc1} = 5000\ A$
$I_{sc2} = 5500\ A$
$I_{sc3} = 6000\ A$

Determine relay settings to protect the system assuming relay type CO- 7 is used.

After completion of the test the students are required to set the sample relay according to the results of their calculations.

The following issues are covered till the remainder of the course: voltage quality, reliability, and supervisory control and data acquisition systems/energy management systems (SCADA/EMS).

The topic of voltage quality is illustrated with the use of a Power Point™ presentation developed in the department. Besides that the students are encouraged to use the slide show developed by the Iowa State University and University of Virginia[7]. To illustrate the topic Fluke true RMS meter is used to display and measure voltages and currents for both linear and non-linear loads. The use of this instrument is very helpful for students as it allows observing various sinusoidal and non-sinusoidal waveforms and their characteristics. One of the members of the Industrial Advisory committee is invited to demonstrate the capabilities of Dranetz analyzer. Students are able to take measurements using both devices and compare their capabilities. The concepts of voltage/power quality are further illustrated and reinforced by the use of LabVolt® electromechanical system with data acquisition interface. This system includes virtual 8-channel oscilloscope, phasor analyzer, and harmonic analyzer. To introduce the concept of Fourier composition a simple LabView® simulation program was developed in the department. It allows students to observe how the square wave could be obtained by combining a number of sinusoidal waveforms with different magnitudes and frequencies. Please, see Figure 1 for a screen shot of the program.

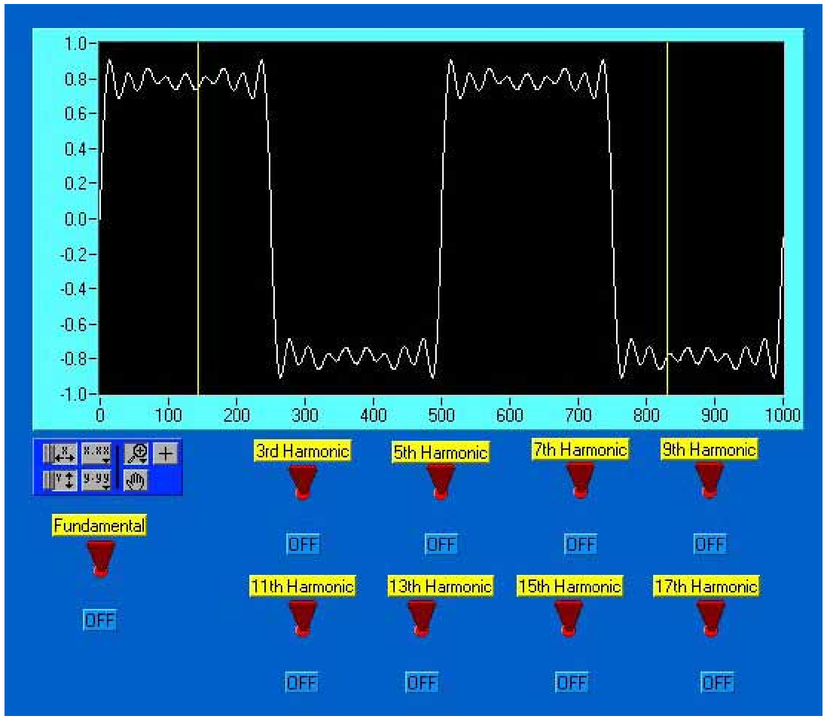


Figure 1. Square wave composition simulation program

4. Laboratory Exercises

Laboratory sessions during the first semester are performed outside the classroom at the local power utility company (Niagara Mohawk). Students visit high-voltage substation in a walk-around format and are guided by the employees of the utility company. This is critical for familiarization with major power equipment and operations of the utility company. The tour starts at the substation's control house where the students are familiarized with the company's structure and transmission configuration. Tour guides (superintendents of power delivery) brief the audience about safety considerations. Types and operational principles of equipment are thoroughly discussed. A load tap-changer of a power transformer is demonstrated in action.

Next trip is to the company's regional control center. Here the students are familiarized with the work environment of the system operators and other personnel associated with their duties. Observing numerous electrical engineering applications, such as telecommunications, control systems, and digital and analog devices under one roof reinforces important systems concepts.

Laboratory sessions during the second semester are also provided at the Niagara Mohawk site and include the company's distribution laboratory – a facility for linemen training, where the students can observe and record parameters of a distribution feeder with different transformer connections and the company's relay protection lab, where the students test relays and are exposed to the state-of-the art testing equipment.

At the distribution laboratory discussions and demonstration of various transformer connections including broken delta are presented. Students are familiarized with specific cases from the company's records. Some of these cases are demonstrated and measurements are recorded.
At the relay laboratory the students are exposed to digital relays and perform actual testing of an overcurrent relay using the company's tools and software.

5. Senior Design Project

At the beginning of the second semester the students are assigned a senior design project. The project objectives are to perform preliminary design of a power distribution system for an industrial facility. Students are given a site plan of the facility as well as dimensions of the buildings. Load characteristics are given for each of the buildings with one building being given in full details. After determining rated demand for the facility, the students have to adjust power factor of the plant and to propose at list two variants of the power system configuration. Cost-effectiveness analysis is performed to determine the proper variant. Selected variant is the subject for equipment selection, fault analysis study, voltage drop calculations, and relay protection decisions among others. The students are required to perform Internet search, contact local equipment distributors for price quotes, and to defend their design. The project is team-oriented and each member of the team is responsible for specific group of tasks. However each of the students is well aware of the work of others. It is interesting to mention that students form fictitious consulting companies to perform the project. It is amazing how creative they are, given the flexibility in their choice of methods. One of the teams performed all the calculations using Excel® throughout the project.

Project presentation is performed at the end of the semester for the faculty members, students, and the members of the industrial advisory committee. All presentations are videotaped. Presentations are followed by discussions with the audience and serve a valuable role of experience sharing with the industrial community.

6. Industry Involvement

The industrial advisory committee was formed to reflect the major components of the system's lifecycle and include representatives from research and design companies, consulting firms, contractors, utility companies, industrial facilities, and big commercial organizations. The committee regularly reviews curriculum and advises on desirable changes, participates in continuous improvement planning, and provides logistical support for the educational process. One of the examples of this support is off-campus laboratory sessions and industrial tours. Several lectures are provided jointly with industry representatives either in the classroom or at the industrial site. Examples of such lectures are presentations on digital relays and SCADA/EMS.

Internship opportunities are always available for students through participating companies and include various activities ranging from design and consulting to facilities management and utility company activities. Interns at Niagara Mohawk Power Corporation were involved in equipment failure analysis, development of manuals, and other technical activities. Interns at the Buffalo General Hospital perform design and maintenance duties.

7. Student Development and Creative Activities

Students in electrical engineering technology program at Buffalo State College are constantly provided with opportunities for personal and professional development. The College sponsors annual research and creativity celebration events that include conference-style presentations and poster sessions. Engineering technology students of the Power/Machines option successfully presented their cases of creative problem solving related to their field of studies.

Many students were involved in applied research projects participating in their development and implementation, such as stepper motor controller application.
During the second semester a special session on creative problem solving techniques in a team-oriented environment is offered to the students. This session is presented by graduate students from the unique Creative Studies program at the Buffalo State College.

IEEE student membership is another way to enhance students professionally. In the fall 2000 semester the student IEEE chapter of the college hosted Buffalo IEEE chapter meeting. Participants were guided through the labs and samples of student works. Students had a great opportunity to increase their awareness of local industries and promote their program to the local engineering community.

8. Evaluation and Assessment

Throughout the course sequence students are assessed on the following:

- Ability to use computer-aided design software
- Ability to demonstrate knowledge of the task procedures
- Performance as a team member and a team leader
- Ability to read architectural and electrical drawings and draw valid conclusions
- Ability to select proper formulas from the instructional material
- Ability to systematize and categorize information
- Ability to read and understand procedures from the National Electrical Code (NEC®)
- Ability to distinguish power distribution system's configuration
- Ability to work with simulation software
- Ability to perform cost-effectiveness analysis and select a proper variant
- Ability to communicate clearly in writing and orally.

9. Conclusion

During the development of technical topics in Power/Machines option of the EET program at Buffalo State College, we utilized the systems approach to the curriculum structure at different levels. This is reflected at the selection of the industrial advisory committee, course structure and content, as well as interdisciplinary cooperation with other faculty and industry.

The project-driven curriculum combines activities that are both stand-alone and project embedded with a team approach. The required disciplinary knowledge is conveyed through real world linked problem-solving and hands-on activities. Constant exposure to current industrial settings and state-of-the art equipment and technologies through industrial tours, internships, off-site laboratory exercises, joint faculty-industry lectures, challenging problem solving and problem finding activities, and professional presentations among others, draws high regards from the students enrolled in the program and from the industrial representatives and employers.

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ILYA GRINBERG
Ilya Grinberg graduated from the L'viv Polytechnic Institute (L'viv, Ukraine) with an MS in EE and earned a Ph.D. degree from the Moscow Institute of Civil Engineering (Moscow, Russia) with a specialization in systems engineering and design automation. He has 28 years of experience in design, consulting, and teaching in the field of power distribution systems and design automation. Currently he is an associate professor of Engineering Technology at the Buffalo State College. He is a Senior Member of IEEE, and a member of ASEE. His interests are in the field of power distribution systems, design automation, and systems engineering.