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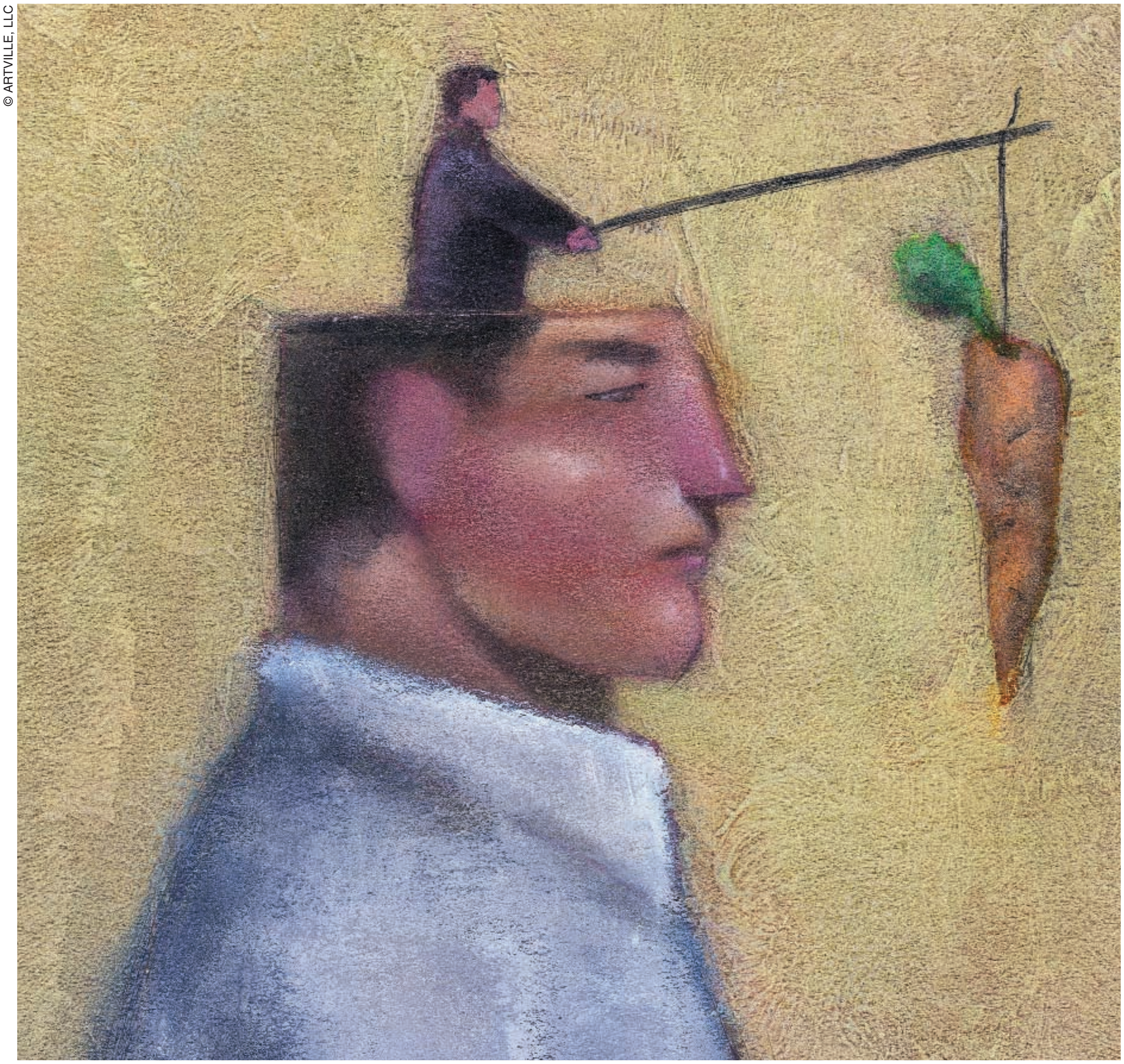

Feeding Our Profession

by gerald t. heydt and vijay vittal

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POWER ENGINEERING EDUCATION FEEDS THE POWER ENGINEERING PROFESSION. If the profession is to continue to be a vital part of electrical engineering, something must be done about the educational stem. In some sense, power education is at a crossroads, and there is a need to take a positive growth path by moving the most pressing and difficult problems in power engineering to a viable high-tech power program. Such an educational program must center on systems, new materials, applications of advanced mathematics and physics, and the integration of economic principles. One potential avenue is to appeal to national governments worldwide to support power engineering research through university-based centers.

A recent upsurge in student interest at the undergraduate level and the importance and complexity of typical power engineering problems are indicative of positive growth in the field; however, vigilance and increased industry participation in all educational sectors are needed to ensure vitality of the field. This article leads off continuing coverage of power engineering education in future issues of *IEEE Power & Energy Magazine*.

Stalled at the Crossroads?

Power engineering is one of the oldest branches of electrical engineering. The status of education in this field has seen golden days and less golden days. With the advent of deregulation and the cresting of interest in information technologies, communication systems, and solid-state electronics, power has taken a less prominent role in many electrical engineering curricula worldwide. In the minds of many educators, power is akin to large-scale system theory, and it falls in an area more closely related to automatic control. But power engineers generally feel that the discipline is sufficiently distinct to stand on its own. Unlike other branches of electrical engineering, power has less support from a deregulated "lean" industry. This has translated in the past to weak student enrollments and questions on the viability of power educational programs at many universities. It appears that the field is stalled at a crossroads: whether to coalesce with other systems-related fields or to strike out on innovative new grounds of energy and environment.

In general, enrollment in engineering educational programs is a function of the demographic population levels, the state of national and international economies, industry needs and hiring rates, and intangibles such as interest levels of students and contemporary publicized breakthroughs in science and engineering. To some degree, engineering trends in North America seem to be a harbinger of conditions worldwide. Undergraduate engineering enrollments in the United States reached an all-time high of about 460,000 in 1983, after which a steady decline in enrollments occurred. Worldwide figures are more dramatic, with reductions in engineering enrollments and increases in soft sciences and business. The increases and decreases in enrollments in North America were felt across all disciplines of engineering, with electrical engineering (EE) seeming to be a trendsetter in that the EE undergraduate enrollment peak occurred before the engineering-wide peak. The engineering-wide undergraduate enrollments reached a low in 1998 in North America; the EE low occurred in 1996, again setting the trend about two years early. The recovery of engineering enrollments in general and EE enrollments in particular have been slow. In an October 1999 *Engineering Times* article,

> What is the current status of power engineering education, and which future trends will lead to a positive growth path?

It appears that the field is stalled at a crossroads: whether to coalesce with other systems-related fields or to strike out on innovative new grounds of energy and environment.

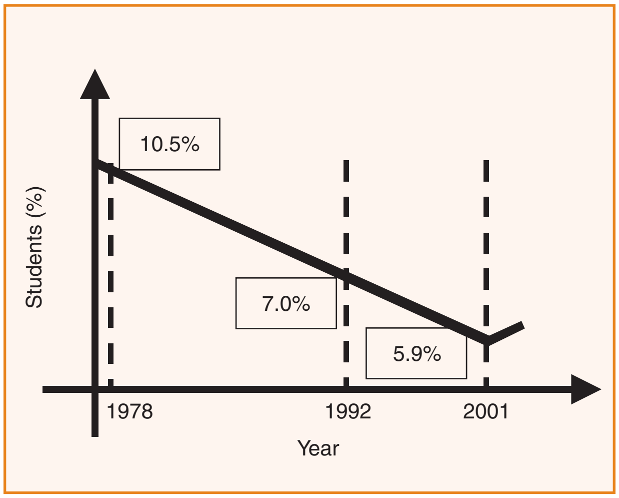

figure 1. approximate percentage of undergraduate electrical engineering students committed to electric power in the United States.

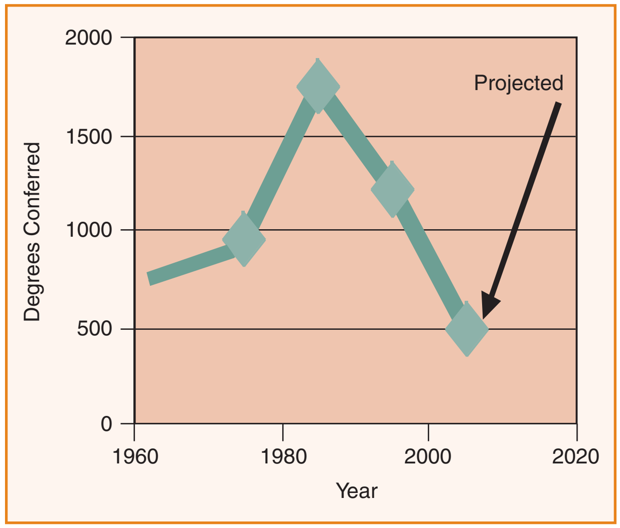

figure 2. undergraduate degrees in electric power engineering conferred annually in the United States.

Dean Eleanor Baum remarked favorably on the 4.4% increase in 1999 U.S. engineering enrollments, but she noted that the increases were mainly in the area of computer engineering. Under-represented groups (e.g., women and minorities) did not show a commensurate percentage increase. Baum warned that the slow recovery and the sparse data are not sufficient to pronounce an end to the weakness of enrollment in engineering educational programs. An added element to the continued frailty of engineering enrollment is the science and mathematics preparation of high school students. In spite of data showing some improvement in the science and mathematics preparation of high school students, engineering educators observe a marked lack of guidance by high school counselors in advising students to take the right combination of mathematics, physics, and chemistry in order to pursue a degree in engineering. Engineering freshman are often faced with the daunting task of having to complete several remedial mathematics and science courses before they get into the beginning engineering courses. The competition in these courses is tough and can demoralize students.

The situation in power engineering is more fuzzy since reliable statistics in this subarea of EE are not as well documented. The statistics are fuzzy partly because there is no universal definition of a submajor of electrical engineering undergraduate students. The undergraduate students themselves are often unsure of their areas of interest, but it is clear from informal discussions with EE professors that power continues to capture a lower and lower percentage of undergraduate students. In the 1970s, power represented between 10 and 15% of undergraduate electrical engineering enrollments in the United States, with international figures being higher, especially in Asia. Recent (2002) estimates are that from 5 to 7% of all EEs in the United States are in the power subarea at universities and colleges that offer power electives. Figures 1 and 2 illustrate the point for U.S. data. In India and China, some EE programs are more traditional, and the power area enrollments are higher; but, educators in China and India also lament the erosion of power enrollments.

At the graduate level, the picture is somewhat different, mainly because of the high percentage of international students entering North American and European educational programs. In North America, the role of research at the graduate level in power has been stable, and this has had a stabilizing effect on graduate (particularly doctoral) enrollments. In the United States, graduate enrollments in EE have been on a slow increase since 1998, with the majority of the increases coming from international students. Figures 3 and 4 illustrate the data for the power subarea in the United States, with 50 to 75% of students coming from abroad. Again, the statistics for power are sparse and mostly undocumented; however, international students form the backbone of graduate programs in power in Canada, the United States, Australia, New Zealand, and Western Europe, with 60 to 85% of enrollments. Students come mainly from Asia, but some North American programs have diverse representation from Europe, Africa, and Latin America. The graduate programs of some Latin American countries have remained fairly strong as industry infrastructure demands have been on the rise. In Mexico, economic growth and deregulation have helped the power industry, and many regional Mexican universities have excellent and well-attended graduate programs. Universities that have relatively large power programs (often more than five professors in the power subarea) have held their own in retaining power graduate enrollments, but real growth in enrollments among these programs is rare.

Some of the information presented above is dated; however, this is the most recent data available in print. The authors have conducted an informal survey among colleagues at other universities and have noted the following. Over the past year, many universities that have a viable power program have seen significant increases in undergraduate enrollment in senior elective courses. At three large North American engineering schools, the increase in power engineering enrollments at the bachelor's level has been in the 30 to 50% range. This can be attributed to positive guidance from electric power utilities regarding the need for engineering manpower and, to some extent, the collapse of the job market in information technology (IT) and communications sectors. At schools that traditionally have had strong power programs, the graduate enrollment at both the master's and doctorate levels has remained steady. There are some particularly bright spots in the graduate picture.

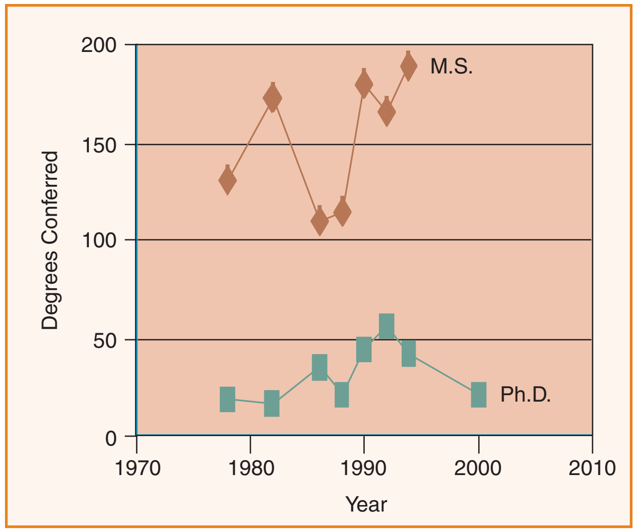

figure 3. graduate degrees in electric power engineering conferred annually in the United States.

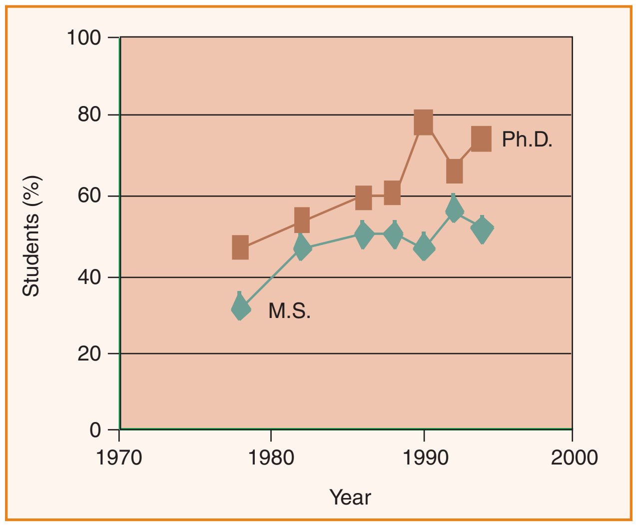

figure 4. percentage of international students enrolled in electric power engineering graduate programs in the United States.

- ✔ Several universities have active power affiliate programs in which industry (mainly local) participates with the university to support graduate and undergraduate students. Industry-relevant topics are brought to the campus, and some hiring program is in effect. Some affiliate programs are quite old, having started with modern staffing and funding in the 1950s and 1960s. At Iowa State University, for example, an industry-funded program formed the base of the power program for at least 35 years. Contemporary affiliate programs often have some government funding. As an example, the Centre for Applied Power Electronics at University of Toronto, Canada, has some industry support, but the base support is from Canada's National Science and Engineering Research Council. The Power Systems National Key Laboratory at Tsinghua University, China, is fully supported by the government. In Europe, solid industrial support is often used as a base of power programs. For example, the Electric Power Systems Group at the Royal Institute of Technology in Stockholm, Sweden, is supported by several European multinational companies. Strong national industries often keep power alive at centers of excellence in Europe.
- ✔ Some power engineering educational programs have evolved on a larger scale, including multinational connections. An example is the National Electric Energy Testing, Research, and Applications Center (NEETRAC) at the Georgia Institute of Technology. The basic mission of such programs is to utilize the expertise of universities to provide a venue for precompetitive research and development. In the case of NEETRAC, strong European connections have been used in both power education as well as power engineering research.
- ✔ In high-growth South American countries, there is an adequate level of industrial and governmental support despite apparently weak economies. Deregulation in Brazil and Chile seems to have had less of an impact on power education enrollments than in North America. It is possible that deregulation in these countries is proceeding at a slower pace or in different forms than in the United States, and cuts in engineering talent are correspondingly less.
- ✔ The Electric Power Research Institute (EPRI) continues to support research, part of which is research at U.S. universities, including a program known as "Tailored Collaboration," in which some EPRI sponsor funds are earmarked for research. Some of these funds form an

important part of university research budgets in power.

- ✔ In the United States, a National Science Foundation (NSF) program for power engineering continues to support university research in power. This program impacts not only U.S. programs but also international students who populate the programs. The NSF program has a US$3 million annual budget, but competition for the funds is high. At NSF itself, there is persistent competition for these funds, and, without "success nuggets" in the educational and research arenas, the budget is subject to erosion.
- ✔ An NSF Industry University Cooperative Research Center (IUCRC) program supports one power engineering center, the Power Systems Engineering Research Center (PSerc), that has a total budget in the range of US$2 million per year. The program has an international component. The NSF IUCRC program brings a mutually beneficial industry/university marriage that has worked out the details of intellectual property agreements, bringing meaningful industry problems to the university, interaction between graduate students, professors, and industry participants involved in research projects, and formalized communication channels between the university and the power industry. As an example, PSerc brings 13 member universities and about 40 industrial sponsors together at four annual meetings, Internet-based seminars and meetings, short courses, and an extensive Web-based information-transfer mechanism.

The issue of the percentage of local students in undergraduate and graduate programs in the Western countries is somewhat of a sociological/political issue. Engineering students from developing countries often do not return to their home country upon graduating. The population of international students in power engineering educational programs has both positive and negative aspects including the following issues.

- ✔ If international students did not enroll in power programs, the programs could die.
- ✔ Many international students come to Western countries with substantial academic credentials.
- ✔ The whole idea of educating internationals is that they would return to their developing country with a positive effect on that country. However, most international students remain in the host country, which is know as the "brain drain" syndrome. In engineering, about 30% of educators are from Asia and have been educated in the West. It is important to note that in the two largest Asian countries, China and India, only a small percentage of the engineering graduates go to other countries to pursue advanced degrees.

There is one factor that is generally agreed upon by all: it is not a healthy sign that local students are not effectively attracted to power engineering. A number of factors contribute to this critical issue. In North America, the enrollment into various subareas of electrical engineering depend on the success of prior graduating classes in finding employment. The restructuring in the electric utility industry and the constant reorganization in many utilities has seriously affected the hiring of new engineers. This has had a significant impact on power engineering enrollment. To some extent, the media in North America also publicizes more recent breakthroughs in technology and tends to pay little attention to critical national infrastructure components unless a major disaster (like a blackout, outage, earthquake, or tornado) occurs. The media coverage plays a role in directing the impressionable young engineering freshman or sophomore into the subareas that are in the media glare.

In recent years, another significant development is the role of engineering internships for sophomores and juniors. Many high technology industries pursue these students quite aggressively and provide them very technically challenging and exciting internships. When these students return to school, they tend to take electives closely related to their internship experience, with the aim of pursuing employment in the industry in which they had the internship. Traditionally, the electric utility industry has not actively involved student interns. It is a recent trend among some utilities to aggressively pursue students. This is a positive trend and will definitely result in increasing student interest in the area of power engineering.

Many companies in the high-tech industries (such as communications, computers, and VLSI) tend to support graduate programs in their respective disciplines. These companies put greater emphasis on the well-trained engineer as the finished product and less emphasis on this kind of support, resulting in innovations and intellectual properties for the companies. In many instances, high-tech companies make a conscientious decision to support a selected set of schools and aim their recruiting of graduate students at these select schools. This kind of support is conspicuously absent in the electric utility industry. A large segment of the power industry expresses disinterest in hiring graduate students and does not see a strong need to support graduate programs in power with an eye towards supporting the intellectual capital that it generates. In many major universities in North America, a strong graduate program essentially drives the undergraduate program. University administrators would be unwilling to support educational programs that do not have strong research exposure and industry interaction. The industry-support issue makes it imperative for the electric utility industry to change gears and reevaluate their position.

Power Engineering Curriculum

Power engineering curricula have enjoyed upgrading and revitalizing in the last ten years. Much of the impetus comes from the proliferation of worldwide information on the Web and the pressure to integrate computers into nearly all phases of engineering programs. Research in the power subarea also has impacted power education at all levels. If the most important need is for the undergraduate student who knows power engineering in the classical sense, then it does not take a research

> We must move the most pressing and difficult problems in power engineering to a viable high-tech program that centers on systems, new materials, applied mathematics and physics, and integrated economic principles.

institution to produce graduates. A good analogy relates to analog circuit design; no one argues that it is not needed or that it is not a legitimate EE topic. Analog circuit design is taught in every undergraduate curriculum, but there are few research programs in the field. Is this what classical power engineering is evolving to? An engineer at a multinational computer company, upon seeing one of the first microchips, reportedly said "But what is it good for?" Power engineers need to have the level of competency in the field to "know what high technology is good for," to break from outdated methods to solve pressing problems. Further, we need the engineers to produce these innovative solutions, and we need educators to produce engineers with the desired high level of competency. The curriculum probably needs to contain subjects such as optimization, communications, economics, software engineering, data structures and databases, and networks. And power needs to span all power and energy related branches of engineering, including the automotive, aeronautical, and construction sectors. Somehow the true long-term needs of the broad power industry must be identified, and the needs should be identified from the right people.

Intriguing alternatives in the power curriculum beg the question of the proper role of mechanical and industrial engineering. It may be that the systems-oriented sector of power education will migrate out of EE into areas that focus on systems solutions. Alternatives such as this may be elements in what it will take for a power program to survive in the university environment. It is important to note that power electronics, often viewed as a branch of circuit theory, may credibly be viewed as part of power engineering. This conclusion is reached by noting that many of the concepts of ac circuits are attendant to power electronics. Surely, power utilization, a key part of power electronics, is power engineering. The undergraduate student appears to gravitate to power electronics because it is real (one can visualize kilowatt-level controls), and the hands-on nature of laboratory experiences in the area is attractive. What appears to be missing from this revelation is the support of power engineering programs at a high level by the power electronics and power utilization industries. Perhaps the educators themselves have not made the connection between power electronics and power engineering. Automotive and aeronautical electronics appear to be fertile areas for student interest. In the experience of many educators, student interest seems to improve when power electronics topics replace transmission line design, for example.

The IEEE Power Engineering Society (PES) has taken a particularly positive stance on education. This is evidenced by financial support for students to attend PES meetings, affording the infrastructure for continuing education in the form of tutorials, preparation of materials such as digital videos and Web sites that help secondary school students evaluate power as a career alternative, and award recognition for student excellence in power engineering. Many of these activities for both education and educators reside in the IEEE PES Power Engineering Education Committee (PEEC).

Supply and Demand

The issue of how many new power engineers are needed each year relates to how "power engineer" is defined by the industry and what knowledge and skills are valued in the job market. The power engineering profession is not static, and new needs in power electronics, new generation sources, digital instrumentation and control, and environmental engineering should be included in the count. The traditional vertically integrated utility company still utilizes engineers, but many new graduates are making careers in less traditional environments. In fact, the majority of new graduates are moving into architectural engineering firms and the service/manufacturing sectors. Deregulation has brought trends in turnkey engineering services that lie outside the traditional electric utility company, and these trends have engineering demands. Two distinct phenomena have appeared that have potentially damaging consequences on power engineering as a whole:

- ✔ Some operating utility companies now do relatively little engineering, and the engineering that they do is driven by pressing needs and is outsourced. This environment does not foster professionalism to the same degree that the traditional vertically integrated environment had.
- ✔ Power may not be well portrayed in the undergraduate EE programs, and local students are not conversant with the challenges of the field. As a result, few enter the field as a career choice.

There have been encouraging signs of selectivity in hiring B.S. level students in the power industry. Hiring B.S. and M.S. level students in power electronics has been strong in the last five years. Software firms have consistently hired power engineering majors at all levels for the last 20 years. In 2001 and 2002, undergraduate students in power have often graduated with multiple offers from a wide range of players in the elec-

> Enrollment in engineering educational programs is a function of the demographic population levels, the state of economies, industry needs, industry hiring rates, and some intangibles.

tricity business. This includes generation companies, transmission companies, power traders, independent system operators (ISOs), independent power producers (IPPs), consulting companies, and large processing and manufacturing companies that have extensive electrical facilities. This optimistic trend is a primary reason for some programs seeing increased enrollment in power engineering electives. In order to sustain the increased interest, the hiring trend should be sustainable and support from the industry at large should be forthcoming. How many power engineers are needed is a matter for conjecture; it seems, however, that the roughly 550 B.S. level engineers and 200 M.S. level engineers in North America could well be doubled with a positive effect on employee recruitment. How the 600 to 1,000 additional students could be educated and where they would come from is problematic; with about 20 large power programs in North America, the number of B.S. and M.S. new hires needed would require a doubling of enrollments.

Faculty Careers

The present age profile of power engineering educators is decidedly skewed to later points in the educators' careers. Because university hiring in the 1980s and 1990s was weak, there appears to be a discernable gap in ages among power engineering educators. That is, the leaders of the near-term future seem to be in short supply. That perception may be deepening as one moves toward the 2010 timeframe. The conclusion is that new doctoral students who are capable of teaching and who want to teach are needed now. Interestingly, many of the same problems occur in the subarea of automatic control. Perhaps students might be encouraged to pursue a major in power and a minor in control (or another under-enrolled subarea). As hiring programs are not too robust, the dual expertise could be advantageous. Faculty careers are impacted by many seemingly uncontrollable forces, such as research funding, popular interest/political correctness, and trends in academics. Most reputable universities place emphasis on academic merits, with practical application potential also being a driving factor. Academic merit is often measured by technical works and research quality. Application orientation might be measured by industry support. Overlying the academics is education; the faculty member must be able to balance research, education, and service and keep the students pleased with their education. In power engineering, the faculty member must face criticisms that power is not at the forefront of engineering, and the faculty member must justify her/his existence in the face of declining enrollment. The power subarea seems to be its worst critic, and this too can negatively impact faulty careers.

In 2002, entry-level faculty openings in power have been mainly in developing countries and outside North America. Research needs have kept faculty openings for experienced persons in clear demand. In 2001, William Kersting wrote an insightful editorial in *IEEE Power Engineering Review*, asking who was expected to fill the role of educator in the area of power engineering in the next generation. The thrust of the article posed the question of, in view of the importance of the power engineering infrastructure and in view of the eroded enrollments in power engineering educational programs nationwide, who will carry on the next generation of power engineering education. The scenario painted is one of reduction in the number of electric power educational programs worldwide and the decrease of power engineering faculties. Subsequently, who will fill the role of the next generation of power engineers practicing in industry? This question and the severity of the erosion are explored herein. Some position statements are made to address identified problems. The inputs of several experts in the field of power engineering in general and power engineering education in particular are included.

With the pressures of deregulation and cuts in education expenditures, power engineering education seems to be hard hit, and there is no clear end in sight. In an October 2000 *IEEE Spectrum* article, B.H. Chowdhury lamented the shortage of new power engineers, but an innovative and effective solution seems to be elusive. Power engineering seems to have been at a crossroads for about 15 years. With reference to a famous quote from Yogi Berra, "when you come to a fork in the road, take it." What appears to be lacking is exactly that: we are at a crossroads, but there does not seem to be the courage or foresight to evaluate the alternatives nor the energy to pursue the proper course.

Evaluation of Alternatives

The evolution or devolution of power engineering education and concomitantly power engineering as a profession is under the control of engineers, educators, and government. It seems prudent to take a position of control of the field to ensure that:

- ✔ power education survives
- ✔ reliability and performance of systems is held to accepted and desired levels
- ✔ advanced concepts are brought to bear on difficult problems in an appropriate fashion
- ✔ engineering talent moves onto future technological fields as those fields become needed and feasible.

Some potential alternatives are as follows.

Limited Number of Power Programs (or Evolution of the Status Quo)

About 30 years ago, L. Dwon made a presentation at a PES Summer Meeting that suggested managing an eroding technology by limiting the number of educational programs. This seems to be the way present power engineering is evolving, with the number of credible power engineering educational programs down sharply in the last 30 years, perhaps to fewer than 20 in North America and 75 worldwide. The infrastructure for this alternative is already in place. It has been argued that competing relatively small programs promotes natural selectivity of competition, allowing the viable programs to survive. However, as research and educational funds decrease in power engineering, dividing those funds further does not seem to be productive. Educators in this plan are increasingly pressed to leverage funds to keep programs alive, and, sooner or later, over-leveraged budgets can collapse. This strategy is not a positive strategy of growth; it is a strategy of managing cutbacks.

Promoting National Strategies in Power Engineering

This alternative is somewhat the reverse of limiting the number of programs. In this strategy, national needs in energy and power are identified in the nations of the world, and a critical mass of support for priorities is solidified. Perhaps this could be done on a national basis or even across groups of nations such as the European Union, Latin America, or North America. As rational national plans in electric power are developed, the engineering needed to attain the plan is put into place. This strategy, while difficult and risky with regard to potential for success, is a positive strategy of growth and a strategy that will allow for the replacement of the classics of power engineering of the past 100 years with what will be the classics of the next century. It seems that industry must take a strongly supportive role in this alternative. Government support is often directed to where it will be leveraged most, and industry support must form the basis of this leverage. The role of industry input in education should not be overlooked; Benjamin Franklin reportedly said "Tell me and I forget, teach me and I may remember, but involve me and I learn." Real engineering brought to the classroom is one of the most effective pedagogical tools available.

Movement into System Theory and Away from Mainstream Electrical Engineering

In this strategy, power engineering education and perhaps the entire field of power engineering as a practice, which has had a progressively difficult time in mainstream EE, might migrate into a systems-oriented field. That is, a controlled movement of researchers, engineers, and educators might elect to find their careers in systems engineering. This is already happening; in many cases, considerable engineering talent exists in the systems engineering (e.g., industrial engineering, operations research) field. This strategy is a compromise between the philosophies of the other two strategies.

The following are some points to note.

- ✔ The role of industries that are not traditional electric power industries (e.g., automotive, aeronautical, ISOs and other quasigovernmental sectors, and power electronics manufacturers) needs to be identified.
- ✔ The consequences of the migration of power engineering to technology and engineers to technicians need to be evaluated. If the most complex problems of power engineering (e.g., control, replacement of equipment by the next generation of hardware, attaining the kind of high level reliability and low level of vulnerability) go unsolved, what are the implications to productivity, the economy, and society as a whole?

Acknowledgments

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