Professional Resources to Implement the "Smart Grid"

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Abstract — A widely supported effort to modernize the United States power system has led to an engineering initiative variously known as 'smart grid', 'intelligrid', "gridwise", "modern grid", "perfect grid", "future grid", and similarly denominated programs. These efforts generally include features of: self-healing from power disturbance events, enabling active participation by consumers, assuring resilient operation against physical and cyber attack, delivering power quality for digital economy, accommodating all generation and storage options, enabling new products, and optimizing the use of assets. This paper addresses the question as to where engineers needed to address the smart grid will be educated, how they should be trained, and to what levels of comprehension in integrative fields they must be educated.

***Index Terms* — Smart grid; power engineering education; power engineering curriculum; power engineering resources; power engineering workforce.**

I. THE SMART GRID

THE "SMART GRID" and similarly denominated programs have been proposed as an effort to integrate the three critical developments in the future grid: expansion of the grid infrastructure to accommodate renewable resources and microgrids; penetration of information technology to implement full digital control in generation, transmission, and distribution systems; and development of new applications. Further, the smart grid programs respond to the political, public, and scientific community requests to implement high levels of low CO_2 emitting renewable energy resources. Although there are a number of incarnations of these programs, perhaps the United States Department of Energy (DoE) 'Modern Grid' program captures the main points. The DoE has defined the main tenets of the smart grid quoted exactly from [1] as the following seven elements:

- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response Operating resiliently against physical and cyber attack
- Providing power quality for 21st century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently.

These seven elements may be viewed more generically as making the grid:

- Efficient
- Accommodating
- Motivating
- Opportunistic
- Quality focused
- Resilient
- "Green."

Since truly implementing the smart grid initiative will take engineering professional resources of broad expertise and different profile than previously available, one may naturally ask the question as to where the new generation of power engineers shall come from. In this paper, the issues of power engineering education suitable for the smart grid shall be explored. The intent is to recognize the specialized *integrated skills* needed by smart grid engineers. Where these power engineers shall come from is discussed, and the desired curricula, levels of instruction, and full utilization of digital instruction resources shall also be examined.

II. INTEGRATION OF DIGITAL TOOLS INTO POWER ENGINEERING: REALIZING THE FULL PROMISE OF THE INTERNET

Modern society is migrating to an Internet based business and societal model. As an example, it is common to pay bills, order equipment, make reservations, and perform many of the day-to-day tasks of living via the Internet. In power engineering, one needs only to examine such tools as the Open Access Same-Time Information System (OASIS) to realize that the same Internet model applies to power transmission scheduling [2]. The identical model appears in many power engineering venues including setting protective relays; trans-commuting of engineering personnel; managing assets and inventory; scheduling maintenance; and

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enforcing certain security procedures. While the open Internet has security issues, similar models in an *intranet* or virtual private network may be used to enhance security. As this general model progresses, in many cases, one may wonder why certain procedures, whether in power engineering or elsewhere, have not been automated.

The essence of the aforementioned automation is at the heart of the smart grid. That is, various decisions in operation may no longer be relegated to operators' action. Instead, operating decisions considering a wide range of multiobjectives might be 'calculated' digitally and implemented automatically and directly. While safety, redundancy and reliability considerations are clearly issues, as this high level of direct digital control is implemented, it is believed to be possible to realize the objectives of the smart grid. To this end, the analogy between Internet opportunities and smart grid needs translates into a new philosophy in power engineering education: develop the cognitive and cyber skills while focusing on domains of specific expertise. This often translates to instruction tools that are highly interactive and having strong modeling and simulation background [3]. Interestingly, the very same Internet philosophy may be applicable to the identification of where engineering expertise will be obtained – and how the complex issues of power engineering, public policy, and information technology can be presented to students in undergraduate and graduate programs. This point is discussed further below.

III. BLOOM'S TAXONOMY: LEVELS OF UNDERSTANDING IN ELECTRIC POWER ENGINEERING

In 1956, Benjamin Bloom developed a taxonomy or schematic of how learning occurs [4]. The taxonomy is not specific to any discipline, but it does represent a consensus schematic of how students learn and to what depth of understanding their learning can be ultimately applied. There are a number of elements to the taxonomy, but perhaps the best known representation is the pyramidal structure shown in Fig. 1. The pyramidal structure is an attempt to delineate and characterize levels of comprehension from the most basic at the bottom of the pyramid, to the deepest at the top. For example, the lowest level is termed *knowledge*, and this level entails memorization and duplication of existing material presented to the student. This level is largely duplicative in nature and does not lend itself to innovation and new ideas. This level is useful, however, in technician training in which standard practices are to be replicated in many venues. In the application to the implementation of the smart grid, the *knowledge* category is the most basic level and does not by itself permit actual engineering designs to attain the seven cited DoE objectives.

The subsequent layers in Bloom's taxonomy show increased comprehension (labeled '*understanding*' in the next layer in Fig. 1). Understanding is different from replication of standardized designs as in the lowest level. In the understanding level, the educated engineer begins to comprehend why the standardized designs are replicated. In the next level, *application*, one finds use in engineering in general, but still not allowing innovation in design. The fourth level from the bottom is denominated *analysis*. At the *analysis* level, one begins to recognize cognitive capability in students to use the students' learning for the dissection of new conditions and how to handle them in an engineering sense. The *analysis* level is approximately at the Bachelor of Science degree level in Electrical Engineering. From the experience of the authors, only the best of BSEE students are able to truly attain the *analysis* level.

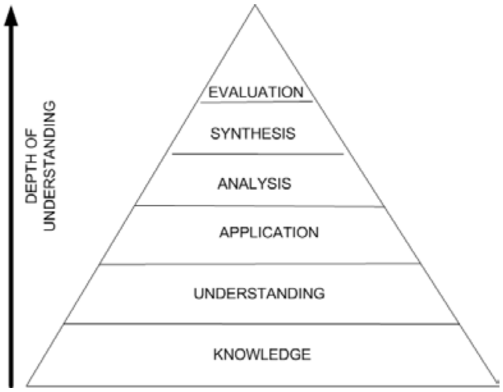

Fig. 1 Bloom's taxonomy [2]

The two highest levels of Bloom's taxonomy are labeled *synthesis* and *evaluation*. The *synthesis* level allows the practitioner to arrange and realize designs. It is believed that in the smart grid milieu, this is approximately the objective of the Master of Science level. This is the case since at the Masters level, the student has the opportunity to focus on design and the integration of targeted technologies and methods to attain a practical design that attains smart grid objectives.

The highest level of Bloom's taxonomy relates to the deepest level of understanding which allows one to argue and debate alternatives, to evaluate arguments, and to place solutions in engineering practice policy. This highest level is termed *evaluation.* The highest level is believed to be the doctoral level since only through serious and innovative research have we been able to render the student capable of evaluation of arguments and alternative policies. At the highest level, the student is trained to participate in the public forum in the area of his / her discipline.

Bloom's taxonomy has been widely accepted in the educational community, and numerous discussions and explanations of the classifications of the concept reported (e.g., [5]).

In view of the foregoing discussion of Bloom’s taxonomy, it is surmised that the integration of the digital technologies commonly known as Information Technologies (IT) with power engineering and the smart grid objectives will require education at least to the analysis level. In most four year BSEE programs, it is difficult to attain any degree of depth in this level-four analysis capability. Consequently, the actual integration of the cited technologies, concomitant with the experience of the authors, must be at the synthesis level at a minimum. That is, the continued design and development of smart grid technologies will require individuals trained at a minimum at the present day masters (MSEE) level.

IV. THE INTEGRATIVE REQUIREMENTS OF THE SMART GRID

As indicated above, the proposed smart grid approach to generation, transmission and distribution system design and operation requires an integrative strategy. That is, several technologies must be brought to bear on the design and operation philosophy. This point is illustrated in Fig. 2. In order to integrate engineering elements in design and operation, the engineer must have a sufficient depth of understanding to put aside preconceived ‘legacy’ notions. These legacy notions admittedly comprise the majority of power system engineering, but in order to realize new paradigms such as the use of time varying wind power, or solar power available in an uncertain schedule, the engineers needs to reconsider: (1) *at the design stage*, control error tolerances, timing of controls, electronic designs of inverters needed to incorporate the alternative energy sources, and other basic system configurations; and (2) in *power system operation*, the operating strategies of generation control, system control, and managing multiobjectives. Figure 3 shows some of the ‘legacy’ control system design time horizons.

The integrative requirements of smart grid philosophies require that the depth of comprehension of engineers extend to the several areas illustrated in Fig. 2. For this reason, it is clear that the level of education required exceeds the usual bachelors’ level, and extends to the analysis and synthesis levels as shown in Fig. 1. For these reasons, the recommended educational experience for smart grid engineers is at least the Master of Science level.

There is a cost saving measure which provides education in a condensed form, namely by deploying instructors to teach subjects who are only casually versed in the elements of the subject’s breadth. This approach, attractive during times of budget reductions, is often characterized by programs that offer instruction in a domain using zero or one domain-experts together with individuals “drafted” from other domains. This approach, here referred to generically as the *one-instructor approach*, when applied to power engineering does permit instruction of power engineering basics at the lowest levels (e.g., ‘knowledge’ in Fig. 1). The one-instructor approach does permit the student to be exposed to replicated designs much in the style of a technician’s approach to repair and installation. It can be argued that colleges and universities that cannot accommodate a more in-depth experience might use the one-instructor approach. However, this approach simply does not afford the needed breadth and depth of coverage indicated by Fig. 2 for smart grid engineering.

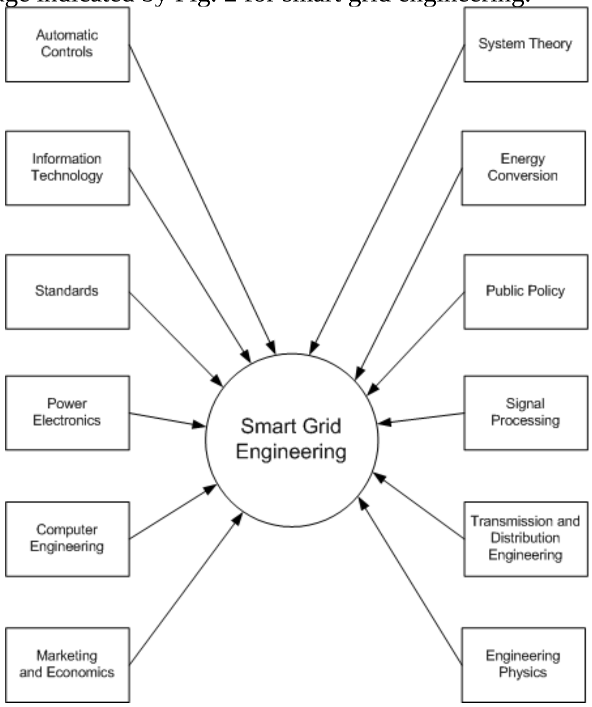

Fig. 2 Main elements of an integrative approach to smart grid design and operation

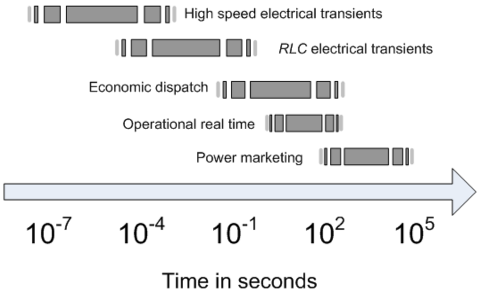

Fig. 3 Timing horizons of legacy power system controls

In engineering education, the general subject of depth of coverage of a subject, and the subject of suitability of instructors to deliver an effective engineering course are directly related to faculty research. To be able to educate to the *analysis* level (i.e., the level at which real designs are formulated, and the levels to which concepts in depth are brought to bear on difficult problems), high quality faculty who are involved in research are needed. The research active faculty, teaching within their domain, consciously or unconsciously stimulate deeper thinking among students. They do this as they pass on capabilities for insights that they experience themselves and as they engage in mentorship, including presenting meaningful classroom material, giving realistic assignments, imparting feeling for real data, and discussing key points with students. Instructors at this level might be contrasted with instructors at lower levels or outside the domain who simply pass on a 'recipe-based' static information (this is, indeed, at the lowest level of Bloom's taxonomy, namely *knowledge*). The problem of depth is more acute in power engineering education than other fields, because of the breadth of the power discipline; for example, there are very few faculty who are research active in all aspects of power systems, power electronics, and electric machines.

We recognize that the one-instructor approach may be necessary for some universities on a temporary basis, and it may be desirable for others unwilling or unable to invest resources into educating engineers to the analysis, synthesis, and evaluation levels. However, it is an unsuitable approach for 'tier I research institutions' which are primarily responsible for producing future smart grid innovators, and this strategy should not be promoted as a viable long-term solution. The most effective solution is to increase the number of research-active power engineering faculty, and we view that three is a *minimum* number for a strong electric power engineering program. An alternative is to utilize multi-university Internet courses (i.e., distance learning in which courses are either videotaped or digitally recorded, and offered to a distant or 'cyber student'). Cyber students or prospective instructors are easily able to take focused courses that afford considerable depth in power engineering (e.g., some programs and successes are reported in [6]). Through cyber offerings, reported to be on the increase as evidenced by the surveys in [7-9], students are able to progress easily through the *understanding* layer of Bloom's taxonomy, probably to the *analysis* layer. When integrated into a meaningful MSEE program of study, these cyber courses are capable of producing engineers fit for attacking smart grid challenges.

V. ENROLLMENTS IN POWER ENGINEERING EDUCATIONAL PROGRAMS: THE SUPPLY OF QUALIFIED ENGINEERS

From an analysis of the survey results presented in [9] which are mainly for the United States and Canada, the following data regarding both undergraduate and graduate enrollments in power engineering educational programs can be deduced. These results are only for the United States power programs. To investigate the annual production of undergraduate students going into power jobs, attention was focused on courses that were electives and that could be considered to be basic to someone planning on a power engineering career. The power systems analysis course was selected in most cases. In universities not listing a power systems analysis course, either a seemingly comparable course was selected (such as transmission systems) or, after reviewing the course offerings, it was determined that there was no comparable course and therefore "zero" was entered for the number of students. A number of universities did not provide these data in [9]. Also, there were universities that had graduate courses but no undergraduate courses that seemed to qualify. The elective undergraduate power courses may have undergraduate and graduate students. The survey does not differentiate between them; in a few cases, a university listed separate courses for undergraduate and graduate students even though the classes could have met together. Table 1 displays the results of this analysis. The median class size utilizing this analysis was 17.

Table 1 Distribution of undergraduate and graduate students by university taking power systems analysis (or comparable) as an undergraduate elective course

Students	Universities	Percent
1-5	3	3.9%
6-10	13	16.9%
11-15	14	18.2%
16-20	13	16.9%
21-30	18	23.4%
31-40	12	15.6%
41-50	1	1.3%
51-60	1	1.3%
61-70	2	2.6%
Total	77	100.0%

The reported total number of students in the selected undergraduate elective courses is 1,675 as reported in the survey [9]. The estimated number of enrolled graduate students was reported to be 1,101. The distribution by individual university is given in Table 2. The median number of graduate students (masters and doctoral) was about 10. The highest number of enrolled students in the survey was 65.

The total enrollment information from the survey is about 545 masters and 536 doctoral students. These data need to be checked further due to some suspected incorrect reporting. There are no data in the survey indicating how many masters or Ph.D. students graduate annually. If it is assumed that it takes 2 years to complete a masters degree and 5 years to complete a Ph.D., then the graduate rates are about 250 masters level students and 100 doctoral students per year.

Table 2 Distribution of graduate student enrollments in power engineering

Number of students	Universities	Percent
1-5	18	25.4%
6-10	18	25.4%
11-15	8	11.3%
16-20	9	12.7%
21-30	9	12.7%
31-40	3	4.2%
41-50	4	5.6%
51-60	1	1.4%
= 65	1	1.4%
Total	71	100.0%

If one accepts the approximate production of 200 to 250 graduate level power engineers per year in the United States, the question remains as to what number are needed, and what number are needed if the smart grid technologies are to be implemented. These questions are more difficult to quantitatively answer, but in [10] key aspects of the workforce needs have been identified as follows:

- Over the next five years, approximately 45 percent of engineers in electric utilities will be eligible for retirement or could leave engineering for other reasons. This could amount to over 7,000 power engineers just in electric utilities alone. Two or three times more power engineers may be needed to satisfy needs of the entire economy.
- About 40 percent of key power engineering faculty at U.S. universities will be eligible for retirement in five years with about 27 percent anticipated to actually retire. In other words, of the 170 engineering faculty working full-time in power engineering education and research, some 50 senior faculty members will be retiring. These facts translate to doctoral level needs.
- There are less than five *very strong* university power engineering programs in the U.S. A very strong program is defined in this context as a power engineering educational program that satisfies all four of the following criteria:
  (1) Four or more full-time power engineering faculty
  (2) Research funding per faculty member that supports a large but workable number of graduate students
  (3) A broad set of undergraduate and graduate course offerings in electric power systems, power electronics, and electric drives
  (4) Sizable class enrollments of undergraduate and graduate students in those courses.

In [11], the Center for Energy Workforce Development has identified estimated potential replacements by 2013 for different sectors of the energy workforce. These estimates are shown in Table 3.

Table 3 Estimated potential replacements by 2013 for selected job categories (taken directly from [11])

Job category	Percentage of potential attrition and retirements	Estimated number of replacements	Estimated retirements only
Technicians	49.0	27,000	20,500
Non-nuclear plant operators	47.6	12,000	9,000
All Engineers	44.7	14,500	10,000
Pipe fitters / pipe layers	45.0	8,500	6,500
Line workers	40.2	29,500	19,000

If one examines the contemporary realities of hiring in the electric power industry, apart from hiring technicians, linemen and other similar persons, some companies in this industry are accustomed to hiring EEs with no power background and getting them ‘up to speed’ with either internal training or external courses. The need for external courses has spawned programs (e.g., ‘certificate programs’) which are not equivalent to an MSEE degree but close a lot of gaps in engineering knowledge and methods. As another alternative, the utilization of many practicing engineers as instructors may be viable to the more usual university structure of professors teaching courses. As one progresses to the full implementation of the smart grid, however, it appears that a greater number of masters and doctoral graduates trained in power engineering and information technologies shall be needed to identify new infrastructures, attain new designs, and implement those innovations.

Considering the estimated number of replacement engineers in Table 3 adjusted for all industries, from 3,000 to 4,000 power engineers will be needed in the United States per year between now and 2013. The data in [10] and [11] do *not* consider the implementation of smart grid technologies. It is very difficult to compare production of masters and doctoral level engineers with the requirements of industry because it is unknown how many of the recent graduates will go into the electric utility field in the United States upon graduation, how many will be attracted to other areas, and how the economic slowdown (and concomitant economic stimulus) of 2009 will impact projections. However, the underproduction of power engineers appears to be clear. And the needs for new engineers beyond the bachelors level are also clear.

The efforts reported in [10] include three approaches to ensuring a strong US electric power engineering workforce in the future. The first focuses on ensuring sufficient research support for universities across the country – ideally in every state. This is considered critical to the future supply of power engineers because production of new PhD graduates to fill the faculty positions created by retirements and technology growth requires a major research experience. The second effort focuses on ensuring strong collaboration between industry and universities. This is considered critical because it provides a mechanism for industrial input to the education process and a source of support to faculty for involving students in industry projects through internships and co-op experiences. It also involves financing student scholarships and seed money for power engineering programs. The third approach focuses on professional image and outreach to K-12 students. The six objectives of this collaborative are:

1. Create a single, collaborative voice on solutions to engineering workforce challenges
2. Strengthen extraordinary efforts to build, enhance, and sustain university power engineering programs
3. Envision the future challenges in electric energy supply and demand and develop an image that increases interest in power and energy engineering careers
4. Stimulate career interest and prepare students for a post-high school engineering education in power and energy engineering
5. Make the higher education experience relevant, stimulating, and effective in creating high quality professionals
6. Encourage and support increased university research to enhance student education through innovation.

Additional information on the collaborative can be obtained from the following web site:

www.ieee.org/go/pes-collaborative

VI. THE POWER ENGINEERING CURRICULUM

It appears that the legacy power engineering educational programs, while valuable for the installation of legacy systems, and maintenance of those systems, are not sufficient to accommodate the main elements of the smart grid. This is the case since simple replicative engineering is not sufficient to formulate new designs and new paradigms. The innovation extends to power system operation as well. The solution to this quandary appears to be in the integration of new technologies into the power engineering curriculum programs, and extending the depth of those programs through a masters level experience. It is desirable that the masters level experience be industry oriented in the sense that the challenges of the smart grid be presented to the student at the masters level. In [12], the concepts of a university consortium and industry 'collaboratory' are discussed to achieve the desired depth of instruction.

The desired elements of the power engineering curriculum for the next generation of 'smart grid' power engineers appears to include all or most of the following elements. The exposure to these subjects is not recommended to be a casual, low level exposure; rather, the exposure is recommended to be at a depth that analysis is possible in a classroom environment. And, it is recommended that research be performed by the student so that synthesis can be accomplished. The elements identified include:

Direct digital control

The importance of direct digital control is important in realizing most of the smart grid objectives. Direct digital control needs to be examined not only in terms of classical automatic control principals (including, if not emphasizing discrete control), but also how digital control relies on communication channels, how these controls need to be coordinated in terms of safety and operator permissive strategies, the impact of latency (e.g., [13]), new instrumentation and how that instrumentation will impact the power system design and operation.

Identification of new roles of system operators

What parts of the system need to be fully automated, and what parts are 'operator permissive' controlled need to be identified. This needs to be presented to the students in a way that integrates computer engineering and power engineering. As an example, visualization of power systems is an especially important subject area (e.g., [18]).

Power system dynamics and stability

Power system stability is a classical subject. However, the new issues of this field relate to how maximal power marketing can occur and yet still insure operationally acceptable system operation and, indeed, stability. The subject appears best taught as an in depth semester course that includes modeling and actual examples. The examples should be examined by the students in a project format in order to achieve the 'analysis' level of Bloom's taxonomy.

Electric power quality and concomitant signal analysis

With the advent of electronic switching as a means of energy control, electric power quality has taken on a new importance in power engineering education. Again, we find that simply a casual discussion of this topic is insufficient to achieve the analytical stage: rather it is recommended that a semester's course, complete with project work and mathematical rigor is needed as instruction. Power quality is discussed as an educational opportunity in [14].

Transmission and distribution hardware and the migration to middleware

New materials are revolutionizing transmission designs. Transmission expansion needs to be discussed in an in-depth fashion that includes elements of high voltage engineering and engineering physics, new solid state transformer designs, and solid state circuit breakers (e.g., [15]). Classical power engineering seems to leave a gap between software and hardware, and it is recommended that hardware oriented courses at the masters level include issues of middleware applications. The use of intelligent electronic devices (IEDs) is deemed to be important. This development is especially important in the area of substation automation and synchronized phasor measurement systems [12,18].

New concepts in power system protection

With increased loading of power systems and dynamic behavior due to accommodating deregulated electricity markets and interfacing renewable resources, designing protective relaying solution that is both dependable and secure has become a challenge. Introduction of microprocessor based relays, high speed communications and synchronized phasor measurement systems made opportunities for adaptive and system wide relaying. Learning how the relaying field evolves from traditional approaches designed for handling N-1 contingencies to new schemes for handling N-m contingencies becomes an integral part of a modern power systems curriculum. The use of modern modeling and simulation tools is required [19].

Environmental and policy issues

Exposure to environmental and policy issues need to be included in a masters level milieu in power engineering education. This exposure needs to go beyond ‘soft science’ and it needs to appeal to the students’ capability in mathematics and problem solving. The main issues are discussed in [16].

Reliability and Risk Assessment

There is little doubt that the importance of reliability of the power grid is widely recognized. However, when transformative changes are planned and implemented, the traditional tried and tested rules to ensure reliability can not be relied on. Such changes need to be modeled and analyzed for reliability assessment based on sound mathematical foundations. Fortunately now a large body of knowledge exists for modeling and analysis of power system reliability and risk assessment. The students at the masters and doctoral level should be provided this knowledge so that they can effectively use it in the integration and transformative process.

Economic analysis, energy markets, and planning

Planning can no longer be done incrementally, motivated largely to satisfy the next violation of planning reliability criteria. Investment strategies must be identified beyond the standard 5-20 year time frame at an inter-regional if not national level, to identify cost-effective ways to reach environmental goals, increase operational resiliency to large-scale, sustained Katrina-like disturbances, and facilitate energy market efficiency. Engineers capable of organizing and directing such planning processes require skills in electric grid operation and design, mathematics, optimization, economics, statistics, and computing obtained at the synthesis and evaluation levels, typically inherent only in PhD graduates [17]. Engineers from BS and MS levels will be needed to participate in these processes, and these engineers will require similar skills at the analysis level or above.

VII. CONCLUSIONS AND RECOMMENDATIONS

The main conclusion of this paper is that there needs to be recognition for the in-depth coverage of integrative elements of the smart grid objectives in power engineering education. The in-depth coverage needs to go beyond the concept of casual explanations in an undergraduate program by a single instructor with no research background. Rather, the recommendation is to include material at the analytical level of Bloom’s taxonomy on the subjects of:

- Direct digital control
- Identification of new roles of system operators
- Power system dynamics and stability
- Electric power quality and concomitant signal analysis
- Transmission and distribution hardware and the migration to middleware
- New concepts in power system protection
- Economic analysis, energy markets, and planning
- Environmental and policy issues.

The recommendation is that the depth of coverage be achieved by graduate education in these areas, enhanced by industry recommended challenges integrated into the educational experience by faculty with strong research backgrounds.

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IX. BIOGRAPHIES

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Anjan Bose (F’89) received the MSEE from Berkeley, and the PhD from Iowa State University. He is a member of the National Academy of Engineering. He has been at Washington State University since 1993 where he has served as Director of the School of EE and CS as well as the Dean of the College of Engineering and Architecture. He is currently a Distinguished Professor of Electric Power Engineering at WSU.

Ward Jewell (M’77, F’03) teaches electric power systems and electric machinery as a professor of Electrical Engineering at Wichita State University. He is Site Director for the Power System Engineering Research Center. Dr. Jewell performs research in electric power quality and advanced energy technologies and has been with Wichita State University since 1987.

Mladen Kezunovic (StM’77, M’80, SM’85, F’99) received the Dipl. Ing., M.S. and Ph.D. degrees in electrical engineering. Currently, he is the Eugene E. Webb Professor and Site Director of the Power Engineering Research Center at Texas A&M University. He worked for Westinghouse Electric Corp., Pittsburgh, and the Energoinvest Company in Europe. He is a Registered Professional Engineer in Texas.

James D. McCalley (F’04) received the B.S., M.S., and Ph.D. degrees from Georgia Institute of Technology, Atlanta. He is Harpole Professor in the Electrical and Computer Engineering Department at Iowa State University, Ames. He is also Systems Stem Leader and ISU site director for the Power Systems Engineering Research Center. He was with Pacific Gas and Electric Company from 1986 to 1990 and he is a registered professional engineer in California.

Dennis J. Ray (M’73) received his BSEE from the University of New Mexico, and his M.B.A. and Ph.D. degrees in Business from the University of Wisconsin-Madison. He has wide-ranging experience in power industry engineering, economics, regulatory policy, education, and research. He is currently the Executive Director of the Power Systems Engineering Research Center.

Peter W. Sauer (StM’73, M’77, SM’82, F’93) received his BSEE from the University of Missouri at Rolla and the MSEE and Ph.D. degrees from Purdue University. He has power facilities design experience with the US Air Force and he is a co-founder of PSERC and a cofounder of the PowerWorld Corporation. He is a member of the National Academy of Engineering. He has been at the University of Illinois since 1977, and he is currently the Grainger Chair Professor of Electrical Engineering.

Chanan Singh (StM’71, M’72, SM’79, F’91) received his Ph.D. and D.Sc. degrees from the University of Saskatchewan. After serving the R&D Division of the Ministry of Transportation and Communications in Ontario, he joined Texas A&M University where he is currently Regents Professor and holds the Irma Runyon Chair in the Department of Electrical and Computer Engineering. From 1997-2005, he served as the Head of this department.

Vijay Vittal (SM'78, F'97) received the B.E. degree in electrical engineering from the B.M.S. College of Engineering, Bangalore, the M. Tech. from the Indian Institute

of Technology, Kanpur, and the Ph.D. degree from Iowa State University, Ames, in 1982. Dr. Vittal is a member of the National Academy of Engineering. Dr. Vittal is currently the director of the Power Systems Engineering Research Center and he is the Ira A. Fulton Chair Professor in the Department of Electrical Engineering at Arizona State University, Tempe.