01 May 1999

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Recommended Citation

C. Singh et al., "Integrating Research Results into a Power Engineering Curriculum," *IEEE Transactions on Power Systems*, vol. 14, no. 2, pp. 404-411, Institute of Electrical and Electronics Engineers (IEEE), May 1999.
The definitive version is available at https://doi.org/10.1109/59.761857

Integrating Research Results into a Power Engineering Curriculum

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ABSTRACT

This paper presents summaries of the activities of six research active power engineering educators which were presented in a panel session of the same name at the IEEE Power Engineering Society Winter Meeting on February 3, 1997 in New York City. Each of the panelists discusses how research results are incorporated into courses and how students benefit from this approach.

Keywords: engineering education, curriculum development

I. INTRODUCTION

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The electric power industry is undergoing a major change, both technically and politically. To prepare future engineers for the challenges they will face, educators must upgrade the power engineering curriculum to reflect changing trends in the industry. One way to respond to the needs of industry is to introduce engineering students to technologically current approaches while they are still in the classroom setting. This may be accomplished by combining traditional and new material. One of the best resources for new material is the research activities of the engineering educator. This paper presents a summary of experiences of six research-active educators in integrating research into the classroom.

Engineering educators nationwide are addressing the future needs of the US industry by adopting the precepts of EC 2000 (also known as "ABET 2000"). The new engineering criteria broaden the definitions of curricular goals and place the interpretation and assessment of these goals directly on individual programs. The purpose of the new accreditation approach is to help educators better prepare technologically competent graduates who can be successful in the international marketplace. Although research is not directly addressed by the EC 2000 criteria, there are several aspects in which it may contribute significantly. For example, future engineering graduates are expected to have the ability to: identify, formulate, and solve engineering problems, design and conduct experiments, analyze and interpret data, and design system, components or processes to meet specific needs. Graduates are also required to have knowledge of contemporary issues. Incorporating research results into the classroom provides the opportunity to address all of these issues. Furthermore, evidence of the integration of research into the curriculum will probably be viewed as a positive indicator of the currency and maintenance of an institutions curriculum by the accreditation committee.

PE-188-PWRS-1-05-1998 A paper recommended and approved by the IEEE Power Engineering Education Committee of the IEEE Power Engineering Society for publication in the IEEE Transactions on Power Systems. Manuscript submitted July 2, 1997; made available for printing May 18, 1998.

II. POWER ENGINEERING EDUCATION - TRANSITION INTO THE NEXT CENTURY

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A workshop [1] was sponsored by the NSF and DOE in June 1995 to discuss the problems facing power engineering education and the issues involved. The workshop was attended by representatives from academe, industry, EPRI, DOE and the national laboratories. The overall consensus of the workshop was that there is a need for significant changes in power engineering education although there was a divergence of opinions about the definition of problems and possible solutions. Another workshop [2] was also organized in July 1995 to discuss the current paradigm shift in engineering education.

With this as the background the NSF and EPRI decided to cooperate in creating a special initiative [3] in power engineering education. The overall objective is to examine the long term needs of power engineering education, generate solutions and develop educational tools to make the educational process intellectually stimulating and more effective. Some of the perceived needs are:

- In order to adapt to the changing environment of the future, power engineering education should prepare engineers with a broad background.
- The power engineering education should recognize that information technology will have a profound effect on the way the students learn.
- The engineers need to be educated to be self-reliant and to learn on their own.
- Power engineering education should link closely with the generic engineering education paradigm shift [2].

This initiative was designed to achieve several objectives outlined below.

1. One of the primary objectives of this initiative is to build partnerships between industry and universities in the area of power engineering education. Each awardee is expected to have a plan for achieving this partnership.

2. The educational institutions together with industry are expected to identify the educational profile of power systems engineers for the next century.

3. The educational institutions are expected to develop curricula and educational tools and implement them to achieve this profile.

4. Another objective is to attract students to power engineering education by making it more interesting,

exciting and more effective by using tools such as simulators and visualization technologies.

5. Integration of economics into engineering curricula has been a challenging task. It is anticipated that the deregulated environment can be used as a test bed to develop innovative means to integrate economic issues into engineering curricula.

6. Power engineering education needs to be better integrated into the overall engineering education.

As part of the initiative three workshops will be held, one each year to promote a dialogue between educators and others interested in power engineering education. This initiative is now developing into a multi-campus activity and is expected to generate ideas and discussions over the next three years. This hopefully will ease the transition of power engineering education in to the next century.

III. CAN FACULTY SUCCESSFULLY INTEGRATE THEIR RESEARCH RESULTS INTO THE POWER CURRICULUM?

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Most power engineering faculty will agree that their research activities contribute to them becoming a more effective teacher. Many pedagogic studies show it, administrators preach it, and merit raises enforce it. We must be careful, however, on how this statement is interpreted. This statement is not meant to imply that spending 40-50 hours each week on the teaching mission alone would result in a less effective teacher. In fact, many of the non-doctoral granting institutions are very successful in their undergraduate teaching missions even though many faculty at these institutions have little to no research agenda. A faculty member's "Battle for Balance" among teaching, research and service is a reality. The fact that faculty must divide their efforts among these three areas further emphasize that academe is a "zero-sum" proposition. That is, the shifting of resources (e.g., time and money) to one area comes at the expense of another.

With this in mind, we can conjecture a number of reasons why a faculty member should integrate research results into the classroom. First, these results can provide a positive motivation to the undergraduate student. Our students should decide what area of electrical engineering excites them rather than that area having the department's "most popular" teacher. Second, when covering a particularly difficult or abstract concept, a real-world example from a research project may be the "Rosetta stone" which allows the student to decipher the concept. But, how much new material should be introduced in a course? How much "out with the old, and in with the new" can the present curriculum handle? As engineering programs across the country continue to move towards a reduced number of hours for the B.S.E.E. degree, power engineering courses are always in danger of being removed from the electrical engineering curriculum during curriculum revision efforts.

So, how does a teacher bring research results into the classroom? The most obvious way is through demonstrations and/or "show-and-tell" exercises. Students need to use all of their senses in the learning process. This includes seeing, listening, feeling, etc. Presentations by graduate research assistants (GRAs) can be a very valuable method. Undergraduate students typically have some familiarity with the GRAs and can relate to them on a one-to-one basis. Special presentations by alumni in industry is also an effective means to provide motivation and "light at the end of the tunnel" for undergraduate students who have no inclination for one technical specialization area over another. Allowing the students to perform basic research functions, such as literature searches at the library and on the world-wide web (WWW), on their topics of interest can be a great motivator. For instance, in this author's electromechanical energy conversion course, one assignment is to write an HTML-based paper with links to various topics ranging from the use of electric machinery in electric/electric hybrid vehicles to wind energy systems. The students seem to really enjoy the freedom and creativity of "designing" their own "electronic paper." Finally, a "hands on" method used to bring research into the classroom is via the classical laboratory experience.

The benefits to undergraduate power engineering students by integrating research into the curriculum is enormous. It can be a real eye-opener for the student! Many electrical engineering students have a preconceived idea that power engineering is not "high tech." Of course, this couldn't be further from the truth. Bringing applications of theoretical material encountered during lecture into the classroom will further stimulate the students' creative thinking and problem solving abilities. Sometimes these applications in class provide the student with direction--good or bad for the power engineering field. They may find that a particular technical specialization is not for them, or alternatively, that this is an area they would like to pursue. As a result, this can give the undergraduate electrical engineering student a sense of direction in terms of their career path, and ultimately, some sense of accomplishment.

One of the most successful initiatives this author has experienced is the National Science Foundation's Research Experience for Undergraduates (REU) Program. Following the same philosophical line, here at the University of Arkansas, the author readily involves undergraduate electrical engineering students in research-oriented special projects. As an example, one of our seniors was involved in performing magnetic and thermal analyses of a switched-reluctance machine using a two-dimensional finite-element model. He also developed a MATLAB$^{(TM)}$-based graphical user interface for obtaining the performance curves of a shaded-pole motor. These types of activities challenge the undergraduate student to be creative, to personally excel and demonstrate "self-starter" characteristics such as: possessing discipline, self-motivation, maturity and self-confidence.

IV. INTRODUCING INTELLIGENT SYSTEMS RESEARCH INTO THE POWER CURRICULUM

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The author's research has focused on intelligent systems (IS) applications in power systems and this section describes the design of a first year graduate course on this research. A discussion of educational objectives and redesign of the curriculum as a whole is used to put this course design in proper context.

A power engineer is expected to have knowledge and understanding of the power system components and the appropriate use of these components in order to achieve the objectives of a safe, reliable and economic electric supply. The classical educational approach has been to begin with a study of components, perhaps with an emphasis on electric machines, followed by a study of power systems analysis. Moving research results into the curriculum should not only enhance this traditional material but also generate student enthusiasm for the power system field as a whole.

Unfortunately, the traditional curriculum performs less than satisfactory as a foundation upon which to achieve either objective. For example, it is relatively difficult to include new technologies, such as FACTS, within the constraints of the traditional material layout and available time. In addition, the typical presentation of the material fails to provide a perspective of the power system which reflects viewpoints not only of utilities but also of manufacturers, customer or other industry players. One of the aims of the author is to design an open curriculum that will easily incorporate technological and industry developments.

Engineering instruction has traditionally been divided into lecture and laboratory courses. Students have often been required to sit passively through lectures while the laboratory instruction provided the primary opportunity for hands on active participation in learning. There is increasing interest in blurring the distinction between classroom and laboratory approaches to teaching. IS applications are an area where programming as a laboratory exercise extends naturally from the course lectures.

This course had as specific objectives to introduce fundamental IS techniques, motivate the need for IS techniques within power systems through illustrating problem complexity, and to improve the overall computer skills of the students. To introduce research into the curriculum requires careful course design in order to avoid overwhelming the student. The philosophy is to design both for breadth – comprehensive coverage of the field – and depth–fundamental understanding of the fields methodologies. Time constraints in a one semester course limit in-depth coverage to one or two sub-areas.

Flexibility is important when including research into the curriculum as newly developing fields must allow the possibility of yearly changes in the material. Flexibility in this course is realized by introducing each fundamental technique in the context of a particular example application. Specific problems for in-depth study are selected depending on the faculty and student interest and any recent research results of particular importance. This also has a pedagogic motivation in that example applications are more effective than simplified problems in generating student interest.

The first problem encountered in introducing research into a curriculum is selecting reading material for the course. Most textbooks have inadequate coverage of research results and are out of date for research purposes almost as soon as they are published. IEEE tutorials are one of the best sources of material in this area. For the course under discussion here, the author has also used general IS texts, programming language manuals, recent journal publications, and the author's own notes.

The next problem in teaching IS material to power students is ensuring adequate computer background. The typical power student has knowledge of FORTRAN and perhaps C, but limited understanding of algorithm complexity and program design. Such knowledge is fundamental to understanding the application of IS techniques. On the other hand, there is not sufficient time to teach all the necessary computer background (to do so would require a separate course). The compromise reached is to teach one low-level language (e.g., LISP or Prolog) to illustrate fundamental IS and programming techniques and to teach one high-level language (e.g., CLIPS) to illustrate program design for practical problems. Still, depth of understanding cannot be expected when introducing more than one language in a course. The primary objective, of course, is not to teach a language but rather a programming philosophy.

As an example, consider the problem of distribution switching to restore customers after faults have been isolated on a radial system. This is a combinatorial problem (*NP* hard). A complete solution must satisfy equipment constraints, protection limits, and communication system limitations, while seeking to balance three phase loads, minimize switching actions, and minimize resistive losses.

If greatly simplified, this problem can be formulated as a classical search problem. Fundamental search techniques are then taught with the goal of solving this simplified example. Introduced techniques include: depth first, breadth first, best first and heuristic search (together with the more theoretical A* search). Students program these search methods in a low-level language (usually LISP). The proper simplification requires removing all but one of the solution objectives and all but one of the constraints. The full problem complexity can then be introduced.

Each of the IS topics is taught through an example application similar to the preceding discussion. That is, a simplified problem is used to illustrate the techniques. The complexities of the full problem are then introduced. Table I lists sample topics in a one semester version of this course. Note that the course is modular in that a short course can be given on any of the individual topics.

Table I: Example course topics

Intelligent Systems Approach	**Application**
Fundamental search techniques	Distribution restoration
Rule-based methods	Voltage control
Case-based methods	Protection failure diagnosis
Model-based methods	Equipment condition monitoring
Reasoning with uncertainty (including fuzzy logic)	Stabilization control
Artificial Neural Nets	Load forecasting

V. INCORPORATING VISUALIZATION TOOLS FOR POWER SYSTEM DESIGN PROBLEMS

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Among the ways research can be incorporated into the curriculum is the use of research results to change instructional techniques. This section reports on the use of power system visualization techniques in a capstone design course. Capstone design courses are widespread in response to existing Accreditation Board for Engineering and Technology (ABET) requirements. New ABET requirements seem likely to increase their importance [4].

Developing design problems for power systems (as distinguished from power electronics, power system hardware, or design of power system analysis programs) is a particular challenge. Power system design is not a common publication topic. Planning seems the topic closest to design. Where the electronics designer, for example, starts with a clean sheet of paper and designs a complete object, informed but not limited by prior designs, the power system designer generally makes small incremental changes in a very large system which is the product of many past design efforts. Finally, power system designers generally do not have complete control over design decisions. Selection among major design alternatives often involves both large amounts of capital and significant social effects, and non-engineers frequently have control over the selection among design alternatives.

The capstone design course offered to seniors at the University of Washington in the spring of 1996 was therefore posed as an integrated resource planning problem. The IEEE 30 bus test case, dating from 1966, augmented by fictitious data for line limits and generation resources, was taken as the existing power system. The 30 bus test case was chosen because the data was readily available, and the system data set was large enough to communicate some sense of the power system data management problem to the students. In particular, the data file occupies more than one computer screen. Data was distributed to the students in IEEE Common Data Format (CDF) along with a format description, over the World Wide Web.

A 50 MW "electronics plant" was to be located in a relatively empty part of the system map. Since the 30 bus test case total load is 283 MW, this presented a significant planning problem for the students, one with design decisions similar to those they might encounter after employment by a utility or industrial plant. System performance requirements on line loading, bus voltages, breaker size and transient stability were set. Students were asked to make “public forum” presentations explaining and justifying their design decisions, with non-presenting students encouraged to take various non-engineering roles such as management, consumers, and environmentalists.

One-third of the ten week course was spent on engineering design issues, one third on generation alternatives, and one third on transmission reinforcement and substation one line design. Students were divided into teams and asked to consider different generation alternatives as solutions for the same problem. Transmission reinforcement would then have different requirements for each team, depending on the way the teams implemented the detailed design of their assigned generation alternatives. In the end, transmission requirements for the two participating teams ended up almost identical as a result of their generation choices.

Analytical tools available to the students included spreadsheets for economic analysis and the Electric Power Research Institute (EPRI) Extended Midterm Stability Program (ETMSP) for transient stability analysis. For static security assessment, a power flow program with a visualization-based user interface was provided. The program, known as WinViz, is the direct result of research into power system visualization reported in [5]. Written in C++, and implemented on a PC, WinViz contains an implementation of a fast decoupled power flow, reading data in IEEE CDF and generating a visualization output as well as a more conventional power flow log. Figure 5-1 shows the visualization of the 30 bus test case pre-reinforcement system with an X at the new plant site.

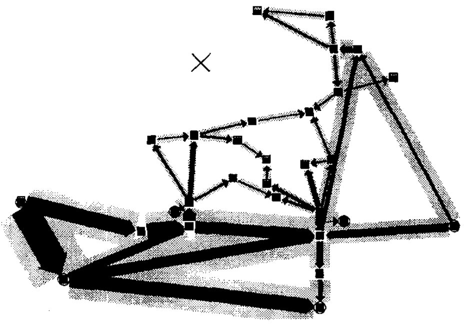

Figure 5-1 Pre-Reinforcement System - Visualization of Power Flow Results

As described in [5], arrow widths represent MVA flow, with the arrows indicating the direction of real power flow. Boxes around the arrows represent MVA limits. Voltage magnitudes are shown as a two-color bar chart in a square box. The top of the box is 1.05 per unit, the bottom 0.95 and the center 1.0 per unit. Actual numbers are shown on a popup dialog box when a bus or line is clicked. The display can be panned and zoomed. The contingency analysis is interactive, and thus rapid and simple, as a line status can be toggled by clicking both mouse buttons, and the program then immediately recomputes the power flow solution and updates the display.

In the design process, visualization enables students to more quickly and easily comprehend system-wide implications of analytical results. It permits them to see all effects of any changes made, and mitigate the tendency to concentrate on a few key variables typical when power flow logs are used. By making data analysis rapid and mentally almost effortless, it permits the students to spend more time thinking about their design's performance, and design alternatives.

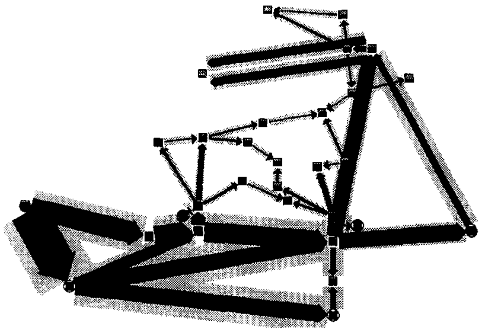

Figure 5-2 Design Alternative 1 - Base Case

Figure 5-2 shows a re-created design alternative. It can be seen that no pre-contingency overloads appear, and that the voltage at the new bus, although the lowest in the system, is above 0.95 per unit. However, when a contingency is applied, the picture quite literally changes, as seen in Figure 5-3. The solution had connected the new lines to tie points rather than through breakers, to save on switchgear, so both the new line and the one it was tied to are outaged. The other line combination is overloaded, and the voltage at the new bus is about 0.90, below the specified criteria. One design alternative to fix this problem was the addition of capacitors to correct the plant displacement power factor. Figure 5-4 shows the improved design, with higher base case voltage and lower line MVA flows. The contingency analysis for this case was satisfactory.

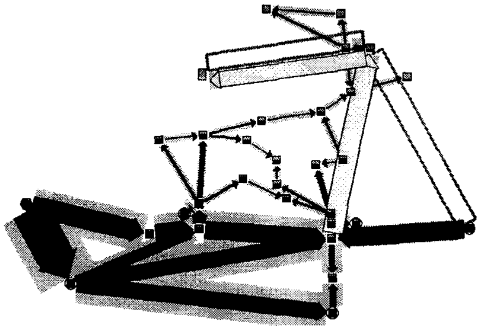

Figure 5-3 Design Alternative 1 - Contingency Case

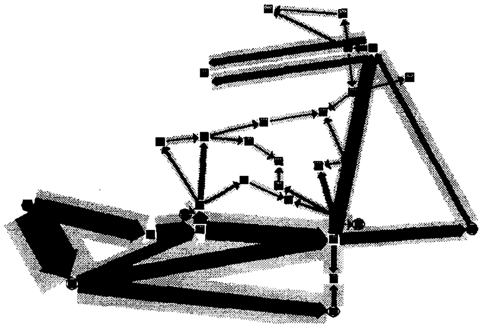

Figure 5-4 Design Alternative 1A - With Capacitor

No formal evaluation of the effects of the use of visualization in the design problem was conducted. Student opinion of the steady state analysis tool was good, even though it crashed occasionally. Students were trained with a 15 minute in-class demonstration, and required little additional help to run the tool and analyze results. This was in stark contrast to ETMSP, which was frustrating for both the students and the instructor, who does not routinely use the package. This is not a criticism of ETMSP, a complex industrial analysis tool, but rather indicates the usability benefits of visualization-based user interfaces. The expected benefits were largely achieved, and there were no unexpected problems. The use of visualization was clearly a success in enabling students to quickly surmount the data analysis problem and to concentrate on key design decisions, and design is, after all, the core learning objective of a capstone design course.

VI. COMBINED RESEARCH AND CURRICULUM IN DISTRIBUTION SYSTEMS (**A. Pahwa**, Department of Electrical and Computer Engineering, Kansas State University, Manhattan, KS 66506-5105)

Distribution systems are a significant part of power systems in terms of overall investment. It is generally believed that in the USA the total investment in distribution systems is equal to that of generation. In terms of percentages the breakdown is roughly 40% in generation, 20% in transmission and 40% in distribution. Distribution systems are also important because they are closest to the customers. Although distribution systems are a large and important part of the power system, research interest related to them, both at universities and at utilities, has been historically low. Very few universities offer a course in distribution systems and very few textbooks are available on distribution systems. Data obtained from the IEEE PES education resources survey of 1993-94 [6] is shown in Table II. Twenty-two (22) out of 91 universities that participated in the survey reported a course in distribution systems. Only 1 university reported 2 courses; 1 graduate and 1 undergraduate. Information related to these 23 courses is listed in the table. Since the survey is taken every other year, it may not be a true reflection of the exact situation at a given time. The data is presented only to highlight the fact that the number of courses on distribution systems and the number of students taking these courses are much lower than other areas of power systems.

Table II: Summary of distribution systems courses at universities in USA and Canada

Course Type	Number of Courses	Number of Students
UG Required	3	100
UG Elective	13	281
GR Required	2	20
GR Elective	5	35

Recently, however, interest in distribution systems both in industry and in universities has increased. Some of the factors contributing to this change are deregulation and unbundling of electric utility business, increased emphasis on quality and reliability by the customers, advances in computer and communication technology, and advances in power electronics technology. The interest in distribution systems should continue to grow because further progress in all the four areas mentioned above is expected in the future.

Kansas State University is one of the few universities that have been actively engaged in research related to distribution systems over the past several years. Recently, KSU had the opportunity to integrate this research into curriculum development through a Combined Research and Curriculum Development (CRCD) grant from the National Science Foundation. The award is for a period of three years (1995-1998) and five professors, Scott Sudhoff and Mariesa Crow of the University of Missouri at Rolla, Kraig Olejniczak of the University of Arkansas, and Shelli Starrett and Anil Pahwa of Kansas State University, are associated with the project. Two courses, one entitled "Flexible Control of Distribution Systems" and the other entitled "Flexible Control of Transmission Systems" will be developed as a part of this project.

Flexible Control of Distribution Systems was offered for the first time in Fall 1996. The main theme of this course is application of advanced communication and control devices for improvement of efficiency, reliability, and quality of electricity distribution. Eight (8) students, 5 at Kansas State University and 3 at University of Missouri at Rolla, enrolled in this course. Of these students, 2 were Ph.D., 4 were M.S., and 2 were B.S. students. Lectures were presented by Anil Pahwa at Kansas State University and by Kraig Olejniczak at University of Arkansas. Video tapes of the lectures were sent to students at other sites. Text material, lecture notes, and other material relevant to the course was made available to the students via the World Wide Web. The first part of the course included distribution automation functions and their economic analysis, techniques of outage location, cold load pick up and its impact on transformer loading, step-by-step system restoration, optimal system design for restoration, system reconfiguration, and voltage and var management. The second part of the course emphasized custom power including static compensator, dynamic voltage restorer, solid state breaker, instantaneous power theory, revised instantaneous power theory, and unified power flow controller.

The second course Flexible Control of Transmission Systems is being offered in Spring 97. The three campuses have been successfully interconnected via Integrated Services Digital Network (ISDN) for transmission of lectures on a live basis. During the next offering of the distribution systems course in Fall 97 ISDN will be used. Improvements in text material, web site, software, and communication between students and instructors also will be made.

VII. COMBINED RESEARCH AND CURRICULUM DEVELOPMENT FOR POWER PLANT INTELLIGENT DISTRIBUTED CONTROL

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An NSF Combined Research and Curriculum Development for Power Plant Intelligent Distributed Control was conducted from 1992 to 1996. New graduate courses on 1) Power Plant Dynamics and Control and 2) Power Plant Intelligent Distributed Control were developed. The capstone Power Plant Intelligent Distributed Control course covered advanced subjects and laboratory experiments developed in the research portion of the project including: 1) extensions to achieve real-time performance of large scale power plant simulations using UNIX network programming, 2) distributed implementation of advanced controller programming in an architecture of workstations and microprocessor-based controllers, and 3) intelligent controls using fuzzy logic, neural network, and genetic algorithms.

The 1992 combined research and curriculum development project was formulated to efficiently transfer the many new specialized skills developed in prior NSF and DOE projects to a next generation of student researchers. A motivation for continued research in advanced control techniques for application to power plants and power systems is that there is substantial industry efforts to upgrade Instrumentation and Control (I&C) at existing U.S. power plants, both fossil and nuclear. These upgrades are economically justified to improve the reliability, economy and safety of existing plants in the face of difficulties in pursuing new construction within recent years. In addition to developing new curriculum to train the engineers for the industry I&C modernization program, an expanded research objective was intelligent control at supervisory and plant-wide coordination levels.

Fig. 7-1 presents a block diagram of the Penn State Intelligent Distributed Controls Research Laboratory (IDCRL) which incorporates a Bailey Network 90 microprocessor-based control system [7]. Real-time distributed simulation of the Experimental Breeder Reactor (EBR-II) nuclear power plant and the Philadelphia Electric Company (PECO) Cromby Unit 2 fossil power plant is conducted in a network of four workstations. One of the four workstations serves as the coordinating computer which maintains a centralized plant database. The subsystem simulations communicate with the coordinating computer to interchange required boundary data using the TCP/IP communication protocol on an Ethernet network. The Local Control Network is the Bailey Network 90 microprocessor-based system and provides the capability to perform hardware-in-the-loop testing of advanced control algorithms implemented at the local controller level.

The "Power Plant Dynamics and Control" course (EE/NucE 597E) was conducted for the first time in the Fall semester 1994 as a first year graduate course, and the course was repeated in the Fall semester 1996. The principal objective of the course was to develop the basic modeling and dynamical simulation of a complete fossil power plant including the fossil-fueled steam supply, turbine-generator, and feedwater systems. Table III summarizes subjects covered and actual time spent on each topic.

The approach adopted in our research as well as this course is to utilize the B&W Modular Modeling System (MMS B&W). The MMS was originally developed as an Electric Power Research Institute sponsored project [8]. The MMS uses the MACRO feature of the ACSL language to provide a library representing all components of both fossil and nuclear power plants [9]. An ACSL MACRO is analogous to a FORTRAN subroutine in that it allows for organization of a large simulation into smaller and more manageable parts. It differs in that each invocation of a MACRO instantiates unique FORTRAN statements for a specific power plant component.

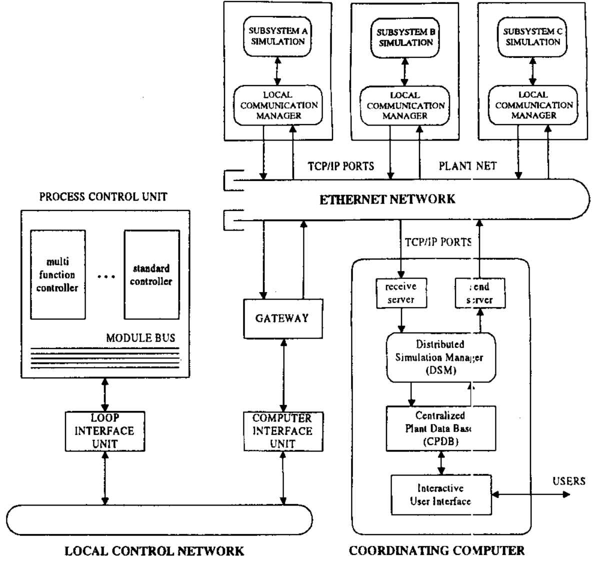

Fig. 7-1. Configuration of the Penn State Intelligent Distributed Controls Research Laboratory (IDCRL).

Table III: Summary of course material for "Power Plant Dyanmics and Control"

3 weeks	General forms of conservation of mass, momentum, and energy. Review of thermal-hydraulics and heat transfer.
1 week	Review of Simulation Methods
2 weeks	Introduction to the ACSL MACRO language and B&W Modular Modeling System
2 weeks	Drum boiler modeling, simulation, dynamics and control
2 weeks	Addition of economizer, superheaters and reheater.
4 weeks	Addition of turbines and generator

The "Power Plant Intelligent Distributed Control Course" (EE/NucE 597I) was conducted in the Spring Semester 1995 as an upper level graduate course, with nine students enrolled. It was designed to prepare new students to continue and expand upon the research completed during the first two years of the research and curriculum development project. The power plant intelligent distributed control course had two major instructional focus areas: 1) the architecture and function of intelligent systems, and 2) implementation for plant-wide automation of power plants using distributed systems programming. Table IV summarizes the subjects covered and time allotted to each.

Table IV: Subjects Studied in Power Plant Dynamics and Control

2 weeks	Overview of intelligent control systems
2 weeks	Artificial neural network controller design
2 weeks	Fuzzy logic controller design
2 weeks	Advanced controller design: optimal, LQG/LTR and robust control
1 week	Controller design by genetic algorithm
1 week	Introduction to computer architectures and UNIX
4 weeks	UNIX network programming
1 week	Implementation of distributed simulation and control.

The initial introduction started with the overview of intelligent control systems. A power plant is a large-scale complex system with a high degree of nonlinearity, a large number of variables and numerous components. Therefore, conventional controls alone are inadequate to achieve maximum possible reliability and economic performance. Intelligent control techniques are to give human like intelligence to controls when plants are complex, uncertain, and changing constantly for various operating conditions. An intelligent control system is in the form of an hierarchical structure with several layers of controls with different levels of intelligence. Low level control involves tight controls with sensors and actuators where conventional control techniques such as proportional-integral-differential (PID), optimal and robust controllers can be used. As the level goes up, controllers require increased intelligence but less precision. Throughout the semester, four basic techniques of intelligent control were presented: artificial neural networks, fuzzy logic control, genetic algorithms, and expert systems.

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