PowerZone: Artificial Intelligence Educational Modules for Power Engineering

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Abstract

PowerZone is an NSF sponsored Combined Research and Curriculum Development project aimed at improving electric power industry competitiveness. Educational modules centered on artificial intelligence (AI) techniques are introduced into senior-level undergraduate and first-year graduate power engineering courses. Four independent modules are developed including: (1) fuzzy logic for *decision making and signal processing*, (2) visualization and intelligent systems for electrical *power quality* studies, (3) short term *load forecasting* using neural networks and fuzzy logic, and (4) fast simulation through *sparsity coding* visualization. These modules are being disseminated using the project initiated *PowerZone* website located at http://ceaspub.eas.asu.edu/PowerZone/.

1. Introduction

Power engineering education has gone through a tortuous history including a golden era of the implementation of electrification (deemed as the top engineering feat of the twentieth century by the National Academy of Engineering [1]), an era of computer applications and control, and most recently a period of restructuring / deregulation. Deregulation of the electric utility industry is forcing most utilities to work harder and smarter. As deregulation takes hold across the country, electric utilities will be (and are being) forced to look at methods that will give them a competitive advantage. To be competitive, utilities need engineers at all levels who are trained to deliver a better product, at a lower cost, with more reliability. The goal of this project is to help improve electric power utility competitiveness by incorporating instructional modules that can be used to train people in these critical areas.

The National Science Foundation (NSF) Combined Research-Curriculum Development (CRCD) Program [2] emphasizes the need to incorporate exciting research advances in important technology areas into the upper-level undergraduate and graduate engineering curricula. The electric power industry is currently in need of instructional modules covering a broad range of topics. This is evidenced by the large number of short courses taught every year on a wide range of practices impacted by deregulation. The instructional modules developed focus on the area of the application of artificial intelligence (AI) and visualization to operation, control and simulation of electric power systems. The modules are largely based on ongoing and/or already completed research by the authors.

Other researchers have developed educational modules for power engineering, although without emphasis on the application of AI techniques. A noteworthy example is the *PowerLearn* [3] material jointly developed at Iowa State University and Virginia Tech.

2. Educational Module Characteristics

The concept used is modular, that is, the modules are independent of one another, and they can be used in different courses. The modules are developed for presentation over 3-5 lectures, thereby displacing a minimal amount of an instructor's original course material. The modules utilize textual materials, lecture notes, presentation slides, simulations, visualizations, and downloadable executable files to effectively convey the AI concepts and applications. The interactive web pages provide external links, assessment feedback, and simple examples, including some designed for cooperative learning environments.

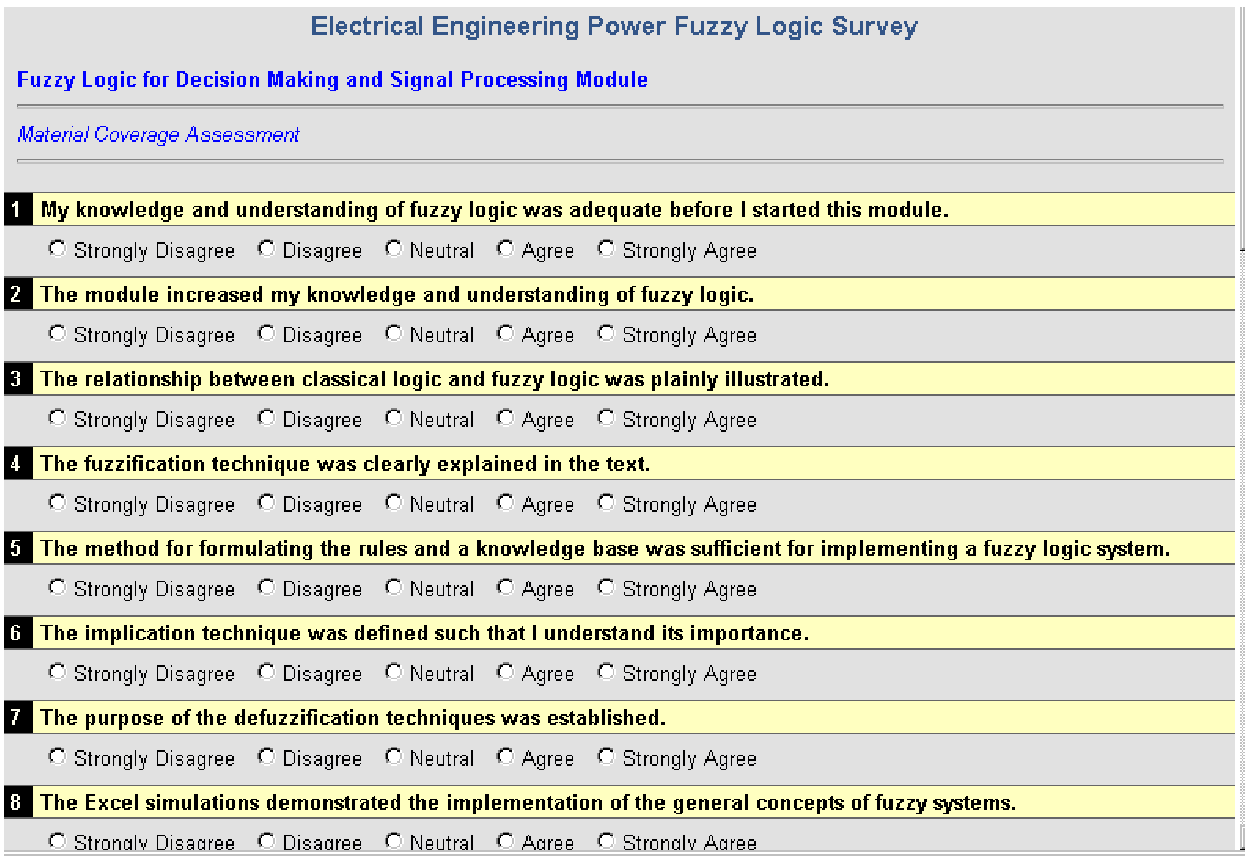
Modules consist of both student and instructor specific materials. The instructor materials contain instructional objectives, team formation strategies, instructional methods, technology requirements, and assessment tools. The student materials feature text quality prose, interactive applications, and in-class lecture notes. It is intended that each module include:

1. *Technical Prose.* Each module contains the equivalent of a textbook treatment of the subject. This includes homework problems. The text integrates the interactive application so that the distance learning student will be able to use this module for self-paced education.

2. *Interactive Applications.* One or more multimedia computer-based interactive applications are the core of each module. The applications aid the student in visualizing aspects of the modular content and meeting the other learning objectives. The interactive applications are made as intuitive as possible; however, a part of the course module is a user's guide with examples for operating the application. This is particularly important to distance learners. The concept is to recognize that learning occurs with a number of sensory inputs (*e.g.*, laboratory work with tactile senses; homework as a visual-mental exercise). The software engines used in the interactive applications are intended to reinforce technical concepts with graphic presentations that are keyed to student selected learning styles.

3. *Lecture Notes.* Each module contains a set of course-ready lecture notes for use as in-class presentations. These lecture notes are integrated with the interactive application and include active learning in-class assignments. Whenever an active learning strategy is first used in a module, the lecture notes contain entries guiding the students through the use of the active learning strategy. Formal cooperative learning (CL) strategies include: affinity diagrams, formulate share listen create, group definitions, interactive lecture, multivoting, numbered heads together, pairs check, round robin, roundtable, team interview, think pair share, write pair share, write pair square [4,5,6]. Because many of these team activities fit less well for problems that have one numerically correct answer, modules include creating cooperative learning activities that obey the four tenets of CL activities: positive interdependence, individual accountability, equal participation, and simultaneity of learning.

Surveys of students are used for assessment purposes. A secure website developed by the Arizona State University College of Engineering and Applied Sciences as part of the ABET EC2000 efforts is being used for this purpose (see Fig. 1). The website allows the instructor to craft various forms of questions (single and multiple button, and text response) which can be accessed by the students using an identification number and password. The website has the ability to automatically send an e-mail notification to the students reminding them to complete the survey(s). Instructors can download the anonymous assessment data to analyze.


Electrical Engineering Power Fuzzy Logic Survey

Fuzzy Logic for Decision Making and Signal Processing Module

Material Coverage Assessment

1 My knowledge and understanding of fuzzy logic was adequate before I started this module.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

2 The module increased my knowledge and understanding of fuzzy logic.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

3 The relationship between classical logic and fuzzy logic was plainly illustrated.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

4 The fuzzification technique was clearly explained in the text.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

5 The method for formulating the rules and a knowledge base was sufficient for implementing a fuzzy logic system.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

6 The implication technique was defined such that I understand its importance.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

7 The purpose of the defuzzification techniques was established.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

8 The Excel simulations demonstrated the implementation of the general concepts of fuzzy systems.
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

Figure 1. Student survey of fuzzy logic module for web-based assessment.

3. Module Descriptions

Briefly described below are the four power engineering educational modules developed at Arizona State University:

1. fuzzy logic for *decision making and signal processing*,
2. visualization and intelligent systems for electrical *power quality* studies,
3. short term *load forecasting* using neural networks and fuzzy logic, and
4. fast simulation through *sparsity coding* visualization.

These modules are being disseminated using the project initiated *PowerZone* website located at http://ceaspub.eas.asu.edu/PowerZone/. Three additional modules are being co-developed at the University of Washington, including: (*i*) transmission system design using AI, (*ii*) intelligent system applications to security assessment, and (*iii*) knowledge engineering in power system operations. The purposes of the multi-university effort include cross assessment of the modules and testing their portability.

The fuzzy logic module focuses on the basis of fuzzy logic and its application to redundant sensor validation and power plant control. The power quality module describes three-phase and single-phase rectifiers, which are a power distribution load type that often gives difficulties. A comprehensive review of short-term load forecasting methods and discussion on the use of AI techniques to improve forecast accuracy are the emphasis of the third module, so that the student becomes familiar with basic forecasting methods and gains an understanding of the economic importance of accurate load forecasting. The final module includes two separate units: (*a*) elementary concepts of sparse matrix methods, and (*b*) use of sparse matrix methods to perform typical algebraic operations in the analysis of large-scale systems.

3.1 Fuzzy logic for decision making and signal processing [7,8]

Fuzzy logic is an emerging field that has been used and proposed for many industrial applications. The deregulation of the electric power industry has encouraged utilities to improve their reliability by incorporating advanced technology into their systems. The module objective is to convey the background and theory of fuzzy logic systems, and educate the students to the point that (s)he can apply rule-based fuzzy systems. Fuzzy logic based decision making and signal processing techniques are targeted to applications for power plant system diagnostics and control. The rule-based fuzzy logic systems are very appropriate examples for applying visualization to enhance student learning. Figure 2 illustrates the graphical complexity of a relatively simple rule base.

This module focuses mainly on teaching fuzzy logic to senior-level undergraduate students in an electric power plant engineering course, although this fuzzy logic module could be integrated into a variety of undergraduate engineering courses. Intended for use over 3-5 one-hour lectures, the instructional module covers the basic concept of fuzzy logic, fuzzy logic rule-based control systems and simple fuzzy logic applications related to power systems. The module concludes with two interactive (Excel) applications to demonstrate the design of fuzzy systems; in particular, fuzzy logic is applied to sensor fault detection and hydro power plant control. The students are provided with extra reading materials, which include several simple examples with each chapter. The instructor may assign homework exercises and design projects, which have been developed to increase the students' understanding of the concepts. The students should be able to design their own fuzzy models after studying this module.

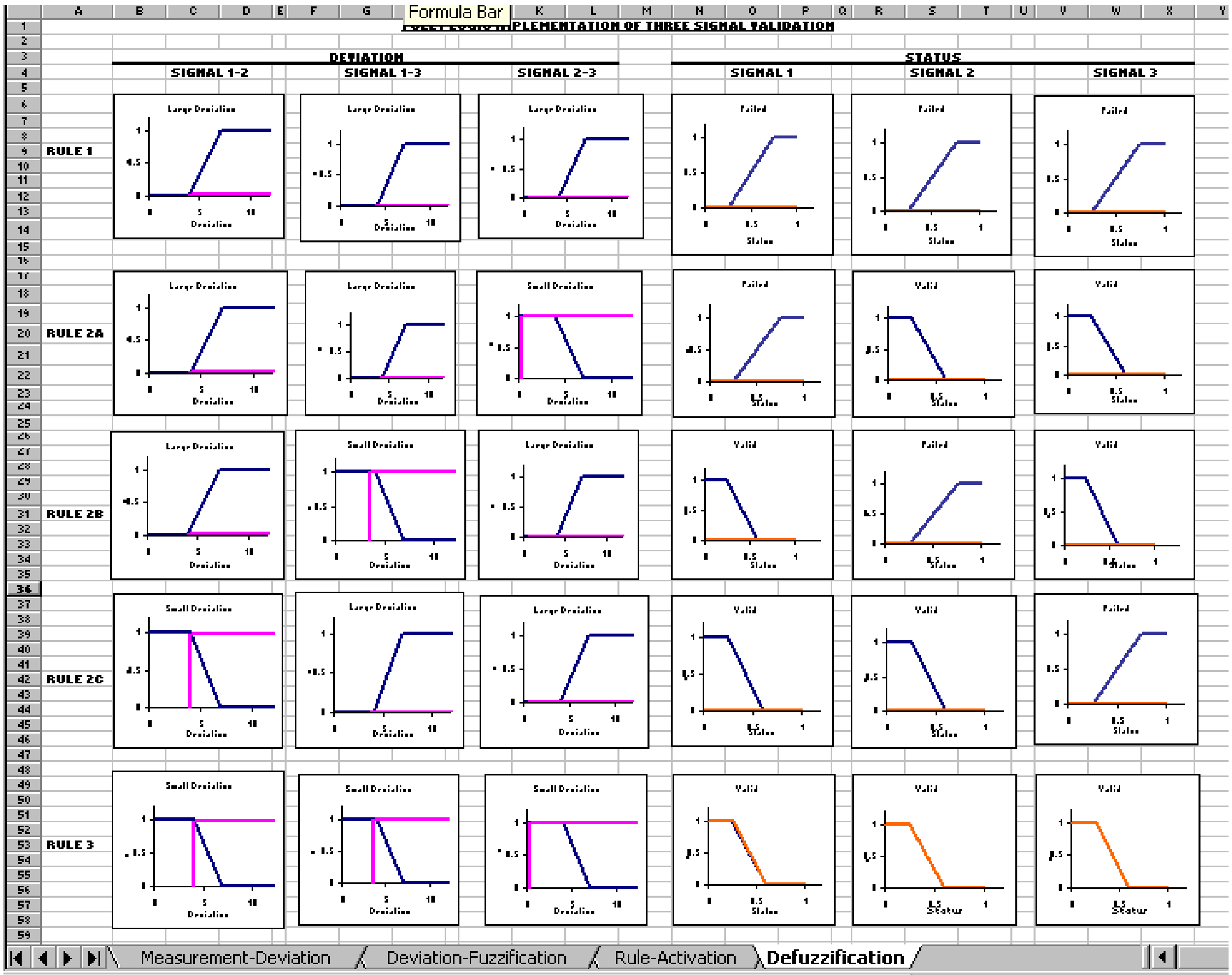


Figure 2. Fuzzy logic module simulation results for redundant sensor validation.

3.2 Visualization and intelligent systems for electrical power quality studies [9]

The objectives of this module are to teach students to define power quality indices, describe how to measure them, evaluate the impact of poor power quality, and evaluate the costs associated with momentary outages. Additionally this module will allow the student to visualize power quality measures and waveforms, and apply intelligent signal processing to extract information from measured waveforms and thereby take corrective measures. The visualization element consists of voltages and currents plotted versus time, including the possibility of varying a circuit parameter. Visualization reinforces the learning process by providing visual sensory input.

The power quality module relates to a power distribution load type that often gives difficulties: rectifiers. Three-phase and single-phase rectifiers are described in text, mathematically and graphically; and PSpice is used to analyze examples. One such example is a simple PSpice simulation of a six-pulse rectifier (see Fig. 3). The concept is to develop the main equations for a six-pulse uncontrolled rectifier. The reasons for selecting a rectifier for the module are

- rectifiers are in nearly every consumer product,
- the topic is usually not well covered in basic circuits courses, and
- the students can relate to the results, and they express interest in the computer simulations.

The expressions for a three-phase rectifier are derived using the principal that the input and output power are equal, and the DC circuit current is purely DC. The validity of the expressions is discussed, and the comparison to the real world case is made. The PSpice simulations are used to find power factor indices.

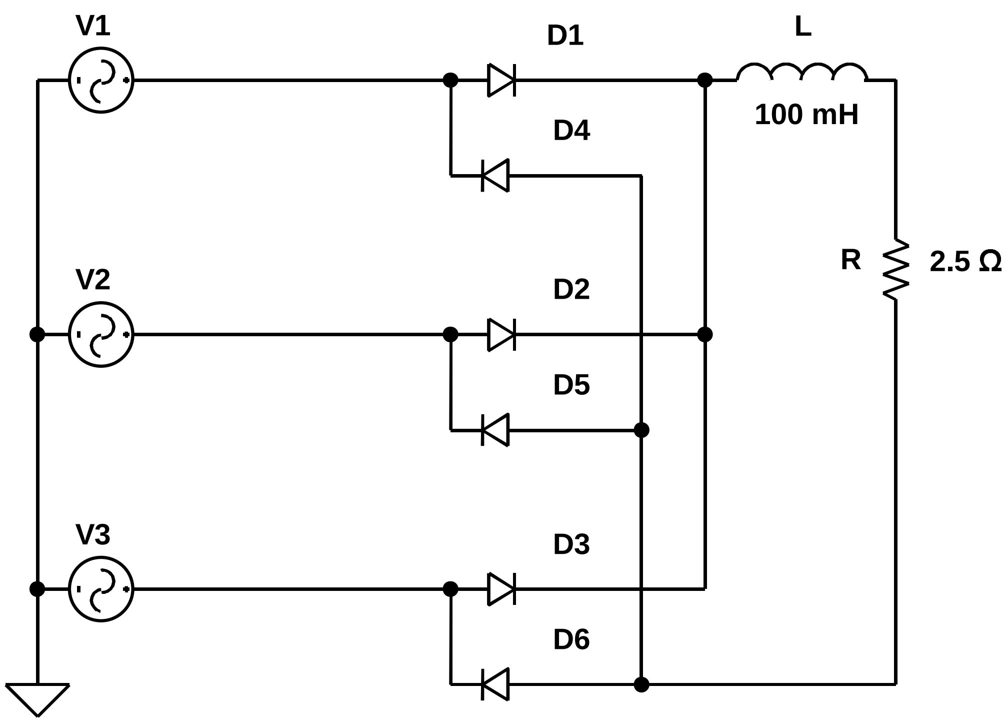


Figure 3. Simulation example in the power quality module.

3.3 Short term load forecasting using neural networks and fuzzy logic [10,11,12]

This module presents a comprehensive review of short-term load forecasting methods and discusses the use of neural networks and fuzzy logic to improve the accuracy of the forecast. The materials can be used for graduate classes and for introduction to an independent study. The objectives of the module are that the student (*a*) will be familiar with the basic forecasting methods, and (*b*) will understand the economic importance of accurate load forecasting. The general concept of forecasting is appropriate in this effort to motivate students: forecasting entails mathematical modeling, heuristics, and advanced mathematical solution techniques, all of which are of interest to students. Additionally, the practical significance of load forecasting implies to the student that their work is more than an academic exercise.

The module begins by presenting the theory behind major load forecasting techniques and discusses the importance of short-term load forecasting together with the economic consequences. Input data and system parameters required for load forecasting are listed, and the expected results are discussed. After a description of the traditional load forecasting techniques, the linear regression based statistical methods are presented in detail along with a practical application of the technique through an interactive example.

The heart of the module deals with the application of a neural network to improve load forecasting accuracy. The students learn the development of a feed-forward neural network for load forecasting. The practical application of this method is based on an Electric Power Research Institute (EPRI) developed and widely used technique. Efficiency of this modern technique is demonstrated with practical examples using data obtained from electric utilities. Finally, the module shows that further improvement can be achieved by using fuzzy logic. The membership functions are selected by trial and error. The evaluation of the load forecasting is based on the traditional fuzzy method. It is emphasized that the fuzzy method is in an experimental stage and has not yet been adopted for use by the electric utility industry. This method is considered as a feature technique, which is on the cutting edge of engineering science.

3.4 Fast simulation through sparsity coding visualization [13]

The interconnection architecture of the electric power grid is such that when mathematical matrix equations are used to simulate the static and dynamic performance of these systems, the matrices that characterize these equations are sparse. Because of the large size of these problems, it is imperative that these zeros be ignored whenever possible; for even with high-speed computing engines, treating all of the zeros in the problem causes prohibitively long execution times. Sparsity programming was invented to handle this problem. Sparsity programming is difficult to teach in a traditional chalk-and-talk classroom. Teaching sparsity coding requires listing many arrays of pointers on the board that change from iteration to iteration. On the chalkboard, pointer values are erased and overwritten many times for the completion of even one example. By the time students are done with their note taking, they have an unintelligible list of numbers crossed out many times. The objective of this module is to allow students to visualize the operations performed in the most complex of the sparse matrix manipulations: sparsity coding of LU factorization and forward/backward substitution of sparse matrices.

Two units were developed for instruction in sparse matrix technology. Each unit is sufficient to cover about four weeks of a typical semester length course. The first unit encompasses the elementary concepts of sparse matrix methods. The second unit addresses the use of sparse matrix methods to perform typical algebraic operations in the analysis of large-scale systems: particularly forward and backward substitution in the solution of linear matrix equations whose matrices exhibit a triangular form and triangular factorization. Each unit consists of a PowerPoint presentation and interactive applications, which allow the students to visualize the data manipulations that occur in: the construction of a sparse matrix from branch oriented data, the ordering needed to minimize fill caused by triangular factorization (two ordering schemes are available), and triangular substitution. Figure 4 shows an example of the interface of one of the applications that allow students to enter branch oriented data to construct a sparse matrix (stored using an adjacency storage scheme) then order the rows and columns of the matrix to minimize fill during triangular factorization. Each PowerPoint presentation is designed for use in a cooperative learning setting, with solutions available for all cooperative exercises. A survey of the results of using the units for the first time is helping define what has been successful and where there is room for improvement.

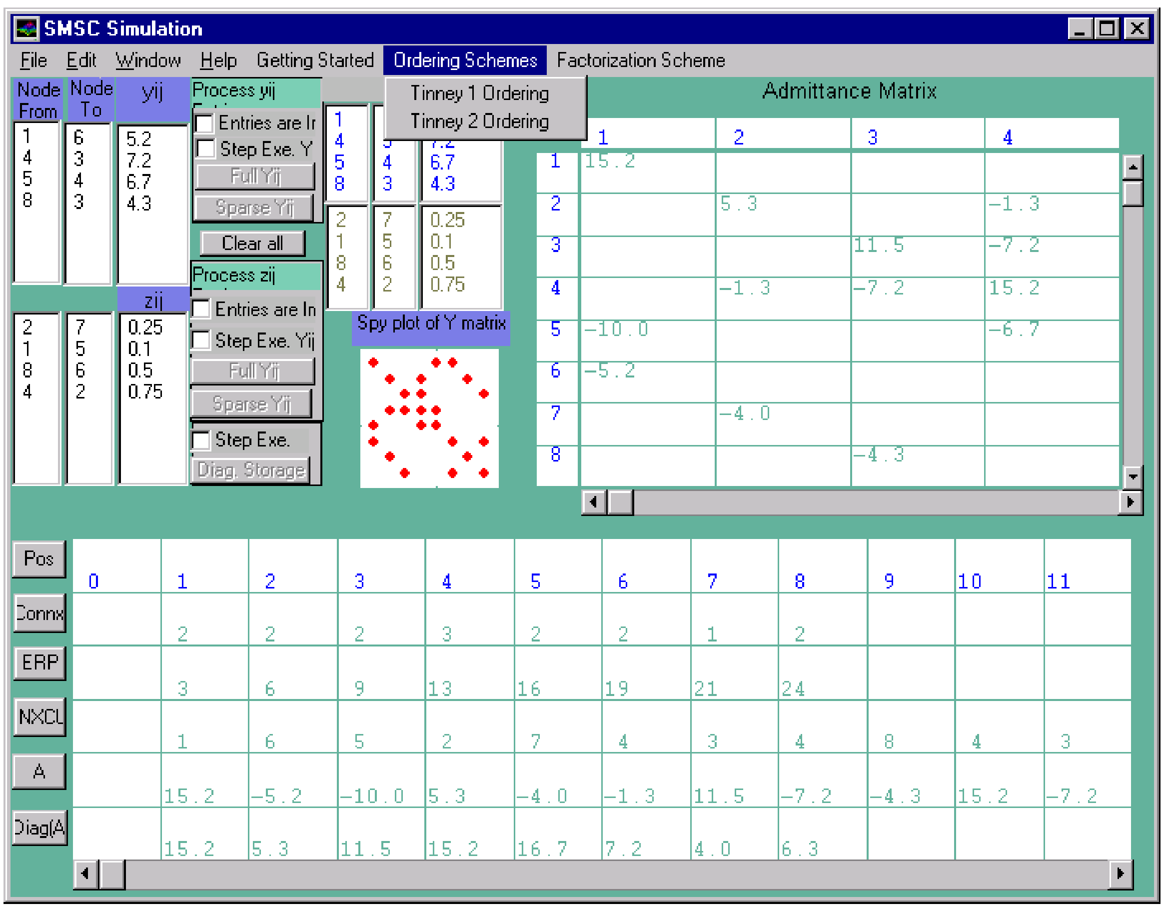


Figure 4. Sparse Matrix Storage Construction (SMSC) simulator emphasizing the ordering scheme menu.

4. Summary

Application of AI techniques to key power engineering topics is formulated in educational modules. The use of various software tools and analysis are highlights of each module. The modules focus mainly on teaching corresponding topics to senior-level undergraduate students and graduate students. Lecture notes, presentation slides and downloadable executable files are the main contents. The web pages are interactive while providing simple and general examples, so as to maximize student understanding. Some of the modules indicated above can be integrated into any (power) engineering course.

The above *PowerZone* modules are still under construction. The expected capabilities of the *PowerZone* website are

- Aid to course education for undergraduate students, graduate students and self-study visitors.
- Introduction to advanced techniques in the power area for potential power students.
- Continuing education for engineers of power industries.
- Updating information and application in the deregulated operation environment.
- Upon-request interactive simulation based on dynamic HTML and Java.

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Acknowledgements
The authors thank the National Science Foundation for its support of curriculum development in electric power engineering through grant EEC-9872500. The authors acknowledge the website development work of graduate students: Sujit Pant, Shameem Khan, and Hui Ni.

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