

USING MODELING, SIMULATION AND DIGITAL SIMULATORS FOR POWER ENGINEERING EDUCATION

**M. Kezunovic, A. Abur
G. Huang
Texas A&M University**

**A. Bose, K. Tomsovic
M. Venkatasubramanian
Washington State University**

USA

Abstract – This paper describes results from a project aimed at developing computer exercises to be used in teaching undergraduate and graduate courses in the power engineering area. The paper first describes details about the project which is funded by the National Science Foundation, Electric Power Research Institute and a number of industry sponsors. After that, a customized power education toolbox developed for teaching power system analysis topics is introduced. The use of commercial software for the teaching is discussed next. Development of computer exercises using the MATLAB software are presented next. Finally, utilization of digital simulators capable of testing outside controllers is outlined at the end.

Keywords: modeling, simulation, power engineering, education, digital simulators

I. INTRODUCTION

Power engineering education is again the topic of great interest ever since the process of deregulating the power industry has been initiated [1]. As a result of this renewed interest, the National Science Foundation (NSF) and Electric Power Research Institute (EPRI) have announced a solicitation for proposals aimed at improving power engineering education. Texas A&M University and Washington State University have submitted a joint proposal and were awarded a development project for implementation of computer exercises based on the use of modeling, simulation and digital simulators. The project titled “**Multidisciplinary Education Using Curriculum Re-engineering, Industry Partnership and Simulation Technology (MERIT 2000)**” has a goal of re-engineering the curriculum taking advantage of the simulation technology as well as developing a partnership with industry making the use of the technology more practical [2,3].

Selecting the simulation technology as the base for developing the computer exercises, the project has concentrated on development and utilization of a variety of simulation environments [4]. The use of customized software developed exclusively for education is studied with a purpose of emphasizing the need for developing user friendly graphical interfaces.

The use of commercial simulation programs is evaluated from the stand point of teaching the system issues that relate the performance of individual power system components to the behavior of the overall power network. The use of general purpose signal processing and mathematical modeling packages is also evaluated to illustrate how those environments may be utilized for teaching the topics that relate to the control issues and signal analysis. Finally, the technology of digital power system simulators is assessed taking into account the need to visualize complex interactions between the power system and advanced controllers such as protective relays.

The first part of the paper is devoted to a brief description of the goals and objectives of the **MERIT 2000** project. The next four sections discuss the following simulation environments and their use in the educational process: customized software, commercial simulation packages, general purpose simulation tools (MATLAB), digital simulators. Conclusions and references are given at the end.

II. MERIT 2000 PROJECT SCOPE

Research objectives and significance. The main objectives of the **MERIT 2000** project are to [2,4]:

- Create a working example of a new re-engineered curriculum for undergraduate and graduate power engineering education.
- Involve various segments of the utility and manufacturing industry, as well as the consulting and engineering services in the process of defining multidisciplinary needs and practical examples for the educational process.
- Exploit unique expertise of the university teams and industry advisors to explore the simulation technology and related benefits in implementing efficient methodologies for classroom and laboratory teaching.

Industry and university partnership. The main philosophy behind the partnership in the **MERIT 2000** approach is to follow the existing trends in the partnership seen between various industries, as well as between industries and their customers. It is understood that a major advancement in the power engineering education cannot be easily achieved by one school, or without the industry input. Hence, the approach taken was to make a team of two universities, four utilities and four vendors that jointly participate in this project from the stage of the proposal writing to the stage of the final curriculum implementation [2].

New educational concept. The new concept is based on three pivotal components:

Multi-disciplinary Approach

The basic idea is to enhance the existing fundamental power engineering topics with the additional themes such as customer relationship (marketing, public relations), advanced technology (communications, intelligent systems), economic considerations (cost analysis, pricing) and new applications (FACTS, renewable energy sources).

Simulation Technology

Simulation environments offer an advanced technology and a powerful methodology to be extensively used in teaching. Each of the fundamental power system topics are being re-examined in order to decide how the required modeling and related simulation can be utilized to enhance understanding of both the fundamental phenomena and practical solutions.

The projects uses the existing packages created in the university environment, certain commercial tools as well as the new software.

Innovative Teaching Methodology

The main ingredient of the innovative teaching methodology is a comprehensive use of digital simulators in the teaching process. This allows for redistribution of the teaching load in the classroom where the time required for presenting and understanding of theories and concepts is reduced due to a well prepared set of visual demonstrations. Furthermore, detailed considerations and practical examples are shown in the laboratory environments which is turned into additional teaching time and self-learning experience.

Curriculum issues. The curriculum includes the **fundamental power engineering issues**, namely:

- Energy sources and conversion,
- Power system design, analysis and control,
- Protective relaying, monitoring and local control,
- Advanced technologies for power system automation and control,

- Power quality design and assessment,
- Distributions systems and automation as well as **additional topics associated with de-regulation and new technologies**,
- Deregulation and market competition,
- Standardization, industry recommendations and quality assurance,
- Social, environmental and economic impacts,
- Communication skills, team work and marketing strategies.

The focus of **MERIT 2000** is to maintain a structure similar to the traditional power system education while adding the new elements to the curriculum.

III. DEVELOPMENT OF A CUSTOMIZED POWER EDUCATION TOOL-BOX (P.E.T)

This section describes a software tool called the Power Education Toolbox (PET) that has been developed for power engineering education at Texas A&M University. The main motivation in developing PET is to provide a simulation environment where the students can easily create realistic size power system diagrams, enter network and application parameters, and finally carry out simulation studies of various different types using the same network all along. The difficulty in accomplishing this using commercially available packages is their complexity for novice users such as junior or senior level students. In addition, the customized user interface allows the use of varying degrees of complexity in the data entry for different application functions supported by the toolbox.

The software package is organized in such a way that the network one-line diagram is built and saved first. All elements in the one-line diagram are treated as objects with different attributes. Depending upon the application to be run on the network, the objects' relevant attributes are entered by the user. For instance, to run a power flow study, the user only enters the positive sequence bus data, whereas additional zero sequence data for the same objects need to be entered, if a short circuit study is to be carried out. The applications currently supported by the P.E.T software are listed below:

- Network Editor
- Power Flow [5]
- State Estimation
 - Network Observability Analysis [6]
 - LAV Estimation [7]
 - WLS Estimation [8]

All applications that make up the software package are implemented in a modular fashion to allow easy modification and/ or replacement of any one or more of them in the future, to reflect changing needs as well as

solution techniques. The user interface allows the user to build one-line diagrams of power systems and also to select desired applications to be run on the created system. Different dialog boxes for the same objects (bus, line, transformer, etc.) will be displayed according to the selected application. Users may choose to enter relevant data for a given system for one or more applications. Each time a power system one-line diagram is opened, all of its associated data that have already been entered for all supported applications will also be retrieved. This will allow the user to switch between applications and execute them for the same system within the same window.

Sample Exercise

Here a sample exercise will be described to demonstrate the utilization of the developed software for education. The exercise is aimed to provide insight to the bad data identification methods used in state estimators. The concepts of critical and redundant measurements are developed through this exercise as well.

Assignment: Run the WLS state estimation for the given 14-bus system and its measurement configuration by adding 0.1 p.u. bias to the injection at bus 9. Analyze the estimator results. Now, add the same amount of fixed bias (0.1 p.u.) to both injection at bus 9, and flow measurement 9-10 and observe the measurements' normalized residuals. Explain your observations.

The normalized residual test [8] is commonly used in the context of single bad measurements, but is not a reliable test when multiple interacting bad measurements are present. This program can be used to study how the normalized residuals are affected by a single bad measurement, multiple interacting bad measurements, and changing local measurement redundancy. The estimator successfully detects and identifies the bad measurement in the first case where there is a single bad data. In the second case, which simulates conforming bad data, the largest normalized residual test fails to identify bad data, as shown in Figure 1.

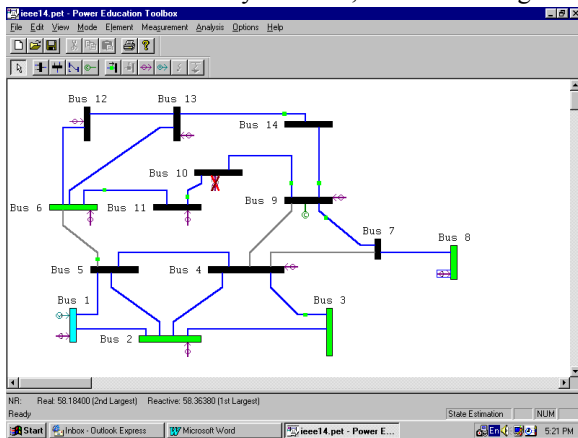


Figure 1. Normalized Residuals for the Second Case

IV. USE OF COMMERCIAL SOFTWARE

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 safe, reliable and economic electric supply. The traditional curriculum performs less than satisfactory in translating these fundamental concepts into usable information for applications. For example, it is relatively difficult to explain the relationship of transformer modeling to the performance of the large interconnected system. The primary role of commercial software is help bridge this gap.

The examples developed at Washington State University emphasize the computational aspects of solving both steady-state and dynamic problems in power system analysis. At the same time, the examples have been designed to allow insight to large system behavior. In terms of steady-state problems, the examples cover the following areas:

- transmission line modeling,
- power flow solutions,
- economic operations,
- state estimation,
- system security,

and for dynamics

- synchronous generator modeling,
- power system stabilizer design,
- system dynamic response,
- slow dynamics, including governor response, load frequency control, and other slow controls.

In each of the above areas, the classroom examples and homework assignments begin from the modeling of simple systems of roughly less than 5 buses. These cases emphasize the fundamental mathematical models and general algorithmic approaches for finding solutions. Subsequent studies are performed on large systems where the students are asked to investigate more practical scenarios. It is the stage of more practical scenarios where the commercial software is introduced.

For example, the load flow load flow lessons require students to develop and compare numerical algorithms (specifically, Gauss-Seidel, Full Newton Raphson and Fast Decoupled) on a small system, usually less than a five bus system. The models for these systems do not include tap changing or off-nominal transformers. Students must then implement a generic algorithm that is valid for systems other than the example system and find solutions under varying conditions. Understanding the nature of load flow solutions (e.g., relationship between voltage and reactive power is sought) as well as the numerical characteristics (e.g., the convergence characteristics of Gauss-Seidel methods).

Students are then asked to investigate power flow solutions on a large practical system, presently a model of the WSCC (Western System Coordinating Council) system of around 6000 buses, using commercial software. The EPRI package IPFLOW [9] is used at WSU. This is a black box exercise in terms of the computational methods but the exercise requires students to gain practical engineering insight into the power flows on this system in different areas and under various loading conditions. Specifically, the students must:

- Examine the load flow solution during the peak summer season, identifying the power consumption for several local cities and the system transfers among regions.
- Next generation is significantly increased at one of the Grand Coulee units and the system transfers reexamined with a focus on which areas receive this increased power.
- These exercises are repeated for the lightly loaded winter season.

Thus, the learning objectives of the load flow lessons are:

- comprehension of fundamental power flow analysis techniques,
- understanding of large system parameters and terminology (zones, areas, interchange data, etc.),
- visualization of MW, MVAR flows between areas, and the voltage profiles,
- development of an engineering sense for practical considerations (season, equip-ment/system limits),
- introduction to deregulation issues.

A similar pattern is followed for the other areas under steady-state response and dynamics. Presently, the EPRI package ETMSP [10] is used for the transient stability studies. Only studies on relatively small systems are presently available but the generator models are higher order than is generally introduced in the senior level course. For the slower dynamics, a package provided by Incremental Systems, Inc., which puts a Java-based GUI [11] on front of the EPRI Operator Training Simulator. This system allows study not only of the slow dynamics but also of the operation environment [12]. Again, this is an area that has not traditionally been introduced at the undergraduate level.

V. DEVELOPMENT OF CUSTOMIZED MATLAB TOOLS TO DEMONSTRATE POWER DYNAMIC, CONTROL AND ASSOCIATED ECONOMIC ISSUES

This section describes Matlab tools that have been developed for teaching power system dynamics, controls and associated economic issues at Texas A&M University. The main motivation is to provide a simulation environment where the students can easily grasp the fundamentals of power system dynamics, associated control actions and economic issues through graphical animations. Once the

students understand the basics, more complicated designs problems can be assigned. The difficulty in accomplishing this using commercially available packages is their complexity for novice users such as junior or senior level students; in addition, they are usually not flexible enough to reflect the different designs, also computationally slow for in-class demonstrations.

The Matlab package is organized in such a way that the network one-line diagram is built and saved first through matlab or Simulink graphic interface. All elements in the one-line diagram are treated as objects with different attributes. Depending upon the application to be run on the network, the objects' relevant attributes are entered by the user. For instance, to run a power stabilizing control study [13], the user only enters the positive sequence bus data, the control device parameters and associated control laws.

All applications that make up the software package are implemented in a modular fashion to allow easy modification and/ or replacement of any one or more of them in the future, to reflect changing needs.

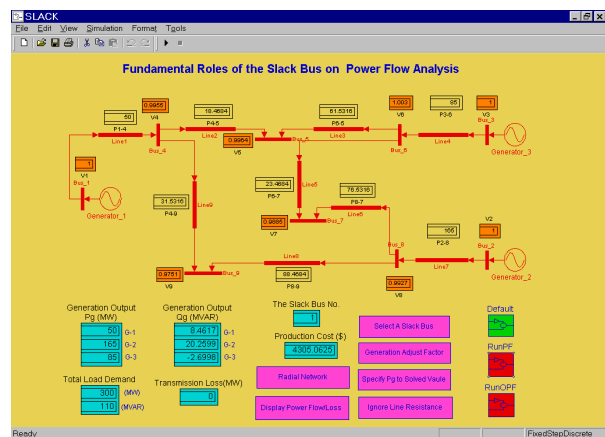


Figure 2. An Interface for the Slack Bus Analysis

Sample Exercise

Here a sample exercise will be described to demonstrate the utilization of the developed software for education. The exercise is aimed at providing an insight into how the slack bus matches the system loss and its associated economic issues. The user interface is shown in Figure 2.

Assignment #1[14]: Run the power flow solution for the given 9-bus system. Demonstrate that the slack bus does not match all the system loss and the power flow solution is independent of the selection of the slack bus when the system data set is consistent. When the other two generation amounts are specified, the slack bus amount is uniquely determined by these two amounts. Accordingly, the critical issue on loss allocation is not the choice of the slack bus but

how to determine the generation patterns for a given load profile. The key is how to distribute the transmission losses to the selling generators during the bilateral transactions in a deregulated environment.

The above figure demonstrates how the Matlab/Simulink is used to implement such an interface. The students are allowed to modify the network topology and investigate its impacts. The students can also change the generation amount to see how it influence the slack bus solution. Examples can be found that the slack bus generation can be less than the total system loss; accordingly, it is not correct to conclude that the slack bus generator is supplying all the system loss. Once the slack bus generation amount is found, we can specify the amount at the calculated value and select another generator as the slack bus; students then will find that the power flow solution is the same and is independent of the slack bus selection. The key concept here is the consistent data set concept: if the system data is consistent, the solution is independent of the slack bus selection.

Assignment #2: Submit generation bidding cost/ load bidding cost curves in a spot market to buy and sell power. What should be the strategy to win the transactions?

A least bidding cost dispatch algorithm [15] has been implemented using Matlab to simulate the market. We do not require the undergraduate students to master the optimization schemes; however, we want them to realize that different market players have their own objective and thus their own strategy to win a bid. The open question is how to formulate the rules for all players to compete fairly.

VI. USE OF DIGITAL POWER SYSTEM SIMULATORS

To better understand the dynamics of interaction between the power system and controllers such as protective relays, the use of digital power system simulators has been explored. This section discusses how an elaborate laboratory infrastructure has been developed and utilized in the educational process at Texas A&M University.

State of the Art Laboratory Infrastructure

The power engineering education, to be competitive, needs to familiarize students with laboratory facilities that they may use as they enter industry jobs. This goal is not new and was always a subject of great concern to the power engineering programs. The cost of providing elaborate laboratory infrastructure for matching the industry standards was always excessive and for the most part not affordable for academic institutions.

The role of the simulation technology enabling construction of relatively low cost digital power system simulators can be

explored in the future. This technology is quite affordable and can be conveniently implemented in the academic institutions since it only requires a computer, appropriate application software, and possibly some interfacing hardware.

A summary of the major developments in the simulator technology is given in Table I. Each of the new developments is correlated to the commercial products available on the US market today.

TABLE I. Summary of the Simulator Technology Developments

New Simulator Technology Developments	Commercial Products
Application Programs for Planning and Engineering	Short Circuit, Load Flow, Transient Stability, Long-term Stability, Voltage Stability Programs
Operator Training Simulators	EMS functions including AGC, Economic Dispatch, State Estimation, Security Assessment
Open-Loop Simulators for Device Testing and Evaluation	Electromagnetic Transient programs, Data File Replaying programs, programs for Automated Device Testing

Development of an Advanced Laboratory Infrastructure

The digital simulator technology developed and utilized in this project relates to the use of the real-time and open loop simulators for testing protective relays and other controllers [16]. The simulators are made a part of a computer network containing a variety of general purpose computers and specialized instrumentation. Arrangement of the computer equipment installed in the laboratory is given in Figure 3.

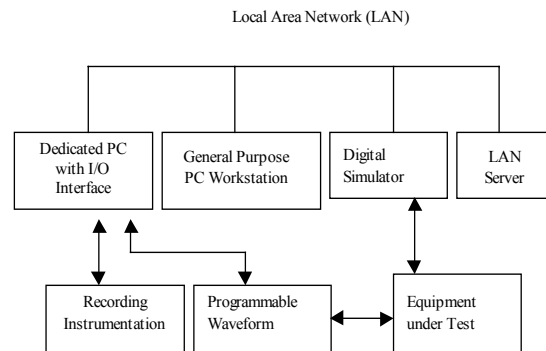


Figure 3. Arrangement of the Equipment in the Laboratory.

This laboratory has some generic features that can be used for teaching a number of courses. The features are listed in Table II together with an explanation of how a feature may be used in the teaching process.

TABLE II. Laboratory's Generic Features and Uses

Feature	Uses
Power System Modeling	Modeling of power system components and sections
Digital Simulation	Simulation of power system phenomena such as faults and other disturbances
Programmable Signal Sources	Generation of power system wave forms through mathematical expressions
Data Recording and Monitoring	Capturing of field data for analysis of various phenomena
Signal Processing and Analysis	Analysis of the captured or simulated signals

An elaborate set of computer exercises for teaching protective relaying has been implemented using this laboratory equipment, in particular digital simulators. A separate paper describing the details is published on this subject [17].

CONCLUSIONS

From the examples given in this paper it appears that a versatile and effective use of the simulation technology may involve a mix of variety of different implementations:

- Customized programs
- Commercial software
- General purpose programs (MATLAB)
- Digital simulators

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