INTRODUCTION OF PROFESSIONAL SOFTWARE INTO THE CURRICULUM OF AN UNDERGRADUATE POWER SYSTEM ANALYSIS COURSE

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Keywords

Abstract - The development of new evaluation techniques for electrical distribution networks has resulted in significant opportunities for more efficient configuration and operation of power systems. This paper presents the introduction of sophisticated professional software for power system analysis in the curriculum of an undergraduate program. As a consequence, an unfolding process takes place. I would like to define "unfolding" as the learning process by which the students learn the principles of a subject with the perspective of developing their understanding through exposure to practical problems currently being investigated. Discovery in the learning process unfolds a real interactive action. For instance, in this particular experiment students have been able to learn about energy losses on a distribution system while using recently developed techniques to minimize them.

INTRODUCTION

Cooperative programs between university and industry (particularly in the area of power engineering) exist essentially to support research at graduate level. Very few of those programs seem to be related to the undergraduate curriculum.

Undergraduate research provides not only an economic means of exploring new ideas but also gives a new dimension to the engineering education process. With those ideas in mind, a sophisticated professional load flow program was introduced in the curriculum of a power system analysis course. The project was given to the students at the beginning of the semester in order to create motivation for learning the concepts necessary to develop the project.

The students used the Distribution System Analysis and Simulation (DSAS) program (1), IIM-PC version, developed by the Electric Power Research Institute (EPRI). The primary function of the DSAS program is to provide detailed simulation of a distribution feeder utilizing load energy models and three-phase circuit modeling. The DSAS program is capable of predicting energy changes as a function of voltage at the circuit level.

The project's goal was to investigate the possibility of energy conservation on a distribution system by a controlled reduction of the voltage levels along the feeders. Applying this approach to a specific case is not always simple. The benefit of using the DSAS program is the use of complex simulation to predict the quality of the system and promote ideas for energy savings. Many state regulatory agencies are either suggesting or requiring that utilities study or perform voltage reduction experiments to see if it is possible to conserve energy by this means. As this project investigates an actual problem confronted by engineers in the power industry it is expected that the experience will lead the students to a better understanding, not only of the basic concepts, but also of the complexity of real life problems. Since this kind of project, together with many others being developed in the Engineering Department, also satisfy the ABET design content in the courses, it is expected that this approach might help strengthen the department's effort regarding the accreditation process.

It is also expected that this approach will bring more excitement to the study of power engineering, as undergraduate students realize that they are discovering, opening-up, and unfolding an actual technological system, rather than just repeating old experiments.

THE PROJECT INITIATION

A meeting of the instructor and students with the manager and technicians of the utility provided the starting point of the project which led also to the development of a senior project done in cooperation effort between the Electric Utilities of Sioux Center and the Engineering Department.

The first step in this project was the collection of the necessary information for the computer simulation. Research and data collection was obtained by identifying the single, two, and three phase lines on a map and drawing a new map on a phase basis. AutoCAD (2) was used for drawing schematics of the feeder. Identification of conductors, transformers, lines and load characteristics helped to familiarize those involved with the system. MathCAD (3) was used to analyze and plot the daily load curves used for energy verification, required by the DSAS program. The students worked in close cooperation with the city officials on this step of the project.

Due to the complexity of the problem, a comprehensive study of the DSAS program was carried out, as the different topics in the power system analysis course were presented to the students.

The major difference between distribution and transmission systems lies in the unbalanced nature of the distribution feeders due to the predominance of single-phase loads. The DSAS is designed to simulate any distribution feeder with any load and time period, in a detailed manner.

Initial simulations were performed which were followed by computer monitoring and site measurements to check the consistency of the energy data and voltage levels. These simulations helped to verify the performance of the system under typical load conditions. A sensitivity analysis was performed in order to identify the buses reaching extremely low or high voltage levels during normal operation for summer and winter loads. No major problems with voltage regulation on the lower band were found.

A detailed analysis was performed to investigate the possibility of energy conservation by reducing the voltage supply, without compromising the recommended voltage levels. An extensive study was carried out to look at the variables which affect the system losses, such as load level (light or heavy load) and load composition (winter or summer) and how they vary with different voltage levels. The voltage unbalance was also investigated.

Project Requirements

The seven students taking Power System Analysis were encouraged to attend an extra class (once a week) in order to learn about the DSAS program and participate in the development of the project. Two students worked 6 hours each week in the college work-study program (one of the students decided to do his senior project on the subject of voltage reduction techniques). In addition to the DSAS, all students were required to write programs in Fortran (dealing with load flow and optimum dispatch) and to use educational software. AutoCAD drafting of the three-phase feeder diagram was also integral part of the course. In order to demonstrate that the project objectives were accomplished, a final formal report, with oral and written presentations was done by the two students in the work-study program / senior project.

The Electric System

Based on the capacity of the program (500 1-phase buses) and the time limitation, just the North East (NE) feeder (one of the feeders supplying Sioux Center electric power) was chosen. The NE feeder is a typical feeder for a small town. It has a large residential load and includes many commercial customers such as an office, downtown businesses, an iron removal plant for the city water system, and schools. The total length of the feeder is approximately 1.2 miles. An overview of the system simulated: 1 Substation, 263 Busses, 122 Branches, 120 Transformers/loads.

Conventional Tool and Models

The DSAS program calculates very accurately the energy consumption and losses of a system as well as the effects of reduced voltage on those parameters. In order to do this, the program uses three phase load flow algorithms. The program also reduces errors by including mutual coupling effects between line-to-line and line-to-ground parameters. Transformer core and load loss models are used. Finally, to accurately describe the wide variety of loads, different load composition were included. The program also uses different load energy models to describe different load components.

Computer Requirements, Data Collection, AutoCAD Drafting

The DSAS and AutoCAD drafting programs used in this project required a IBM AT—286, 20 megsabyte hard drive, 640K memory, and a math coprocessor.

Data collection was a major part of this project. Many different steps were involved in the data collection which was transferred later into the program.

AutoCAD was used to display, in an efficient manner, the information collected. The NE feeder was redrawn to show the flow of energy more clearly. Additional information was then added to the drawing. This information included the following: bus names and numbers, branch types, transformer sizes, 3-phase information, and load levels. A preliminary attempt to interact the DSAS program with the AutoCAD drafting was made. A program in AutoLISP was developed to read bus/line data from DSAS and automatically create a schematic depicting locations and information of the power study (see Figure 1).
Load Curve

Since load behavior is different for each season of the year and at different times of the day, it becomes important to determine the seasonal and hourly changes and compositions of the load. The program takes into account the following parameters:

- Light or heavy loads
- Summer, winter, or off-season loads
- 1-phase or 3-phase loads
- Commercial, residential, or industrial loads
- Average temperature during load periods
- Time period of load levels

An average work day load was calculated using monthly kW demands obtained from billing information. The time period selected was Oct. 19 - Nov. 18. From the kW demand information, an average load curve was calculated (see Figure 2). This curve was divided into a high and low demand average, and these values were used to simulate a typical day in November. Other demand levels were also simulated by changing the kW demand.

![Load Curve](image)

Figure 2. Load Demand Curve (kW) (week in October 88)

Load Models

To model the residential component of the load, an average residential load was calculated from fifty typical household demands. This value was then used for the kW demand of each household. Large demand cases were obtained directly from individual kW demands. Different load compositions were investigated. Table 1 shows the load composition type 10 (winter) for the single-phase residential loads.

Lines/Cables and Transformers

To account for the mutual impedance between lines, an accurate model of line parameters was used. The program has a library of conductor parameters for different types and configurations. Sioux Center uses only underground cables. Models built-in into the program, which take into account copper, core, and load losses, were used.

Table 1

<table>
<thead>
<tr>
<th>Single-Phase Load Composition (%)</th>
<th>Type 10 (Winter) Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Water Heater</td>
<td>4.7</td>
</tr>
<tr>
<td>2 Clothes Washing Machine</td>
<td>0.9</td>
</tr>
<tr>
<td>3 Clothes Dryer Machine</td>
<td>2.8</td>
</tr>
<tr>
<td>4 Range</td>
<td>11.2</td>
</tr>
<tr>
<td>5 Microwave Oven</td>
<td>0.9</td>
</tr>
<tr>
<td>6 Television</td>
<td>3.7</td>
</tr>
<tr>
<td>7 Incandescent Lamp</td>
<td>15.0</td>
</tr>
<tr>
<td>8 Sodium Lamp</td>
<td>1.9</td>
</tr>
<tr>
<td>9 Mercury Lamp</td>
<td>1.9</td>
</tr>
<tr>
<td>10 Fluorescent Lamp</td>
<td>0.0</td>
</tr>
<tr>
<td>11 Refrigerator</td>
<td>14.0</td>
</tr>
<tr>
<td>12 Freezer</td>
<td>2.8</td>
</tr>
<tr>
<td>13 Single-Phase Central Air Conditioner</td>
<td>0.0</td>
</tr>
<tr>
<td>14 Window Type Air Conditioner (120)</td>
<td>0.0</td>
</tr>
<tr>
<td>15 Window Type Air Conditioner (240)</td>
<td>0.0</td>
</tr>
<tr>
<td>16 Single-Phase Heat Pump</td>
<td>24.4</td>
</tr>
<tr>
<td>17 Single-Phase Motor (variable torque)</td>
<td>6.5</td>
</tr>
<tr>
<td>18 Single-Phase Motor (constant torque)</td>
<td>0.0</td>
</tr>
<tr>
<td>19 Resistance Heating</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Total 100.0

Voltage Regulation and Load Efficiency

Normal tolerances for voltage regulation are ±.95 V - 1.05 V (p.u.). Recent studies have shown an increase in energy conservation when the system operates at the lower 5% of the acceptable voltage band. Lower voltages do not result in lower quality of service provided they do not drop out of the tolerance band. In fact, many devices run better in the lower 5% voltage band.

By operating at the lower 5% of the voltage band, some type of voltage regulation might be necessary. This would be true especially for long lines, but in the case of short feeders this may not be necessary. Maintaining a restricted voltage level is not difficult for a short feeder of lengths less than a two miles.

The following effects of reduced voltage have been reported (4):

- Most motors run more efficiently at lower voltages when operating at less than full load; refrigerators, freezers, and washing machines run more efficiently at lower voltages; air conditioners and heat pumps are not affected significantly by voltage reduction; energy conservation is greater in small 1-phase motors than large 3-phase motors when operating at reduced voltages; fluorescent lights, inductance lamps, and television conserve energy at lower voltages. These facts are particularly relevant when in our case 2/3 of the electric load is motor oriented.

SIMULATIONS AND RESULTS

The following is a summary of the findings of the students described in detail on the final report (4).

Voltage Profile

The NE feeder was simulated for several different operational conditions. The resulting data was entered into a spread sheet type file using MathCAD. The influence of other variables such as summer or winter loads, different load types, and different temperatures were also investigated.
For different voltage levels the load was varied from 300-2600 kW to correspond to light and heavy load extremes. The lowest voltage of the feeder was on a heavily loaded transformer at the iron removal plant. Comparison of the results revealed that the voltage drop for a summer load is slightly greater than for a winter load. This was due to the predominance of inductive loads during the summer time.

Actual voltage measurements made at average and heavy load agreed with the voltage levels predicted by the simulations.

Energy Conservation

Plots of the different types of losses (line, core, and copper) show that the greatest factor in energy losses is the core losses. Line losses surpassed core losses only for extremely low voltages, remaining about constant for the normal range of operational voltages. Figure 3 shows the losses in MWh versus voltage (in p.u.). The load and voltage dependence of the core losses (in MWh) is illustrated in Figure 4.

The biggest savings in reducing the voltage is a reduction in core losses. Core losses are almost independent of the load and depend mainly on voltage levels. Figure 5 shows that a 5% reduction (either from 1.05 to 1.00 or 1.00 to .95) in the voltage will produce about a 9% reduction in energy losses for a light load whereas an average high load of 1500 kW leads to a 6% reduction in losses.

Total losses were shown to decrease as voltage reduced, particularly for lighter loads (Figure 6). At heavy loads this trend continues until motors, which are drawing more current at lower voltages, increase in line and copper losses and overcome the savings in core losses. Figure 7 shows the total energy losses reduction (%) versus voltage (p.u.) for different load levels.

Translating Energy into Cost

It has been verified that a 5% voltage reduction from the actual present operating levels will not lower the voltage below .95 V. (p.u.) anywhere on the feeder for any load level. Savings of about a 7% reduction in energy losses would occur on average. Translating this into cost for the Sioux Center case this would result in savings of over $5,000 per year.

The potential is clear for energy savings, on a small utility environment, by operating the feeder voltage in the lower 5% of the acceptable voltage band. For feeders that experience little voltage drop, as the Sioux Center system, voltage reduction is definitely a viable option. Further more, time of day is also an important factor. During light load periods, the feeder voltage should definitely be reduced. This is particularly true on a system with underground cables.
LESSONS LEARNED

Despite the intensity of the course, the complexity of the software, and the amount of detail working the project, students were able to absorb the material and, in a short period of time, to contribute to insightful observations about the nature of the problem being investigated.

It should be noted that the success of this experiment could be attributed in part to the small size of class (7 students).

Nevertheless, the students took the challenge and with enthusiasm and dedication were able to participate actively in the learning process - unfolding, opening-up ideas as they learned the rudiments of power engineering.

Expanding the Project/Program

Based on this experience it is expected that future projects for a power system analysis course will be developed by expanding the use of the EWSR and other sophisticated computer programs available in the engineering department.

The results of this project were well received by the Utility people. The success of this project has encouraged the Engineering Department at Dordt College and the Sioux Center Utility to proceed with this cooperative program.

CONCLUSIONS

From the results obtained in this undergraduate teaching/research experiment the potential is clear for energy savings by operating the feeders of the electric system of the city of Sioux Center in the lower 5% of the acceptable voltage band. Even on a small utility the savings could be significant to justify the implementation of such procedures. It must be noted however, that operating at a reduced band may require additional capital expenditure, especially if the feeder length is rather long. These expenditures would have to be offset by the resulting benefits in order to justify installation of additional equipment.

This project has investigated an actual problem confronted by engineers in the power industry. The experience has led the students to a better understanding, not only of the basic concepts, but also of the complexity of real life problems regarding power engineering.

It is expected that this kind of project, that has integrated a senior project, the work-study program, a power utility problem, and a research effort as part of a undergraduate power system analysis course, may demonstrate both the possibility of the development of meaningful undergraduate research projects, and a model relationship between colleges and communities, regarding power engineering education.

Finally, a bit of statistics: 43% of the students (who were undecided about the area of specialization before the course) decided to pursue power engineering as a carrier. The instructor hopes that these students may have been encouraged by the approach used for this course.

ACKNOWLEDGMENTS

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REFERENCES


BIOGRAPHY

Paulo F Ribeiro was born in Recife, Brazil, on November 14, 1952. He received the B.S. in Electrical Engineering from the Universidade Federal de Pernambuco, Recife, Brazil, in 1975. In 1979 he completed the Power Systems Engineering Course with the Power Technologies (PIT), Schenectady, New York. He received his PhD from the University of Manchester Institute of Science and Technology (UMIST), Manchester, England, in 1985.

From 1976 to 1987 he was with the Companhia Hidro Eletrica do Sao Francisco (CHESF), Brazil, working with the transmission system planning studies department. He chaired the Brazilian CIGRE WG 36.09 from 1985 to 1987. In December 1987 he joined the Faculty of the Engineering Department at Dordt College, Sioux Center, Iowa, where he is an Assistant Professor. Dr. Ribeiro is a member of the IEEE, and CIGRE, and Senior member of the IEEE. He is a registered Professional Engineer in the State of Iowa.