

AC 2009-80: A SOFTWARE VISUALIZATION TOOL FOR POWER SYSTEMS ANALYSIS

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A Software Visualization Tool for Power Systems Analysis

1.0 Introduction

This article presents a novel software visualization tool for presenting some power system analysis problems, namely load flow, economic dispatch, and unit commitment in introductory undergraduate electrical engineering courses. The software package uses effective visual simulation tools to enable students to obtain a concrete understanding of the analysis problems and solution algorithms. This project comes as a response to the urgent need for newer, more efficient educational tools to reform the outlook of power engineering education. The visualization tool aids students in quickly obtaining a detailed understanding of the power system analysis problems when used as a supplement to traditional lecture approaches. Therefore it allows for introduction of other demanding topics within the limited time of an undergraduate curriculum. In addition, the software visualization tool enables students to spend more time on power system analysis topics outside the classroom, which have been shown to result in effective learning and development of reflective thinking skills.

An earlier version of the visualization tool presented in this paper was developed using the user interface toolbox (GUIDE) in MATLAB®,^{1,2} but this new version is designed and developed using C# to overcome the graphical interface limitations present in the MATLAB® environment. Unlike the previous version which required the MATLAB® environment to run, the new version is completely portable and does not require special software other than an operating system, such as Windows or UNIX. While MATLAB® may be readily available in many of the engineering departments some students cannot afford to install it on their personal computers. By eliminating this issue, the new visualization tool enables students to spend extra time on the treated topics out of the classroom and school premises. In addition, the new version provides more functions that allow students to enhance their understanding of the power system analysis concepts. It also represents a refined design process that makes the visualization tool modular and expandable to other power system concepts.

2.0 The state of power engineering education

Electric power engineering education has been a focus of debate and extensive discussion in the educational and political arenas over the last decade. An IEEE Power Engineering Society (PES) report³ noted that in the U.S. power engineering programs' enrollment was low but stable as of 2003. The report also points out that the major long term concern for the US universities is the difficulty in maintaining faculty members and student interest as new technologies emerge and draw attention away from electric power engineering. In response to these reports experts and technical societies such as CIGRE⁴ and IEEE⁵ have voiced concerns about the state of power engineering programs. Recognizing the need for drastic and radical modifications very early on, the National Science Foundation initiated in 1997, a new solicitation for research projects aimed at investigating new approaches to teaching power engineering courses⁶. A number of educators and authors have embraced that initiative, analyzed the situation extensively,^{7,8,9} expressed their concerns, and proposed solutions.

Major changes in the power industry related to restructuring, deregulation of the utility sector and the much-anticipated retirement rate has resulted in new work environment outlook. The new environment places the burden on educational institutions to produce a new breed of power engineers with deeper understanding of the principles of design, analysis and modeling of power systems, as well as knowledge of economics and communication skills. The challenge to meet these needs in the ever-changing work environment and industry demands that curricula be diversified. This calls for newer and more efficient educational tools with a novel philosophy that helps to expose students to various technical, modeling and analysis problems within a limited period of time. The power system analysis concept visualization tool stems from the same urgent need for radical modification to the power engineering curriculum and its educational tools.

3.0 General description of the tool and development process

The power system analysis concept visualization tool is developed to facilitate teaching three major power system analysis problems in introductory power engineering courses: load flow, economic dispatch, and unit commitment. The visualization tool focuses on the use of effective visualization graphical user interface methods that provide students with concrete understanding of some power system analysis problems and the algorithmic approaches to solve them. Therefore this visualization tool is designed to include educational features that many other software packages such as PowerWorld¹⁰ lack. This includes visual interactive descriptions of the algorithm used to solve the problem and emphasis on important parameters that affect the solution of the problem. It is developed using C#; hence, it can easily be used in any personal computer with a Windows or UNIX operating system. This eliminates the cost associated with acquiring the learning tool when compared with other packages. Furthermore, it can be distributed to students for their personal use on university facilities or at home. This is expected to increase student involvement in the learning process and promote effective time spent in studying power system analysis topics. Studies show that the time a student works effectively on a certain topic increases the efficiency of learning.¹¹

The software visualization tool is developed to resolve the difficulties of understanding the concepts and mastering the analytical skills needed in power system engineering introductory courses due to the absence of effective visual learning tools. Therefore, it exhibits refined, user-friendly toolboxes and menus that require very minimal time to understand and master. In addition, the philosophy of development has incorporated all of the five components necessary in the learning processes: comprehending information, organizing ideas, analyzing and synthesizing data, applying knowledge, and evaluating ideas and algorithms.¹¹

The development and design of the power system analysis concepts visualization have benefited greatly from the object-oriented programming (OOP) features of C#. The visualization tool is designed to be modular and expandable. That is, models of components and functions are structured according to a clear hierarchy, which is a key feature of OOP.¹² The power system is projected in the programming and design process, primarily as a collection of interconnected generators, transmission lines, buses, and loads. A class describes each of the components, and classes benefiting from inheritance features of OOP also describe the relations between these components. Moreover, member functions have been developed to depict other relational

quantities such as transmission line currents and power flow. This hierarchical structure reflects the physical interconnection of the power system and will help in terms of future expansion of the tool to other power system analysis problems such as state estimation.¹³

The development process has focused on reflecting high transparency. That is, the graphical representation of components closely matches their models. In addition, flowchart and other graphical descriptions are designed to be illustrative and meaningful. Warning and error messages are displayed whenever user entries are not valid. Moreover, some of the invalid user entries and erroneous initialization is handled gracefully by correcting to default acceptable values, displaying warning messages but without interrupting the application. Programming tricks and shortcuts have also been avoided, even at the expense of computational efficiency for future expansion and debugging processes.

4.0 The load flow application

For the study of load flow the visualization tool stresses the following concepts:

- Basic bus types and models, such as slack, voltage controlled (PV), and load (PQ) buses.
- The network admittance matrix.
- The iterative numerical analysis approach to the problem represented by the Newton-Raphson method.
- Algorithm concerns of convergence, multiple solutions, initialization, and computational efficiency.⁵

For the load flow problem the visualization tool base case consists of three buses, three transmission lines and two generators.¹⁴ The default three-bus system is the typical starting point for discussing the load flow problem in introductory power system analysis textbooks. The default system of the power flow problem visualization tool is shown in Fig. 1. The case can be expanded to include up to five buses, seven transmission lines and three generators through the settings menu of the visualization tool shown in Fig. 2. The expanded system of power flow problem is shown in Fig. 3. The application includes menus that enable the user to modify system configuration and parameters to obtain in-depth understanding of the effect on solution. Menus are available to modify line impedance, load levels, and voltage levels at generator buses.

The visualization tool includes two different views, a grid representation and a flowchart view. The first view displays a one-line diagram of the power system (Fig. 1) that represents the traditional view of the system as interconnection of components, such as buses, generators, and transmission lines. This view is common in most commercial software packages available. However the visualization tool, unlike other packages, enables the user to obtain a solution of the case iteratively, offering the user a step-by-step insight into the nature of the load flow problem, the various parameters that affect the solution and its convergence process. The second view displays analysis of the case in a flowchart fashion (Fig. 4). The dynamic flowchart view is not found in any of the available software packages. It is a unique approach that describes the characteristics of the load flow problem, the iterative numerical analysis nature of the algorithm used to solve it, the equations being solved at each step and the parameters being calculated at each stage. The dynamic flowchart view does not only explain the nature of the problem but also introduces students to concepts such as initialization, convergence and computational efficiency.

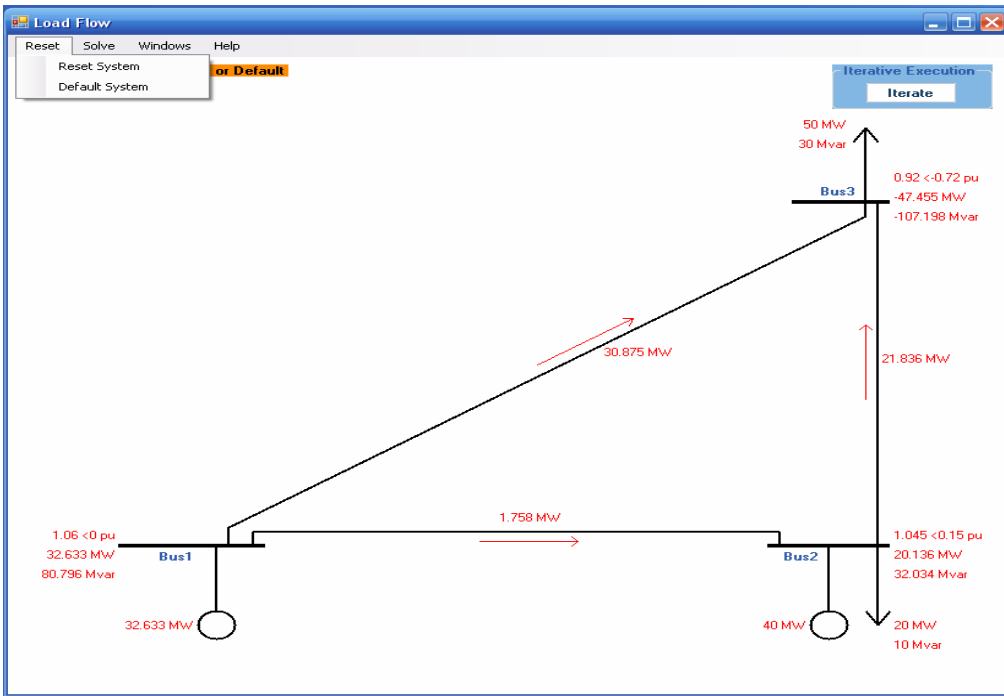


Fig. 1. The grid view of the solution of the default case of load flow application



Fig. 2. The settings window of the load flow application

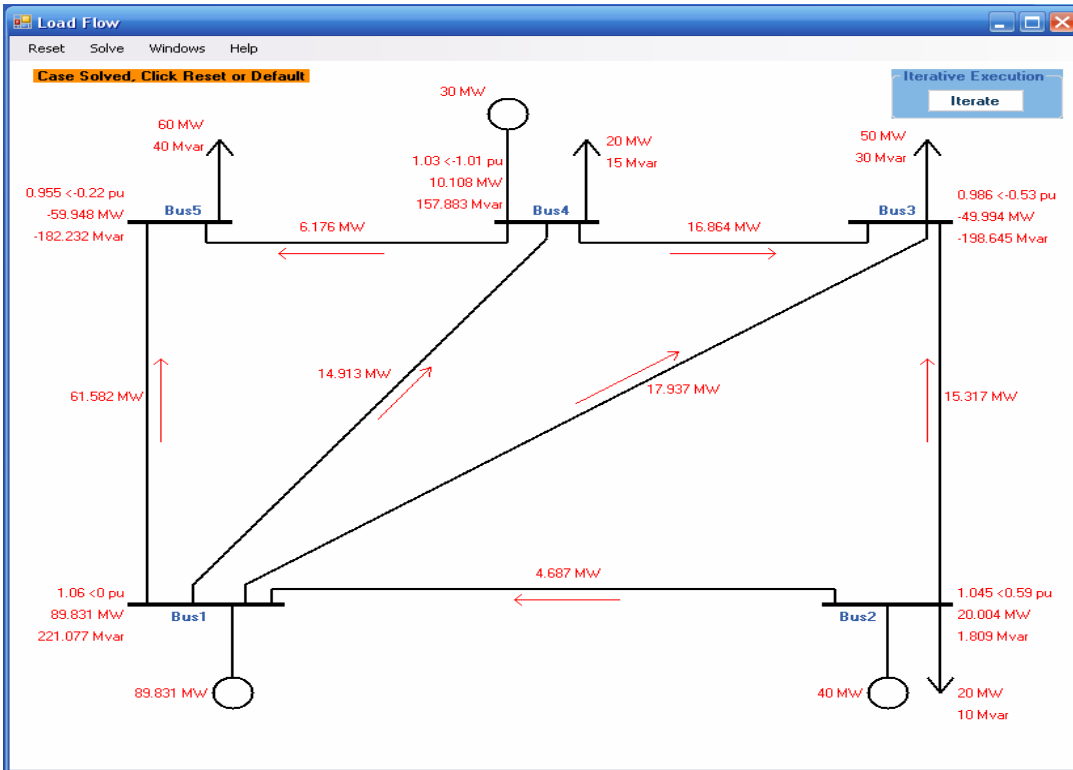


Fig. 3. The grid view of a 5-bus, 7-line system

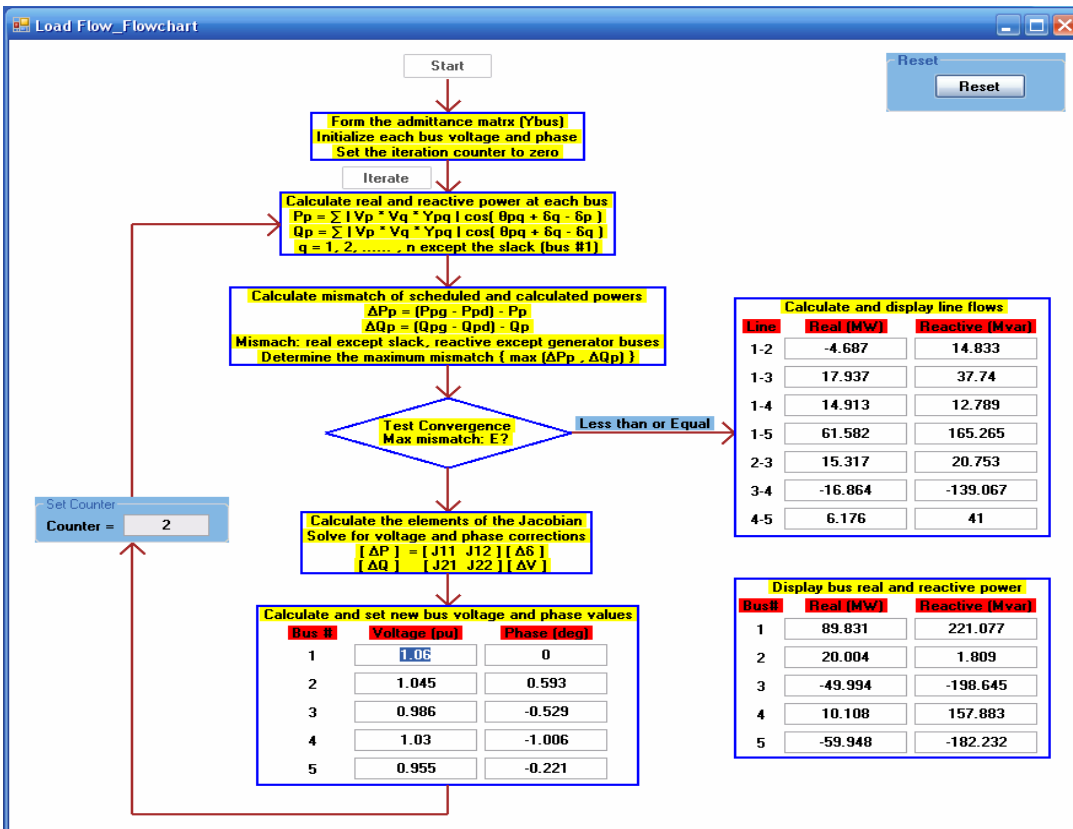


Fig. 4. The flowchart view of the load flow visualization tool

5.0 The economic dispatch application

The economic dispatch visualization tool aims to emphasize the following concepts:

- The cost function parameters of a generator and their effect on the solution of the ED problem.
- The system incremental cost and its role in the solution of ED problem.
- The nature of the classical method of Lagrange multipliers.
- Computational concerns of convergence, limitation, initialization, and efficiency.

For the economic dispatch problem, the visualization tool includes two views similar to the load flow problem. This application uses the same system as in the load flow application described in the previous subsection. Consequently it offers the same menu options as the load flow application. The grid view of the problem is shown in Fig. 5. More parameters are displayed due to the different nature of the problem. For example, the cost of each generating unit in dollars per hour is displayed. Moreover, the application offers more adjustable parameters in addition to the options offered in the load flow problem as shown in the settings window displayed in Fig. 6. For example, the application menus enable the user to adjust the parameters of the generators' cost functions, which are very important factors to the solution of the economic dispatch problem.

The flowchart view of the economic dispatch visualization tool offers an iterative step-by-step solution of the problem with a detailed description of the algorithm used to solve it. As with the load flow problem, this view of the economic dispatch problems enables the user to obtain a concrete understanding of the numerical analysis iterative nature of the algorithm and introduces the concepts of initialization, convergence, and multiple solutions. The flowchart view of the economic dispatch problem is shown in Fig. 7.

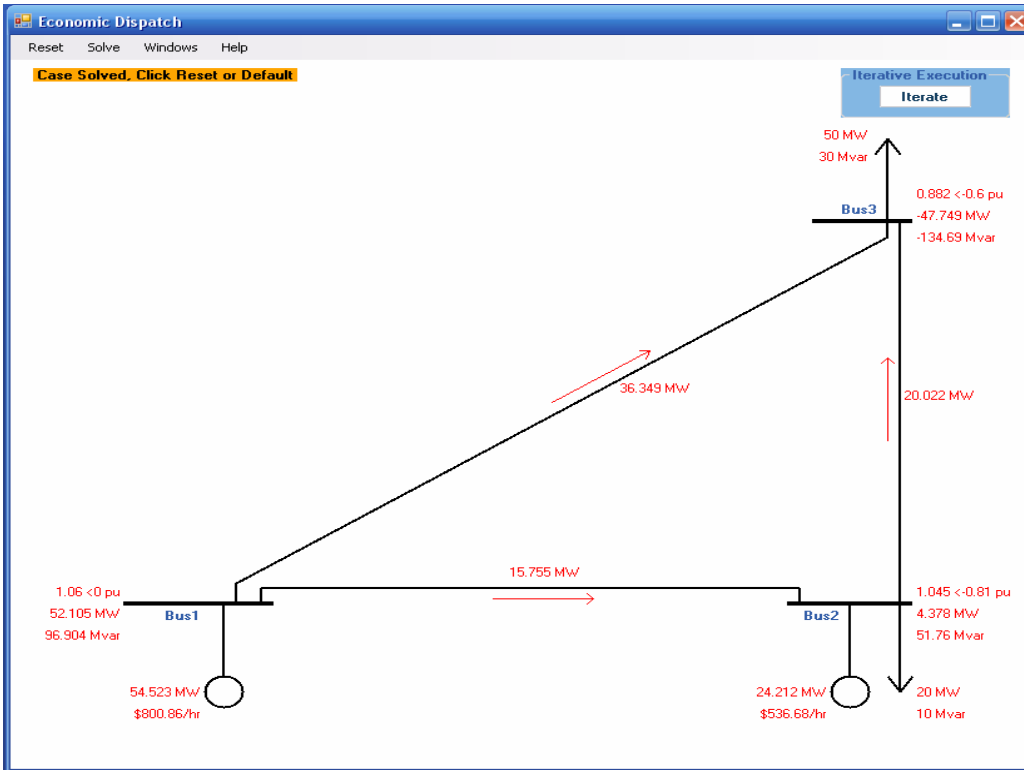


Fig. 5. The grid view of the economic dispatch tool



Fig. 6. The settings window of the economic dispatch visualization tool

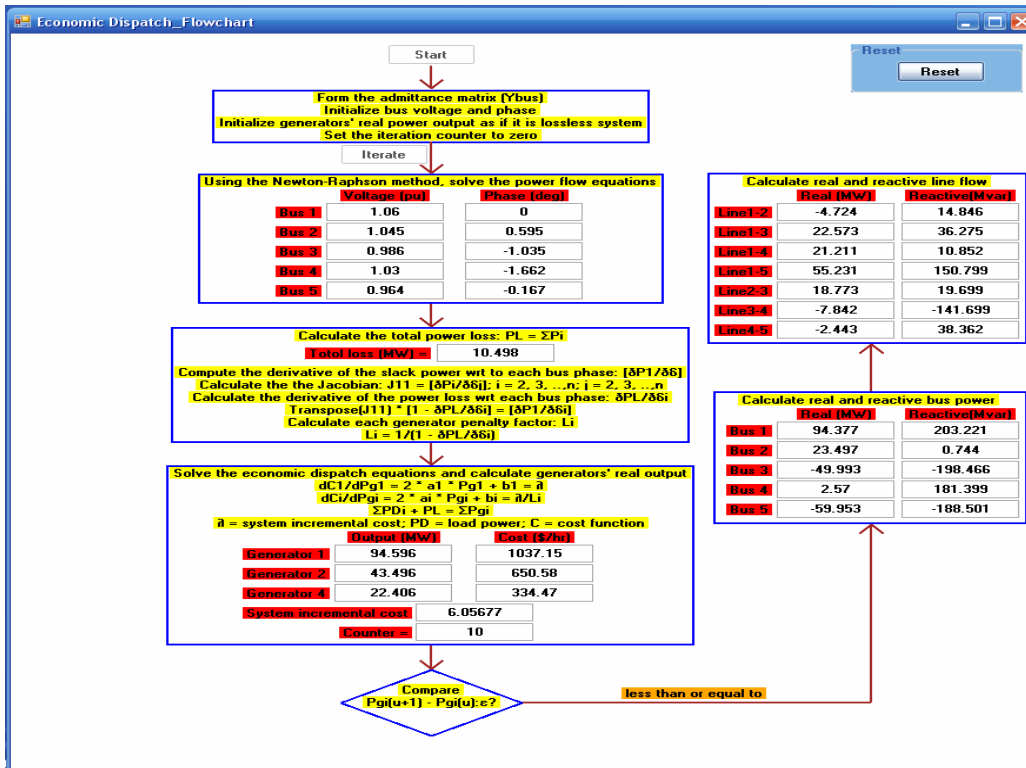


Fig. 7. The flowchart view of the economic dispatch visualization tool

6.0 The unit commitment application

The unit commitment visualization tool aims to emphasize the dynamic programming method used to solve the problem. Therefore, for simplicity, it only treats a lossless power system and ignores some of practical limitations on real generating units. It highlights the following concepts:

- The maximum and minimum capacity limits in generating units output.
- The daily load profile concept.
- The role of generators' cost function parameters on the solution of the unit commitment problem.
- Algorithmic approach via the dynamic programming methods.

The visualization tool considers a lossless case in which there are four generating units with different limitations and cost functions.¹⁵ This case is solved for a load profile that is divided into six stages, four hours each. The case used in the visualization tool incorporates some practical constraints. For example, the first and second generators on this case are must-run generators; that is, they cannot be turned off. Further, these two generators are the only ones that can run at the first and final stages of the daily load profile. The case also imposes \$3000 start-up cost and \$1500 turn-off cost on any of the four generators.

Since a grid view is not descriptive of the nature of the unit commitment problem, the visualization tool only includes a flowchart or cell array view of the unit commitment problem. The visualization tool employs a flowchart view that describes the unit commitment problem and

illustrates the dynamic programming algorithm in a step-by-step fashion. The flowchart shown in Fig. 8 is an array of nodes or cells; each column of this array represents one of the six stages of the daily load profile. Further, each group of four rows of the array represents one of the four generating units' groups available for commitment. The scheme illustrates the essence of the optimality principle and dynamic programming approach. Therefore, it consists of two sweeps: the first one provides backward evaluation of each of the six stages of the daily load profile and the second one is forward sweep that tracks the trajectory of the generating units' sequence that results in the minimum accumulative cost. Several menus and toolboxes are available to adjust system parameters, such as generator cost function constants, load levels, and generation capacity.

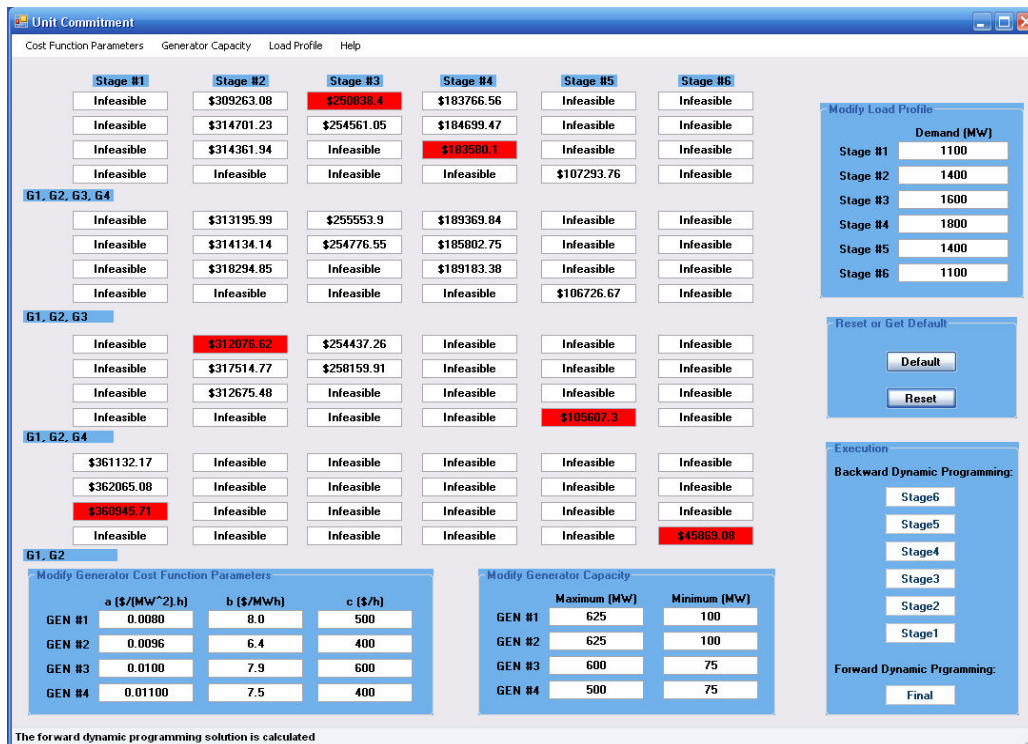


Fig. 8. The main window of the unit commitment visualization tool

7.0 The evaluation process

A research study was developed under the guidelines of the Office of Research Protection at the University to evaluate the power system analysis concepts visualization tool developed in this project. In the evaluation process, a pilot version of the visualization was distributed to a group of six students and young engineers. The group was provided with three practice assignments, one for each of the three problems treated by the visualization tool. The practice assignments were designed to introduce users to the features and toolboxes available in the visualization tool. Further, the practice assignments were developed to examine the user understanding of the problems and assess the progress made after using the visualization tool. In addition, three questionnaires were provided to the evaluation group to obtain qualitative measure of the

effectiveness of the visualization tool. The composite result of responses aggregated over the total of 18 respondents is summarized on Table 1.

Table 1. The aggregated results of the evaluation process

1. Rate your prior familiarity with the power flow, economic dispatch, and unit commitment problems							
Not familiar 0	1	2	3	4	Very familiar 5	Average	Percentage
0	9	0	6	1	2	2.27	45.56%
2. The visualization tool was very helpful in understanding the load flow, economic dispatch, and unit commitment problem							
Strongly Disagree 0	1	2	3	4	Strongly Agree 5	Average	Percentage
0	0	0	6	9	3	3.83	76.67%
3. The visualization tool for load flow, economic dispatch, and unit commitment is intuitive and easy to use							
Strongly Disagree 0	1	2	3	4	Strongly Agree 5	Average	Percentage
0	0	0	3	12	3	4.00	80.00%
4. After using the visualization tool, I now have a fairly good understanding of the load flow, economic dispatch, and unit commitment problems							
Strongly Disagree 0	1	2	3	4	Strongly Agree 5	Average	Percentage
0	0	0	3	12	3	4.00	80.00%
5. Given the opportunity, I will like to further explore power systems analysis topics							
Strongly Disagree 0	1	2	3	4	Strongly Agree 5	Average	Percentage
0	0	0	0	9	9	4.50	90.00%

The evaluation summary shows that the tool was generally well received and judged helpful by this group of users. As many as 90% of the participants expressed further interest in exploring power system analysis topics following the limited exposure to the visualization tool. Plans are in place for more extensive evaluation of the impact of the tool on learning over several semesters when the power systems course is offered.

8.0 Conclusions and future work

A software visualization tool has been developed to help in teaching core power systems analysis problems in introductory undergraduate courses. The power system analysis concepts visualization tool consists of simulation applications that focus on three problems: load flow, economic dispatch, and unit commitment. It incorporates user-friendly, effective graphical interfaces that aid students to acquire deeper understanding of the power system problems and help them to develop the analytical skills needed in the industry. Further, the visualization tool enables students to visualize the effects of changes in the power system configuration and to observe the flow of information through the immediate steps.

The visualization tool was designed using C# offering the benefit of platform independence and therefore can run on computers with a basic operating system such as Window, UNIX or Linux. The learning tool is designed to be modular and expandable by employing various object oriented programming features of C#. Future work will include expanding the visualization tool to other power system analysis problems such as state estimation, symmetrical components and fault analysis. This can easily be achieved since special classes and algorithm have been created to model the components of the power system and member methods were created to represent the relational quantities of these components.

The visualization tool is available free of charge for educational use.¹⁶

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