A Novel Approach for Implementing Power System Analysis and Simulation Tools*

K. K. CHU and H. W. NGAN
*Dept. of Electrical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.
E-mail: eehwngan@polyu.edu.hk*

A typical way of learning power system operation is by modeling the system and simulating its performance. Convention requires development of mathematical algorithm and user interfaces on dedicated hardware and software platforms. It has the drawback of a heavy overhead of development and learning time. In this paper, a novel approach is presented to provide a heterogeneous development platform for designing the power system analysis and simulation tools. Highlights of other market-available platforms like MATLAB, EMTP, EMTDC, PFLOW, PowerGraf, POWERWORLD and Ptolemy are summarized. Case studies are carried out to illustrate the approach and its success in integrating various essential components.

AUTHOR'S QUESTIONNAIRE

1. The paper describes software/hardware/simulation tools suitable for students of signal processing and electrical power system analysis and simulation.
2. Level of students involved in the use of the materials: final year of undergraduate program or postgraduate program.
3. The aspects of this contribution which are new are: heterogeneous computing and feasibility of incorporation with multimedia technology
4. The material presented can be incorporated in engineering teaching laboratories by installing the Ptolemy software (Unix based) by downloading from the web site: http://ptolemy.eecs.berkeley.edu/
5. It comes with detailed installation guide and user manual.
6. A hands-on workshop was conducted for a class of 20 students. They were able to master the basic technique of operation and get it moving straight away.
7. Ptolemy is really interesting and worth for a trial. In order to get better benefits from the software, students have to understand UNIX, OOP and JAVA for the latest version.

INTRODUCTION

AS OPERATION of power systems becomes increasingly complex, there is a need to make available improved tools for training. Traditionally, the training facilities require setups for both hardware and software which often prove quite costly in terms of development effort mainly due to integration of resources from different platforms. Over the years, computer simulation in power systems has widely been adopted as a means to understand and control the power system operation. It now requires that the computer-based power system educational tools should have provision for enabling users of different backgrounds to handle their application-specific problems readily. Development efforts are expected to be one of the main concern of the tools designer.

In this paper, a novel approach for developing the power system analysis and simulation tools is presented. It aims to integrate a variety of hardware and software components through a heterogeneous development platform known as Ptolemy. The advocated environment has all the attributes to make it a promising development platform for both educational and research purposes. The tools were used in a research project [15] to develop contingency control strategies for modern power systems. Proven experience shows that they are effective in providing a mix of visual/textual design syntax, which can broaden the perspective beyond a schematic or block-diagram approach in the course of understanding power system analysis and simulation.

OVERVIEW OF DEVELOPMENT TOOLS

There are a number of platforms available in the market in which power system analysis and simulation tools can be developed. Each of these platforms, like MATLAB, EMTP or PSCAD/EMTDC, PowerGraf, POWERWORLD, PFLOW and Ptolemy, has its own advantages and

disadvantages. A review of their features can provide an overall picture of the development environment.

MATLAB with power system toolbox and voltage stability toolbox

MATLAB is a computing environment which provides numerical analysis, matrix computations and graphical interface for users. Also, there are various toolboxes providing application-specific solutions on areas such as signal processing, control system design, neural networks, power systems, etc. For instance, the power system toolbox (PST) developed by Joe Chow of Rensselaer Polytechnic Inst. in 1992 [1, 3] allows users to perform power system analysis within MATLAB. The voltage stability toolbox (VST) developed at the Center for Electric Power Engineering, Drexel University [2] can further show the symbolic and graphical representation capabilities of MATLAB through the proven bifurcation theory. It can be used to perform voltage stability analysis and provide intuitive information for understanding power system planning, operation, and control.

Advantage:
- Provides a power computation engine in terms of different analytical analysis.

Disadvantages:
- Non-flexible simulation environment.
- Difficult to integrate with foreign package such as C or C++ library for enhancing its basic functions.

EMTP, PSCAD/EMTDC

EMTP is a popular electromagnetic transient program [4] providing a comprehensive and general working environment for performing both dynamic and transient simulation of power systems. It is a public domain program accessible by users over a decade. FORTRAN-77 is the popular language for EMTP. Due to its closed architecture, it requires a large number of code lines to meet the task requirement ranging from low level data manipulation to visualization of the mathematical solution. A PC version of the EMTP known as ATP (Alternative Transient Program) [6] is being used in many universities and by authorized organizations in many countries over the world.

PSCAD/EMTDC [5] is another popular tool in this category which was developed at the Manitoba HVDC Research Centre. In this program, a comprehensive palette of components is available for constructing application circuits by dragging and dropping appropriate model blocks on the drawing canvas and connecting them afterwards by drag and stretch wires.

Advantages:
- Good for modeling and studying transient behavior of electrical elements like the small-signal simulation program SPICE.

- It is a commercial grade of product for performing the power system analysis.
- Good classroom demonstration tool for undergraduate courses.
- Its simulation data files are portable.

Disadvantage:
- It is more complex and difficult for simulating large-scale systems.

PowerGraf

PowerGraf is a convenient graphical user interface (GUI) tool for building one-line diagrams and displaying data [7, 8] (http://www.umr.edu/ yang/ PowerGraf/PowerGraf.html). The GUI is open and friendly for performing power system design, analysis and control. PowerGraf is developed under the multimedia ToolBook environment and its main features include:

1. Line diagram of power system can be drawn very easily.
2. Multimedia applications can be added to this interface very conveniently.
3. Power flow and other power applications developed can be added to this interface easily.

Advantage:
- A convenient tool for configuring and visualizing power system parameters.

Disadvantages:
- Difficult for extension to include modern power system devices.
- Difficult to integrate with other packages such as MATLAB.

POWERWORLD

POWERWORLD is a user-friendly and powerful simulation package for learning power system operation and control [9]. The self-intuitive educational tools are written by DEPHI (Object Pascal) and have the best GUI for non-technical users.

Advantages:
- Easy and flexible for users to interact with all objects on the screen.
- It comes with small source and executable files, extendable and reusable codes, and user-friendly GUI.
- Allows dynamic interaction with the animated power flow.

Disadvantages:
- No extension to include innovative power system devices.
- No interface with other systems or libraries.

PFLOW

PFLOW is a powerful research tool designed to calculate local bifurcation characterized by singularity of the power system Jacobian PFLOW. The program is developed based on

continuation power flow method. It generates a series of output files suitable for further analysis, such as to determine initial tangent vectors, left and right eigenvectors at the bifurcation point, power flow solutions at different loading level, etc. PFLOW comes with accessible open source written in C language and is available free throughout the world.

Advantage:
- Comes with various readily available utilities for performing power system analysis.

Disadvantage:
- Lack of GUI interface.

Ptolemy

Ptolemy (also known as Ptolemy Classic) is a heterogeneous simulation and design environment supporting multiple models of computation. It is written in C++, and has a graphical user interface for constructing models visually as block diagrams. It supports dataflow, discrete-event, process networks, synchronous/reactive, and finite-state machine models of computation. It supports implementations in C and assembly code for at least two programmable DSPs from certain dataflow system descriptions.

Advantages:

The Ptolemy software environment has been used for a wide range of applications including signal processing, telecommunications, parallel processing, wireless communications, network design, investment management, modeling of optical communication systems, real-time systems, and hardware/software co-design. Ptolemy software has also been used as a laboratory for signal processing and communication courses. Currently, Ptolemy software has hundreds of active users at various sites worldwide in industry, academia, and government. Although Ptolemy is new for

applications on power system analysis, publications by Javier Contreras [11–13] show that it is suitable for his study on power transmission planning.

Summary

From the above review, it shows that different package have different pros and cons. The attributes of a suitable development platform should include the following:

- open architecture;
- small development overhead;
- support multiprocessing or distributed computing applications;
- portability;
- modular computational approach;
- heterogeneous computing environment.

In this regard, Ptolemy is considered as an all round suitable environment having the attributes required for developing the envisaged power system analysis and simulation tools.

IMPLEMENTATION OF POWER SYSTEM ANALYSIS TOOLS USING BLOCK DIAGRAM LANGUAGES

In the process of developing the power system analysis tools, coding for the system simulation is one of the major hurdle to be overcome. Apart from taking care of the complicated model equations, conventional approach of using structural computer languages such as FORTRAN, C and C++ takes considerable time to organize even a simple configuration which includes generation of codes and debugging the coded algorithm. As an improvement measure, the approach of using predefined block diagram language is proposed for implementing the tools. In fact, MATLAB and its associated power system tool box and
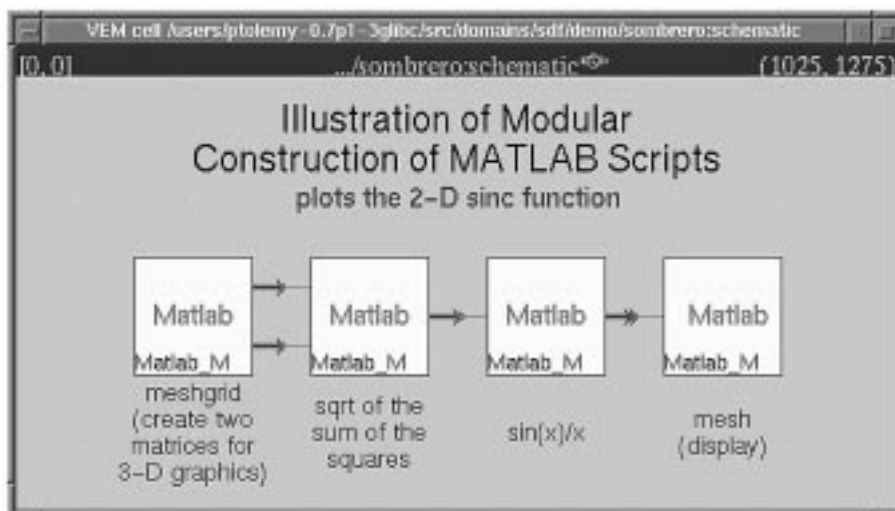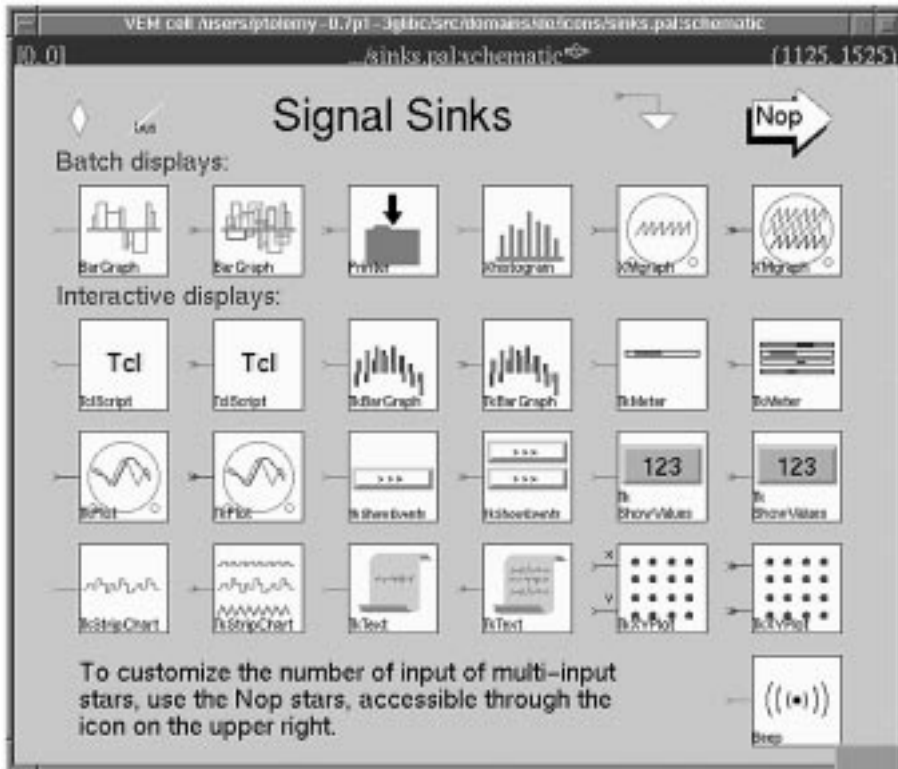

Fig.1. Connection blocks.

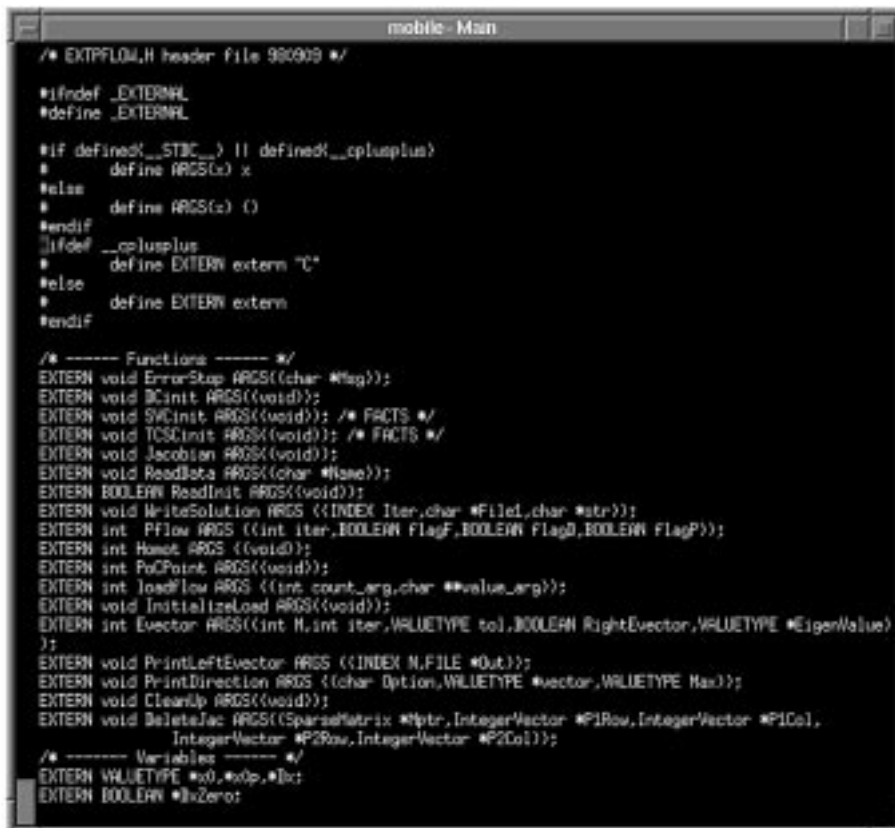Fig. 2. Library blocks for 'signal sinks'.

Fig. 3. Sample of the header file.

Fig. 4. A 'makefile' file for rebuilding.

MatEMTP [14] are examples of using the block diagram languages whilst programming of the graphical user interface is based on the MATLAB-SIMULINK toolbox. Hence, new component icons or subcircuits can be created through the block masking.

Based on this approach, Ptolemy programming can be viewed as a process of linking up certain blocks with the help of the standard graphical user interface. Each building block is formed as a module of codes giving specific relationship between its input and output data. The application

Fig. 5. Sample of star declaration.

Fig. 6. Interactive data selector.

entity is invoked at run-time and has to run to completion once triggered. Essentially, a number of small and manageable blocks have to be developed and test-run independently. In the Ptolemy environment, it has provision for developers to keep proper documentation for the blocks and have them stored in standard libraries by providing a preprocessor that produces not only C++ code for the block but also a manual entry describing its use. Thus, the blocks can be regarded as some sort of modular and reusable software components.

The modular (block) design approach permits the user to interface with any customized analysis package, such as PFLOW, regardless of the computer language used. A sample of the block connection and the library blocks for 'signal sinks' are shown in Figs 1 and 2.

IMPLEMENTATION UNDER THE PTOLEMY ENVIRONMENT

A heterogeneous computing environment is one which allows integration of different computing hardware and software components together regardless of their orientation. Consolidation of the strength of each component is desirable, such as using MATLAB as powerful computation engine, EMTP for electromagnetic transients program, POWERWORLD for the GUI and PFLOW for open source, into one common platform for modeling and simulation. Integration of the EMTP into MATLAB known as MatEMTP [1] is one example towards this direction. It is the heterogeneous nature of Ptolemy that has been proved to be successful in DSP design since its inception in 1990. In this paper, the same nature of Ptolemy is explored for implementing the power system analysis and simulation tools.

Hence, the envisaged approach is to integrate a number of C and C++ routines into the Ptolemy library which can readily be employed in task-specific applications. Understanding of the approach is achieved by porting external routines to the Ptolemy environment. This includes establishing a header file of the C program so as to enable all external variables and functions to be accessed freely by the Ptolemy. The header file is given in Fig. 3.

After recompiling the C program, it can be linked as a shared library file. This library file must be integrated into the Ptolemy kernel by rebuilding the execution file so as to include the user-defined library in the Ptolemy kernel. It is given in Fig. 4.

On the other side of the star declaration, this header file is also included into the star such that it can access the required functions and variables. A sample of star declaration is given in Fig. 5. Application of the PFLOW under the Ptolemy environment is employed to illustrate the flexible and portable nature of the approach. By the same token, a variety of analysis programs are developed in this environment for implementing different types of load flow solution techniques.

CASE STUDIES

In accordance with the designed approach, case studies are carried out to demonstrate the function of the PFLOW under the Ptolemy environment. One example is to make use of it to identify the weakest bus based on the IEEE 300 bus test system and to display its voltage profile.
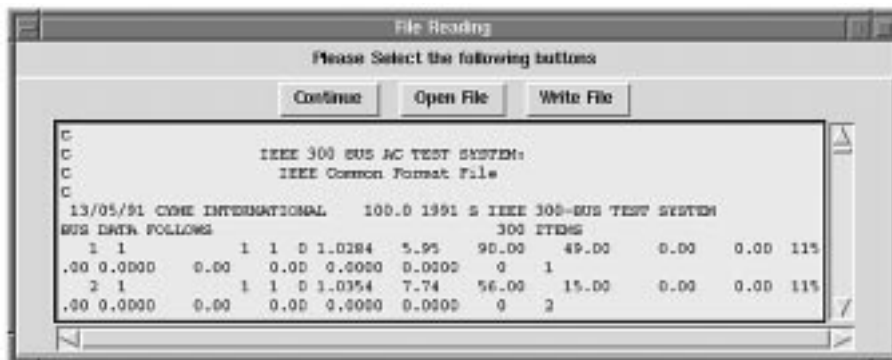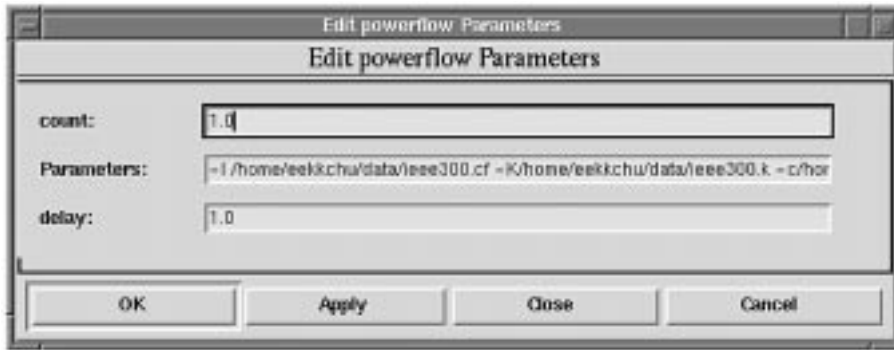

Fig. 7. Output of 'filereadwrite.tcl' file.

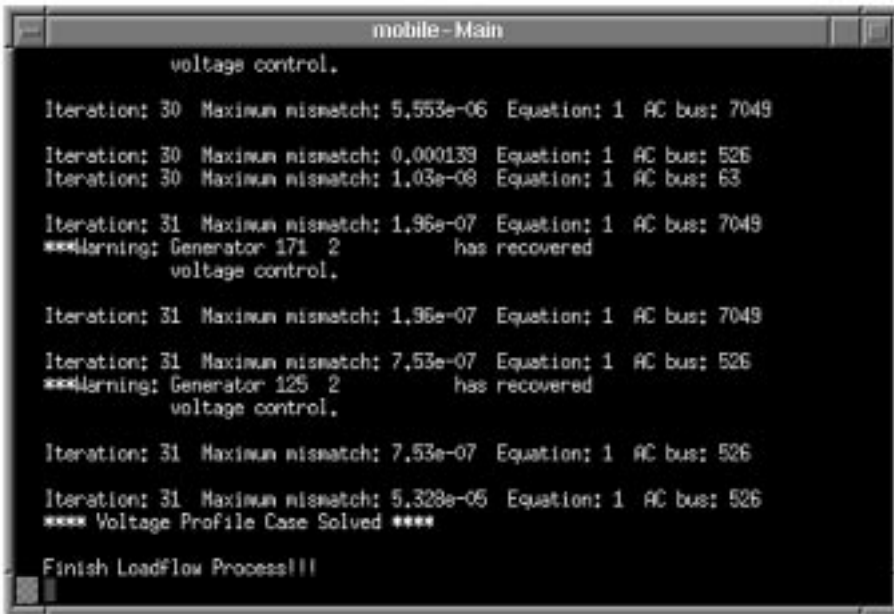Fig. 8. Command line input for PFLOW parameter.
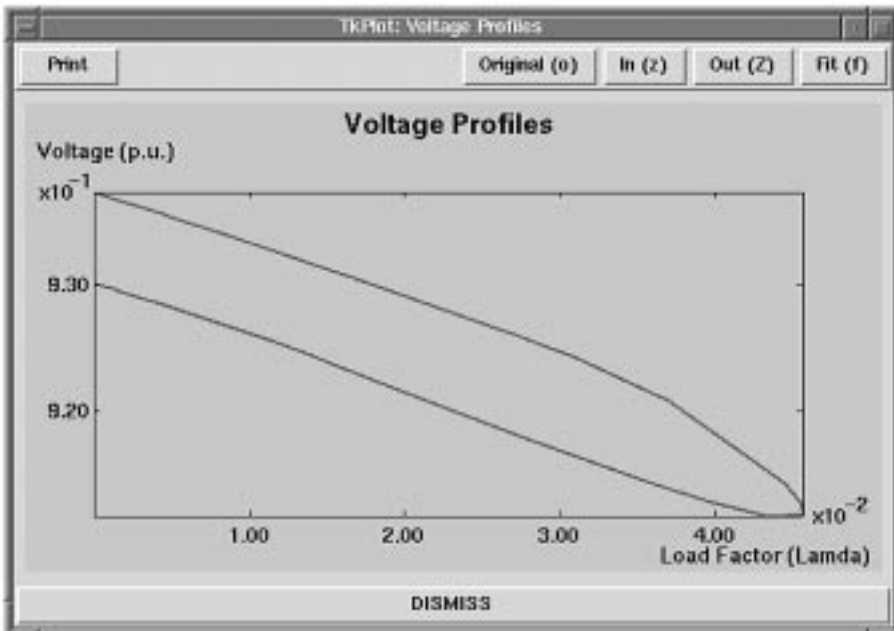
Fig. 9. The result of PFLOW.
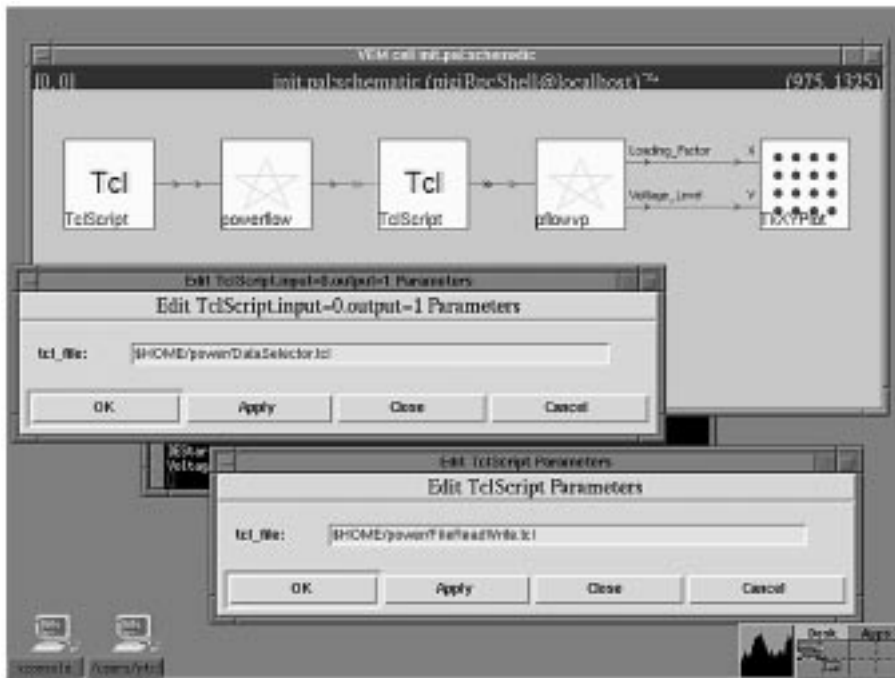
Fig. 10. Voltage profiles.

Fig. 11. The block connections of power system analysis application using PFLOW program.

The example power system analysis blocks contains input data for original versions of the IEEE 14 bus, 30 bus and 300 bus test systems which can be used for benchmark comparison. All the data are stored as IEEE Card format for easy exchange with other databases. It can be selected on the interactive mode during the simulation by using Tcl/Tk scripts as shown in Fig. 6.

Tcl/Tk provides the flexible GUI interface for the interactive environment within the Ptolemy. Popular features such as file open and save menus are also included by using the Tcl/Tk. The FileReadWrite.tcl is the front end of the package and is called by 'pop-up' windows. It handles the file reading, data entry, and file management. The system description is entered at the text area. Figure 7 shows a screen from the FileReadWrite.tcl module.

The figure shows the buttons and window nature of the user interface. There are two main windows shown in the figure. In the right hand side of the figure, a window displaying the open file menu for editing the data files.

Communication between the result of PFLOW and Ptolemy-defined star is done through the command line or ASCII files only. It is shown in Figures 8 and 9. A demonstration of the novel use of Tcl/Tk enhanced graphics capability is given in Figure 10 in which the voltage profiles at the weakest bus is displayed.

The beauty of the proposed approach is that it requires no programming knowledge on the normal users. They can simply select to run each program by selecting from menus and answering questions as prompted in an interactive and user-friendly manner. Data entered can be saved and kept as cases on disk. The block connections of this sample application using PFLOW is given in Fig. 11.

CONCLUSIONS

Results of the case studies show that the envisaged approach can integrate the PFLOW into the Ptolemy environment. By means of the attributes of the Ptolemy, it provides a heterogeneous computing environment to incorporate Power System Stars for performing the analysis and simulation. Extension of these features is possible by integrating C and C++ routines, foreign simulators and /or synthesis tools (MATLAB, Mathematica) to form a library of Stars and customize their user interfaces as desired by using the Tcl/Tk.

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K. K. Chu received his B.Sc. in 1993 from the University of Macau. He works as an electrical engineer at the Companhia de Electricidade de Macau, SARL–CEM. He is pursuing his part-time M.Phil. study at the Hong Kong Polytechnic University with research interests on modern power system control and analysis using FACTS devices and heterogeneous computing tools.

H. W. Ngan received his M.Sc. in 1979, MBA in 1985 and Ph.D. in 1993 from the University of Aston in Birmingham, University of Hong Kong and University of Strathclyde respectively. From 1980 to 1983, he was with the China Light & Power Co. Ltd. as a Section Engineer of the Generation Project. Since 1983, he joined Hong Kong Polytechnic University and is now Associate Professor in the Department of Electrical Engineering. His current research interests include computer simulation of power systems, system control of FACTS devices and energy policy and planning.