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COPERITE-computer-aided Tool for Power Engineering Research, Instruction, Training and Education

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ABSTRACT

A graphics-oriented, primarily PC-based tool for education, research and training in power engineering is introduced. The tool called COPERITE has all user interfaces resident on an "IBM-386" microcomputer. Menus and windows are used generously for the interface and attractive graphical representations and displays are used. Application programs that are interfaced are power flow, contingency analysis, economic dispatch, security-constrained dispatch, system stability and fault analysis. These programs are executed on a VAX 8800 computer mainly for speed of execution. Information exchange between the PC and the VAX is made through an ethernet connection which is transparent to the user. Results of execution show up on the graphical front-end accessible to the user. COPERITE has a powerful network editor having the capabilities of adding, deleting, moving and finding symbols with a graphics cursor. Provisions are present for building and using artificial intelligence techniques for system operation enhancement.

Keywords Power system analysis, Personal computer, mainframe computer, man-machine interface, artificial intelligence.

1. INTRODUCTION

Recognizing the fact that the power industry is currently the third largest user of computers, it is only logical to emphasize that power engineering education and/or training should incorporate computers as an important medium of instruction. Coupled with the immutable fact that a realistic power system network presents a highly non-linear set of equations which can only be solved by iterative techniques, the medium of computer-aided analysis is almost as necessary as a theoretical treatise of most topics in power system studies. Although computer-aided instruction can never substitute a thorough understanding of the principles, it can effectively complement the latter to the extent of generating a high level of confidence in the student/trainee. A well-defined and carefully-planned program of computer-aided power system education which incorporates industry-standard techniques can provide a power engineering student the vehicle to make a smooth transition to the power industry work force and a professional trainee the framework to gain more insight and therefore find more efficient solutions to system-specific problems.

Although computer-aided instruction in power engineering is not a new concept, only recently has there been an infusion of software which are more suitable for classroom use [1-15]. The trend is directly attributable to the widespread popularity and availability of the personal computer. Several years ago, the mainframe computer was almost invariably the choice for such analyses. Most of us who have used or are still using the mainframe will agree that factors such as accessibility problems, unforgiving input/output requirements, the problem of learning the operating system, high cost of CPU time, etc. far outweigh the advantage of fast computation time.

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At present, the computing power of a mainframe of two decades ago, can be found on a desktop computer and judging from the rate of the current development of computer hardware and software technology, most computational barriers which seemed impossible to reach a few years ago, could conceivably soon be shattered by the simple PC. Techniques are already being developed in order to take advantage of this technology which will transform power system analysis into a more exciting activity where the user spends more time working on power system aspects rather than learning about the computer itself.

This paper introduces a graphics-oriented, primarily PC-based tool for education, research and training in power engineering studies. The tool will henceforth be called COPERITE which is an acronym for **CO**mputer-aided tool for **P**ower **E**ngineering **R**esearch, **I**nstruction, **T**raining and **E**ducation. All user interfaces are resident on an IBM-PC with a 32-bit processor. Menus and windows are used generously for the interface and attractive graphical representations and displays are used. Application programs for analyzing a power system for power flow, system stability, fault analysis, etc. are executed on a VAX 8800 computer. Information exchange between the PC and the VAX is made through an ethernet connection which is transparent to the user. Results of execution show up on the graphical front-end accessible to the user.

No attempt has yet been made to execute the application programs on a personal computer such as the "386" or the "486" machines. However, it is noteworthy that all such software related to power engineering studies are both memory and computation-intensive. The limitation of "DOS machines" to 640 kilobytes base memory also presents a serious roadblock. Hence, any full-scale implementation of power engineering software on the PC will have to rely heavily on matrix sparsity techniques as well as other sophisticated machine-memory management schemes. Certain commercially available application software are being marketed with such capabilities, however the price tags on these are prohibitively high for educational institutions.

COPERITE was developed fundamentally with the aim of handing to the student or researcher, a simple and friendly tool for analyzing power systems without the requirement of advanced programming skills or the knowledge of operating systems. It can also be used for training electric utility professionals such as dispatchers, in most aspects of specific system operation. It is also useful as research tool specially in the areas of security-constrained dispatch and static and dynamic security assessment. A significant amount of research effort is required in order to make the above functions integral parts of modern energy management systems (EMS) in a control center. The potential benefits of applying artificial intelligence techniques such as expert systems and artificial neural networks for aiding the execution of security-constrained dispatch and security assessment can be experimented with efficiently by using COPERITE.

During the development of COPERITE, certain criteria that were believed to be essential ingredients for an effective education/training tool were defined and adhered to. These criteria are:

- The tool should allow for learning network modeling through per unit representation on one-line diagrams.
- The tool should be able to provide the behavior of sample networks under steady state and transient conditions.
- The tool should allow for control of the network for economy/security conditions.
- The tool should have similarities with EMS now being used at the control center.
- The use of AI techniques for system operation enhancement should be provided as an option to the user.

Specific application programs in power engineering which are native to COPERITE at the present time are:

- Power flow: This includes options for Gauss-Seidel, Newton-Raphson and fast-decoupled methods of solution.
- Power flow control: Control schemes consist of capacitive and reactive compensation, synchronous condensers, tap-changing transformers, phase-shifters, generator real power and line switching.
- Contingency analysis: Generator, single line and transformer contingencies are allowed.
- Economic dispatch: Transmission losses are considered as an integral part of the dispatch.
- Security-constrained dispatch: A combination of an economic dispatch and an expert system for security control is used to create the same functional effect as a security-constrained dispatch.
- Stability analysis: Transient case is allowed.
- Fault analysis: Symmetrical three-phase and unsymmetrical line faults are simulated.

Descriptions of each of the above programs including implementation of input and output parameters on the graphical user interface is presented later in the paper. An overview of the entire process is shown in Fig. 1.

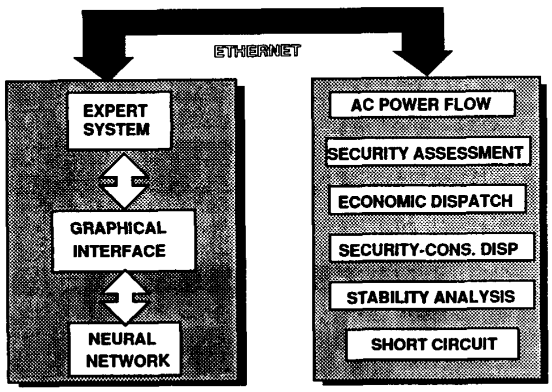

Fig. 1. Block diagram representation of COPERITE

A graphical front-end, which supports both EGA and VGA graphics serves as an all-important man-machine interface (MMI). The MMI which resides on the PC is developed in PDC PROLOG (a product of Prolog Development Center) and makes use of BGI (Borland Graphics International) libraries. An overlay linker is used with the PROLOG compiler for the purpose of memory management. Several data bases are developed and these are shared by the MMI and the power system software on the VAX. All network simulations are done on the VAX mainframe computer because of the intensive nature of the numerical analysis. The two computers are linked be ethernet allowing two-way communications. An AI interface is also possible on the PC for problem diagnostics and recommendations for economy/security conditions.

2. THE GRAPHICAL USER INTERFACE

The PC-based graphical user interface which constitutes the MMI is an outstanding feature of the COPERITE process. User interaction is facilitated by use of menus and windows. Menus and sub-menus provide options to the user which may be selected by a moving highlighted bar. Windows provide access points by means of which the user can enter data and create the databases. Windows are also used to show user-selected results from system analyses as well as to plot desired curves from the stability analysis. The capabilities of the MMI include:

- A graphical work area where schematics can be drawn. Attractive colors are used to display system components, alarm conditions, etc.
- Easy modification of data required to run cases without the need for exiting the environment.
- Interfaces to all application programs including the AI software is done by the touch of a key.
- All analysis results are displayed on the schematic.
- Hardcopies of the schematic or any tabulated results can be directed to either a plotter or a printer.

2.1. The Graphical Editing Environment

The work area for developing system networks from scratch and the main menu give the user convenient and error-free means to prepare data. Fig. 2 illustrates the PC screen that is displayed when COPERITE is started. Highlights of the display are:

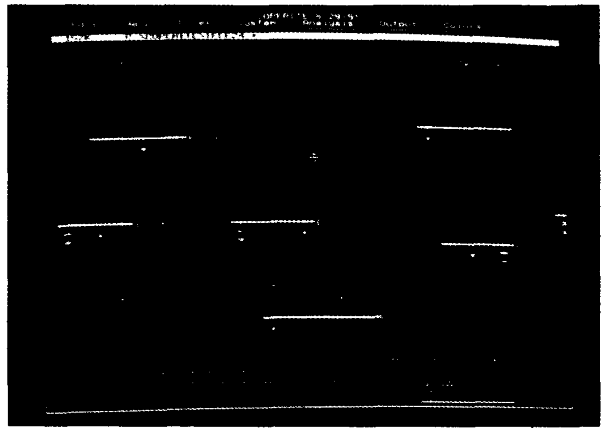

Fig. 2 The User Interface Screen

Menu bar: Shows all pull-down menus available

Editor: Allows the drawing of a one-line diagram of a power system network. The drawing area is large enough so that a 500-bus network can be drawn. The editor also automatically creates the database to be shared by the application software.

Graphics Cursor: Marks the point where a network component is to be drawn.

The Main Menu

Choosing "Help" from the menu bar provides the user instructions on building/editing networks, executing application software and on active keys under different modes of operation. The "Files" menu item provides options for loading from memory a particular power system network to work on, saving into memory a new or modified system network or just exiting from the environment. "System" allows one to set system-wide common variables, such as the base MVA and the reference generator. Three menu items are listed under the "Analysis" option - "ES Interface," "ANN Interface," and "VAX interface." Selection of any of these items leads to further sub-menus. "Find_Problem" and "Solve_Problem" are the two sub-menu options under the "ES Interface" item. These options provide interface to the expert system which may be invoked in order to provide recommendations for remedial action in case the system becomes vulnerable. The "ANN interface" gives one the options of "Train" - for training the artificial neural network in security assessment and "Apply" - for using the trained network in predicting the security level of the system.

The "VAX Interface" option on the "Analysis" menu item provides a list of the application software that can be executed on the VAX computer. Selecting a particular program will automatically provide direct communication through ethernet to the VAX.

Choosing the "Output" item of the Main menu displays options for hardcopy output of results of executing the application software. A plotter may be selected for graphical output of the schematic, along with its associated text; a printer may be selected for text output; summaries of analysis results as well as recommendations from the expert system may also be printed.

The "Colors" menu item provides options for choosing appropriate display colors to customize the environment.

2.2 Building a Schematic

Once the user is placed in the graphics environment, he/she has the option to either draw new network components or change/modify existing components or their attributes. Several drawing keys are available in the editor for various functions. The capabilities of the editor are:

- Drawing a bus on the one-line diagram. Entering this command will draw a horizontal bar with a sequential number on its right. Generator, load, reactive and capacitive shunt compensators can be drawn in any combination by choosing from options that appear in a pop-up window. The user has the option of deleting any of these components by moving a highlighted bar over the desired item and selecting it. Other windows will pop up to accept bus component attributes. Bus-name, bus-voltage magnitude (if a voltage-controlled bus), load demand at the bus, generator MW & MVar values, generator min/max powers, capacitor setting, capacitor min/max values, reactive compensator setting and RC min/max values are entered in these windows at appropriate places. For generator buses, cost coefficients, inertia and damping constants can also be entered. Corresponding databases for all elements associated with the bus are automatically created from these user inputs. The information relating to network components are stored in memory as PROLOG facts. An example of such a fact is

  gen ("Bus-22",vcoord(37,4))

  The above fact represents an assertion that a generator is connected to bus number 22 of the network. The second parameter in the argument list instructs COPERITE as to the virtual coordinates on the screen wherein to draw the bus and the generator. A sample screen display for editing a bus is shown in Fig. 3.

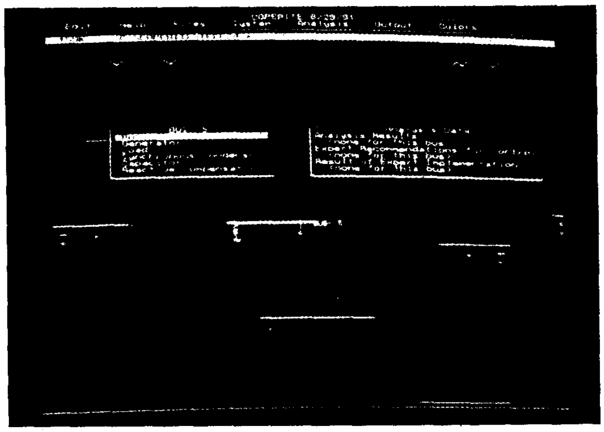

Fig. 3 Editing a Bus

One of the priorities set during the development of the package was to incorporate into the editor a certain amount of intelligence. Consequently, the editor will not accept absurd input from the user and will also alert the user to that effect. For example, an attempt to draw a generator and a reactive compensator on the same bus will be discarded; parametric values beyond set limits will not be accepted and so on.

- Drawing a line between two buses. A mouse may be used to connect the two buses. The editor is smart enough to not complete the line until the start and end buses have been found. A transmission line parameters database complete with line lengths and ratings is created by COPERITE through interaction with the user by means of dialog windows.

- Drawing a tap-changing transformer. Transformer reactance, tap setting, tap min/max and transformer rating can be entered inside windows. A transformer database with associated limits of taps is also created again by user interaction within dialog windows.

- Drawing a phase-shifting transformer. Transformer reactance, phase setting, phase min/max and transformer rating can be entered inside windows. Again, a database with associated phase angle limits is created.

- Editing or changing network parameters, e.g. the bus voltage magnitude.

- Obtaining information on a bus or line after execution of analysis programs.

- Moving a network component from one physical location to another. Moving a bus will move at the same time all elements including lines and transformers attached to it.

- Deleting a network component, e.g., a generator from a bus. The editor will delete all associated network elements along with the deleted component. For example, if a bus is deleted, all lines connected to the bus will also be deleted.

- Finding or locating a particular network component, e.g., a bus with a given characteristic so that specific information may be obtained.

- The capability of drawing schematics of very large networks on the same diagram. A portion of the diagram is displayed at any time but the user has the capability of moving in any direction by using the cursor to display other portions of the network.

- A zoom feature. Specific portions of the one-line schematic may be magnified for easy readability. Conversely, the diagram may be reduced for display of a larger portion of the network.

- A redraw key may be used for redrawing the schematic after a change like moving or deletion is made on the system.

The databases which are automatically created from user-interaction along with others created as a result of executing the application programs are used to give the user an extremely powerful tool to determine the system steady-state or transient operating conditions by means of the MMI.

One of the distinct advantages of the graphical user interface is the capability of modifying network schematics. Adding new components, deleting specific components, modifying values of parameters and moving network components from one location on the diagram to another are all intrinsic features of the MMI. Any modification to the the network components leads to an automatic updating of the internally created databases.

COPERITE also makes necessary data completion checks before executing an application software. The extensive nature of the input data requirements for the resident software can potentially cause the user to overlook some vital pieces of information required to execute an individual program. For example, missing values of inertia constants for generators although not important for executing a load flow, will yet cause the transient stability program to abort. In such events, COPERITE will attempt to use default values if at all feasible or will caution the user regarding the missing information.

3. EXECUTING APPLICATION SOFTWARE

A general description of the interactive procedure implemented in COPERITE for executing power system analysis software follows. All execution procedures start with entering case study parameters and culminate in the display of results. The former may be accomplished in one of two ways:
(i) by entering specific parameter values inside pop-up windows on the display, one network component at a time, or
(ii) by directly accessing the databases and making necessary modifications.
Although the latter process is functionally more efficient in terms of speed, it requires a working knowledge of the database format.

Results of program execution can be shown in any combination of the three available options:
(i) display on the schematic on screen
(ii) display on the hardcopy output of the schematic
(iii) creation of external text files with tabulated listings of results.
The following sections are devoted to highlighting the important features of the execution procedure of some of the software in COPERITE.

3.1 Executing Power Flow

The power flow program requires as input, a set of bus loads, a set of real power generations, a set of transformer settings and a set of bus voltage magnitude specifications at voltage controlled buses. The user is given the option of selecting one of three widely used methods for solving the power flow equations. These are: the Gauss-Seidel, the Newton-Raphson and the Fast-Decoupled methods. We are presently working on a mechanism which will allow starting the power flow solution using the Gauss-Seidel method in order to obtain bus voltage estimates and then switching after a few iterations to the Newton-Raphson method for faster convergence.

COPERITE presents results of the load flow on the graphical display and at the request of the user, also as hardcopy output. The on-line graphical display adapts quite naturally to show results of the load flow. Colors are used to show calculated results. Bus magnitudes and angles, real and reactive power generations from all generation sources, real and reactive branch flows, etc. are displayed. A sample display is shown in Fig. 4. In addition to the results screen showing bus voltages and line flows, one can closely examine a single bus, line or a transformer. The pop-up window on the right shows three items: the power flow analysis results at the bus, expert system recommendations for that bus if any and the result of implementation of the expert recommendations at the particular bus.

As an educational tool, COPERITE also permits comparisons of the results of applying the three methods for solving load flow. Successive runs of the load flow using these methods will store results in appropriate databases. The graphical display can only present the results one method at a time. However, selecting "compare" from the "Load Flow" menu will allow the user to select from a list of buses and lines, a particular item to compare. A pop-up window will display the results obtained from the three methods for the selected bus or line.

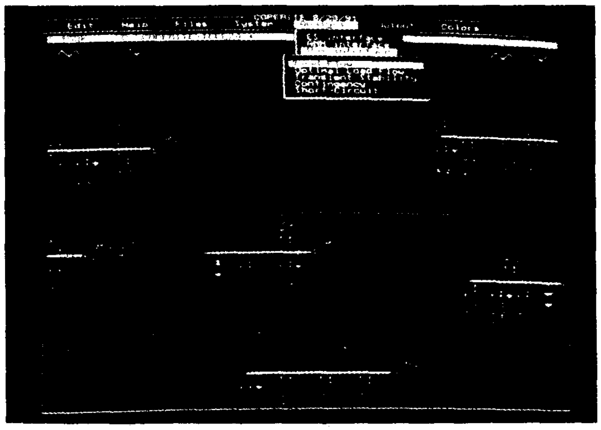

Fig. 4. Displaying power flow results

3.2 Contingency Analysis

Contingency analysis is an integral part of an overall security assessment scheme. Single line, generator, transformer or load outages can be simulated by COPERITE. On selection of "Contingency Analysis" from the "Vax Interface" sub-menu of the "Analysis" menu, user command is transferred to the following window on the graphical display:

Select lines only
Select transformers only
Select generators only
Select loads only

Instructions specific to a single item on the menu will appear when the item is selected by the highlighted bar. The user will be asked to select the desired outaged network component by moving the graphics cursor to the position of the component on the screen and "clicking" the mouse button. A list of contingencies may be selected in this manner. However, only single contingencies at a time are evaluated by the program. COPERITE makes necessary checks for correctness and validity of user inputs and alerts the latter to that effect. For example, if a line is selected for outage which is the only link to a generator, a message stating this fact will appear on the screen.

In presenting results of the display, the user is given the list of contingencies that was created before execution, from which a single contingency can be selected for review on the screen. Potential security violations such as bus voltage limit violations and/or branch overloads, due to any contingency is shown in a different color than the rest of the system.

3.3 Security-Constrained Dispatch

Security-constrained dispatch (SCD) seeks to allocate generation among individual units and to adjust the system controllable quantities such as reactive and capacitive devices and transformer taps and phase angles, in order to minimize the cost of power generation and ensure operating security of the system. The purpose behind the development of the algorithm for SCD implemented in COPERITE was to provide one with a background on real-time implementation of the optimal power flow (OPF). A full-fledged OPF will certainly run on the VAX 8800. However, building such a software requires a high level of skill in optimization methods and was beyond the capabilities of the authors. On the other hand, OPF software available commercially are principally meant for use in actual control centers and are therefore extremely expensive. Besides, an on-line version of a full-fledged OPF would most likely be unable to yield proper corrective measures within the time allowed for real-time actions. Hence, it was decided to use an expert system as an aid in the dispatch strategy formulated in SCD.

The algorithm combines a transmission-constrained economic dispatch with the expert system. The latter is not meant to substitute the "real thing", rather it merely acts as an assistant to the dispatcher. It is invoked to determine system security violations and then to suggest relief measures such as relieving line and transformer overloads and remediating bus voltage limit violations. The expert system can effectively guide the user to the right control actions under simulated emergency situations. The graphical user interface is used to communicate with the expert system by the use of pop-up dialog windows. Fig.5 shows the PC screen after the expert system is invoked for solving voltage and branch overload problems.

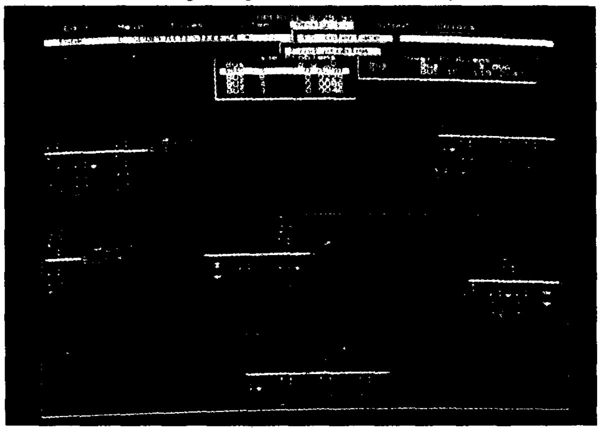

Fig. 5. User interface for security-constrained dispatch

The example in the figure shows two windows, one indicating buses which have voltage deviations and the other indicating overloaded branches each item listed in the order of decreasing severity. The user has the option of selecting either a bus from the "bus list" or a line from the "branch list". The former choice will fire a set of rules directly related to alleviating over- and under-voltage problems by using any number of reactive devices, while the latter choice invokes rules for relieving overloaded lines and transformers by using a combination of active generations and phase-shifting transformers. All changes in the settings of control devices such as tap-changing transformers, reactive compensators, etc. are recommended by the expert system only after it confirms their optimality under the existing system conditions. The ES also recalculates new bus voltages, line flows and reactive generations after changes are instituted in the control settings, thus eliminating the need for a load flow analysis.

3.4 Stability Analysis

Transient stability analysis in power systems relates to determining how the system behaves in the seconds following a sudden disturbance such as the loss of a line or a generator. COPERITE has several unique features for performing stability analysis. These include:

- Simulation of a multi-generator case.
- Simultaneous determination of swings in rotor angles, rotor velocities and bus voltage magnitudes.
- Capability of handling single or multiple disturbance events in any sequence.
- Interactive user inputs on the MMI through dialog windows.
- On-screen plots of desired parameters such as rotor angle versus time using a plotting package built specially for COPERITE.
- Choice of textual outputs on screen or hardcopy.

The model used for the synchronous machine is the classical representation of [16] and is shown in Fig. 5.

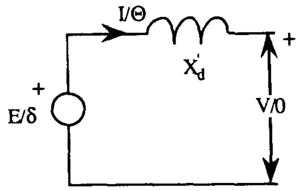

Fig. 6. Synchronous machine model

In the above figure:

E/δ = emf behind the direct axis transient reactance.

X'_d = direct axis transient reactance

Fig. 7 shows the PC screen when stability analysis is invoked from the main menu.

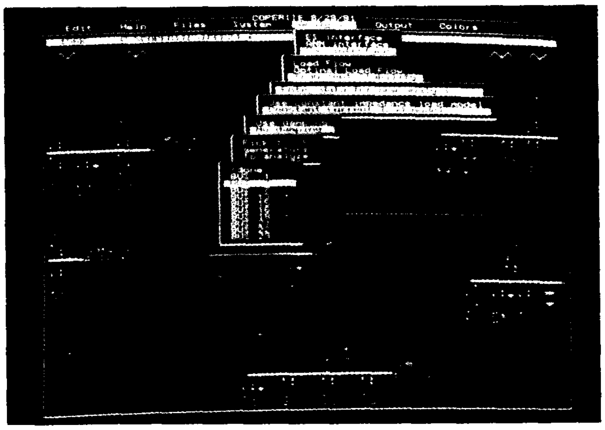

Fig. 7. Stability analysis screen

Following a stability run, the user is placed back in the graphical environment where results display options can be exercised. One of the choices for displaying results is the use of plots of rotor angles and rotor velocities of synchronous generators versus time. Fig. 8 shows a sample plot of rotor angle versus the time of simulation. The plot shows points where a disturbance is applied. Similar plots are displayed for investigating the behavior of bus voltages under fault conditions.

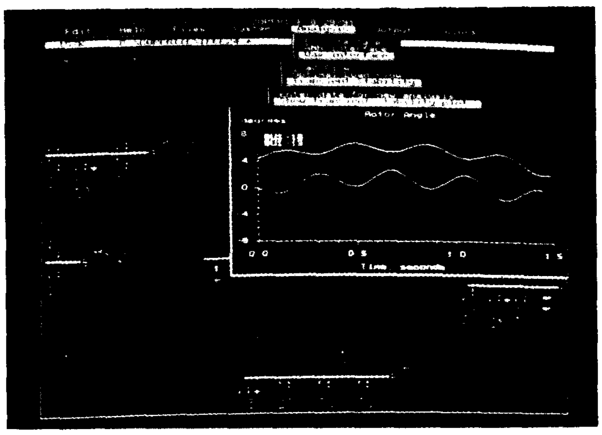

Fig. 8. Plot of rotor angle δ vs. time

3.5 Short Circuit Analysis

Fault currents are determined at a bus due to three phase, line-to-line or line-to-ground faults. The program also determines the contributions to the fault current from other line elements in the system. All user inputs to the short circuit program are again facilitated by the MMI through the use of menus and windows. In order to run the short circuit program for a symmetrical or an unbalanced fault, the user needs to enter data on positive, negative and zero sequence impedances for all the generators, lines and transformers in the system. This can be done by either editing each element separately on the graphical environment or by adding and modifying the appropriate databases in the text format. Buses where faults are to be simulated can be selected from a menu of buses by using a highlighted bar. Similarly, contributing elements can be selected from a menu of lines. Having the network schematic in the background of the PC screen provides a convenient means of relating to the system being studied while making the above selections inside windows in the foreground.

Results of the short circuit program are displayed on the network schematic. Fault currents are displayed in close proximity to the faulted buses. Also, contributions from other elements to the fault current are displayed along with an arrow pointing to the direction of the flow.

4. CONCLUSIONS

A microcomputer-aided tool for education, research and training in power system engineering topics has been presented. The tool combines the powers of a fast personal computer and a mainframe computer for an effective and highly efficient environment. A graphical user interface provides a large work area on the screen for drawing network schematics. The network editor allows for easy modification of the schematic as well as the parametric values associated with each component through the use of windows. Automatic validity checks of the entered data is built into the editor. Data preparation to run different cases of the same application program is therefore very convenient and error-free. Application programs for analyzing a power system for power flow, system stability, fault analysis, etc. are executed on a VAX 8800 computer mainly for speed of execution. For certain large systems (over 500 buses), convergence of the algorithms can be slow and the time of execution can become a factor if run on a PC. However, information exchange between the PC and the VAX is made through an ethernet connection and is transparent to the user. Results of execution show up on the graphical front-end accessible to the user. Results of program execution can be shown in any combination of the three available options: (i) on screen display on the schematic (ii) display on a hardcopy output of the schematic or (iii) creation of external text files with tabulated listings of results.

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