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AN INTERACTIVE POWER SYSTEM ANALYZER WITH GRAPHICS FOR EDUCATIONAL USE

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ABSTRACT

The paper presents a student-oriented power system analyzer with an interactive graphics display. Its capabilities include studies of (1) load flow, (2) load and generation , (3) voltage level control, (4) economic dispatch, and (5) contingency and planning analysis. Power network configurations of up to 30 buses can be presented clearly on one screen. The interactive nature of this program makes such studies effective and easy to use. With the support of a computer with graphics software and many graphics terminals, this program can be a useful teaching tool for power system studies.

INTRODUCTION

High speed digital computers are now solving power system problems previously solved on ac network analyzers and have proved to be more economical for nearly all load flow, modeling, and simulation problems. The combination of digital computers and graphics displays is widely used by the electrical utility industry in power dispatch and in operator training.[1]

Several power system simulation studies and developments have proceeded this work. Staponski pioneered the development of an operator training simulator using the NOVA 800 minicomputer with color graphics displays. [2] Liao expanded on Staponski's work by adding the economic dispatch and the emergency simulation programs. [3] Yek added an interactive man-machine interface to this simulator. [4] All of these programs facilitate power system operator training and as such are oriented more toward utilities, and less toward the student user. Furthermore, there were some limitations on the speed and memory capacity of the computers used at that time. More powerful computers with graphics facilities are now available.

Wei pioneered the development of interactive graphics using the IBM 4381 with the Tektronix 4014 display terminal for fault analysis.[5]

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The object of this work is to produce a computer/graphics facility for power system studies that the junior and senior students can use. The computer available for student use is the IBM 4381 which is linked with an interactive graphics system. The Tektronix 4014 display terminal is a CRT storage display device with an enhanced resolution of 4096*3120. This system is supported by many software packages including TCS which has been chosen for this study.

The power system analyzer is designed to include the following features:

(1) Interactive:
The most outstanding feature of this analyzer is that it is interactive. The potential saving in time by achieving the solution within a few seconds rather than a few hours or days is important.

(2) Easy graphics display:
Two kinds of graphics displays are used. For a small system, an automatic display mode is available. No graphics data are needed. For a large system, the graphics display is built step by step by moving a crosshair and pressing a function key.

(3) Flexibility:
The configuration of any power system is not constant, especially that used for power system studies. Therefore, a power system analyzer should reflect this flexibility; i.e. any combination of buses and lines should be allowable, and any subsequent alterations should be easy to make. These are done by simple cursor movements and key-strokes in response to prompts from the analyzer.

SCOPE OF THE ANALYZER

Every effort has been made to facilitate easy use of the analyzer. The student can complete his study by just following the instructions appearing on the screen; i.e., the user is prompted for the next data item to be entered. Basic data such as the number of buses, number of lines, line impedances ... etc. are entered interactively in free format in order to help avoid mistakes. After the execution of the base case, the student can observe the power network and associated data. Four "change cases" are then provided for further studies as described below.

Load and Generation Studies: After execution of the base case the student may want to change the load and/or generation data of a bus. The new data can be entered from the keyboard, and the load flow program is executed again.

Voltage Level Control: The bus voltage magnitude is not expected to deviate from the rated voltage by more than 5 %. However, sometimes bus voltages may be lower than 0.95 per unit or above 1.05 per unit due to system

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demand variations. The student can control the voltage level by adjusting the reactive power of the generators and by adding (subtracting) capacitance to (from) load buses.

Economic Dispatch: A power system containing more than one generator unit can provide a specified load demand in an infinite number of generation combinations. Only one of the schedules gives the "best" economic operation of the system. During the course of the analysis, the student is first provided with the base case, and then prompted to input the coefficients of incremental cost curves for each generator. The Lambda-iteration [6] and Bisection method are used. The computer prompts the user to supply an estimated lambda, and possible maximum and minimum lambda values. Finally, through the execution of the economic dispatch program, an optimal generation schedule is computed and presented to the student.

Contingency and Planning Studies: The loss of a transmission line may create an emergency situation. The student can simulate these contingencies and then try to find a solution to correct this situation. A line can be added by entering line data for planning study. The contingency case of losing a generator unit can be simulated under the load and generation studies facility.

DEVELOPMENT OF THE ANALYZER

The hardware facilities used for this project are described below.

IBM 4381 : The local UMRVMB system is supported by the main computer, an IBM 4381, which is mainly used for computer aided design (CAD). The IBM 4381 has sixteen million bytes of processor storage and can handle three million instructions per second. More than one hundred IBM 3278 display terminals are connected to the main computer. Through these terminals the user can develop his own program by using the CMS TEXT EDITOR.

Tektronix 4014 Display Terminal [7] : The Tektronix 4014 terminal has a keyboard and a display unit. Through the keyboard the user can deal directly with the main computer. The display unit is a CRT storage type which can display the image for 15 minutes without damage to the screen. This feature can minimize the requirements of memory storage for refreshing a graphics display. The normal resolution is 1024*780 and can be enhanced to 4096*3120. A set of crosshair lines can be controlled via thumbwheels, thus enabling the input of a point in the construction of a line or circle for example. Similarly, by the use of the crosshair any point on the screen can be identified. Many software packages are available to support this Tektronix 4014 terminal, such as IDF, SAS, and TCS. A hard copy of the display can be made via the Tektronix 4631 hard copy unit. More than 20 terminals are available at UMR, thus making it the best tool for student use in graphics courses.

Software Implementation:
A large number of programs have been developed for this power system analyzer, and they can be grouped into two categories : calculation programs and graphics programs. Load flow and economic dispatch FORTRAN programs are used as primary vehicles for calculation. TCS(Terminal Control System)[8], a software package supplied by Tektronix, is selected as the basic element in graphics development subroutines as it is compatible with the other FORTRAN programs. A complete listing of the source program is presented in Appendix A of reference 12. It contains approximately 1800 statements.

Main Program : The flow chart of the main program is shown in Figure 1. The program begins with the initialization of the TCS mode. An old data file or a new data file can be chosen to run the program. The old data is read directly from disk file, while the new data is entered at the terminal. After inputting all necessary data, the load flow program is then invoked. The results of the base case are presented to the user. The graphics display program is called to display the power network and associated data.

A menu is provided for further studies:
(1) Load and generation studies
(2) Voltage level control
(3) Economic dispatch
(4) Contingency and planning studies
(5) Stop.

The user can select any above case for study by pressing the appropriate number, and upon execution may resume further studies in the same way. To exit "5" is entered.

Load Flow Program: The load flow program uses the Gauss-Seidel iterative method.[9]Some modifications have been made to meet the particular needs of the interactive analysis of the power system.

Graphics Display Program: The graphics display program is the central part of this work, and much effort has been expanded to make it user-friendly. Two kinds of display methods are used; they are the auto display method and interactive manual display method.

The auto display method is designed to deal with textbook power systems of 6 buses or less. The results are automatically displayed once the system study is run. Buses and lines are located at predefined locations on the screen depending on the number of buses. An additional benefit of this feature means that it is possible to identify a bus or breaker simply by locating the crosshair near the object symbol, a feature used in the voltage level control study.

To extend the applicability of this work, an interactive graphics display method [5] is incorporated. Up to 30 buses can be displayed on one display page. The user can maneuver the crosshair and press different function keys to build the power system step by step. Skillful manipulation of the system ensures that no overlap of lines occurs. As a convenience to the user, the location on the screen at which the power flow results are presented is determined simply by the initial identification of the line or bus concerned. For example, the voltage of a bus will be traced directly under the label of that bus, the latter having been determined by the initial

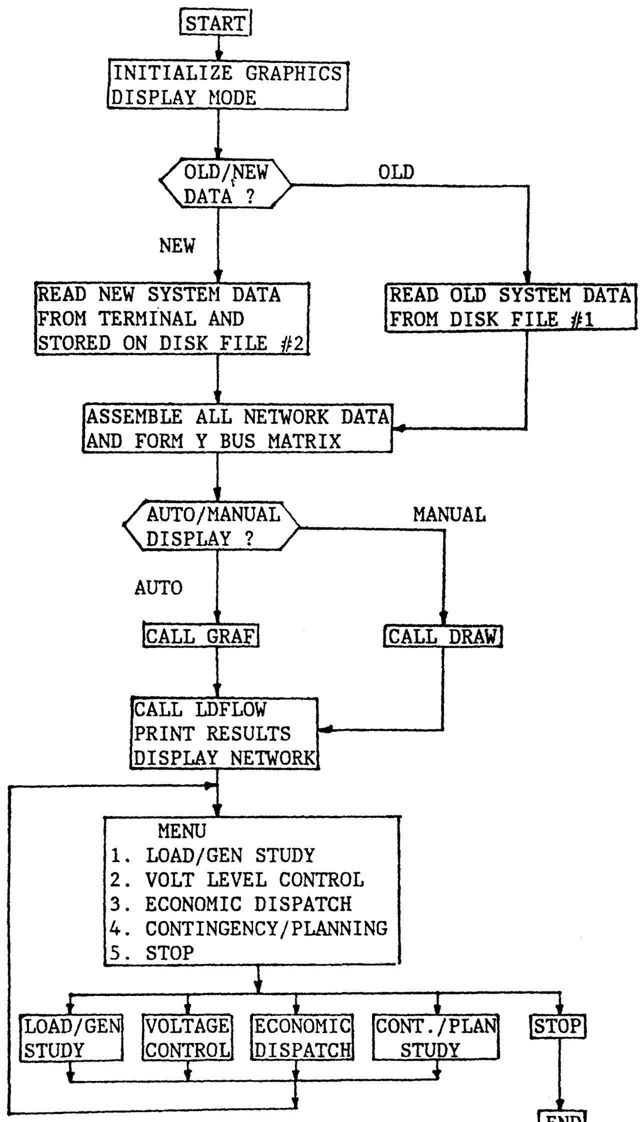


Figure 1. Flow Chart of Main Program

graphical construction. The subroutines used in the graphics display program are listed and explained in the following paragraphs :

Auto Display Programs: For a small power system, the subroutine GRAF is called to display the network automatically. The following subroutines are called by this program. The flow chart is shown in Figure 2.

Subroutines MOD2 to MOD6 :
Predefine the coordinates of buses and breakers for systems of up to six buses.

Subroutine DRWBUS :
In the auto display method, A bus may be drawn either vertically or horizontally depending on number of buses. For example, bus #4 is a vertical one in the case that NB=4, while it is a horizontal one if NB=5. A decoding method is used to verify the orientation of each bus before drawing it. Subroutine BUSX is called to draw a horizontal bus, while BUSY is used to draw a vertical one.

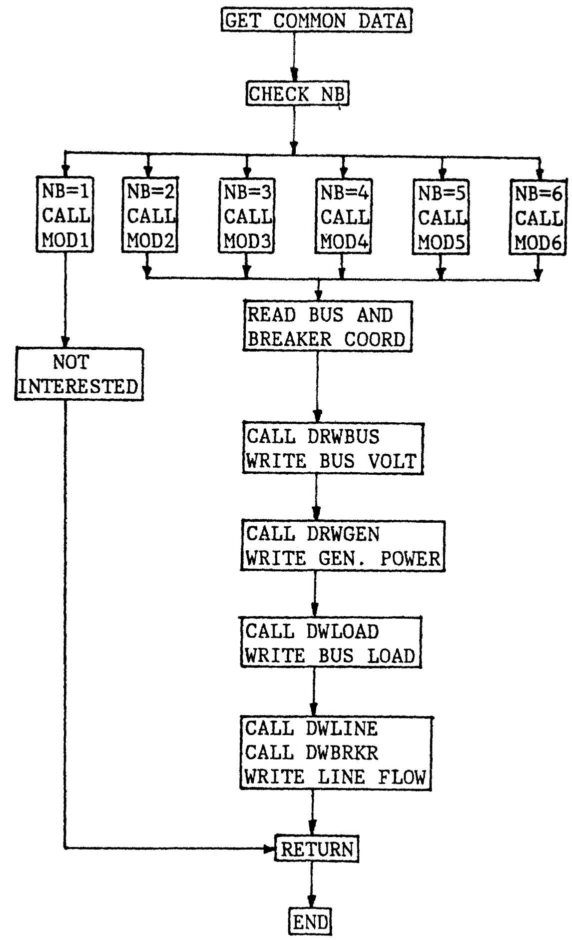


Figure 2. Flow chart of Auto Display Program

Subroutine DRWGEN :
A generator connected to a bus is drawn with the same decoding technique as in DRWBUS. A subroutine DRWCIR is called to draw a circle representing a generator. Generated powers are written under the generators' labels.

Subroutine DWLOAD :
A load connected to a bus is drawn with the same decoding technique as in DRWBUS. Again, the loads are written beneath the bus demand labels.

Subroutine DWLINE :
The lines connected between buses are carefully constructed in order to avoid unnecessary overlapping. Similary, the line flow is located such that it does not overwrite any other data. Subroutine DWBRKR is called to draw a square representing a circuit breaker.

Subroutine LOCATE :
This subroutine provides the user with the facility for adding capacitance at a bus, or switching off a breaker. In each case, the bus or breaker is identified merely by placing the crosshair in its vicinity, and then pressing the keys "C" (for capacitance) or "B" (for switching off a breaker). If "C" is pressed the user is asked to supply the desired MVAR at the bus in question.

Manual Display Programs: For a large power system, the subroutine DRAW is called to build up the network step by step. The following subroutines are called by this program. The flow chart is shown in Figure 3.

Subroutine CIRCLE :
This subroutine draws a circle representing a generator with center fixed by the first location of the crosshair. The radius is the distance between this and a second one. In both case the key pressed is "C".

Subroutine LINE :
Used to draw a line between two crosshair positions. The specified key is "L" (twice, once at each end).

Subroutine BUS :
Ten lines are closely drawn by this subroutine to simulate a bus with center at the first crosshair position and length twice the distance between the center and a second crosshair position. The specified key is "B" (twice).

Subroutine ARROW :
Used to draw an arrow to indicate the direction of line flow. The specified key is "A" (twice).

Subroutine DELETE :
When errors are made, deleting the element and its label becomes necessary. This is achieved by moving the crosshair to the starting position of the element and pressing the "D" key. The network is redrawn without the erroneous element.

Subroutine REDRAW :
If the user presses a wrong key, a warning message is displayed on the screen. By pressing the key "R", this subroutine refreshes the display.

Subroutine LABEL :
This subroutine handles the labeling of each element. The user moves the crosshair to the position desired for the label and presses the "2" key. Then the label is entered and the program will save this information on disk after pressing the "RETURN" key. The crosshair will then reappear.

Subroutine SORT and WVALUE :
The positions of inputted labels are used as position indices to display associated data such as bus voltages, line flows, ... etc. The WVALUE subroutine writes data in ascending sequence. i.e. B1, B2, ... D1, D2, ... L1, L2, ... etc. This will generally not be the same as the user input sequence, as there is an internal sorting process being implemented. Subroutine SORT performs this work. The subroutine WVALUE is called by pressing the "F" key to file the label and symbol data and then display the computed data.

Load and Generation Studies Program : This program accepts load or generation changes. The user is asked to input the bus number and the quantity of load or generation to be changed. The load flow program is then run again to check for possible exceeded

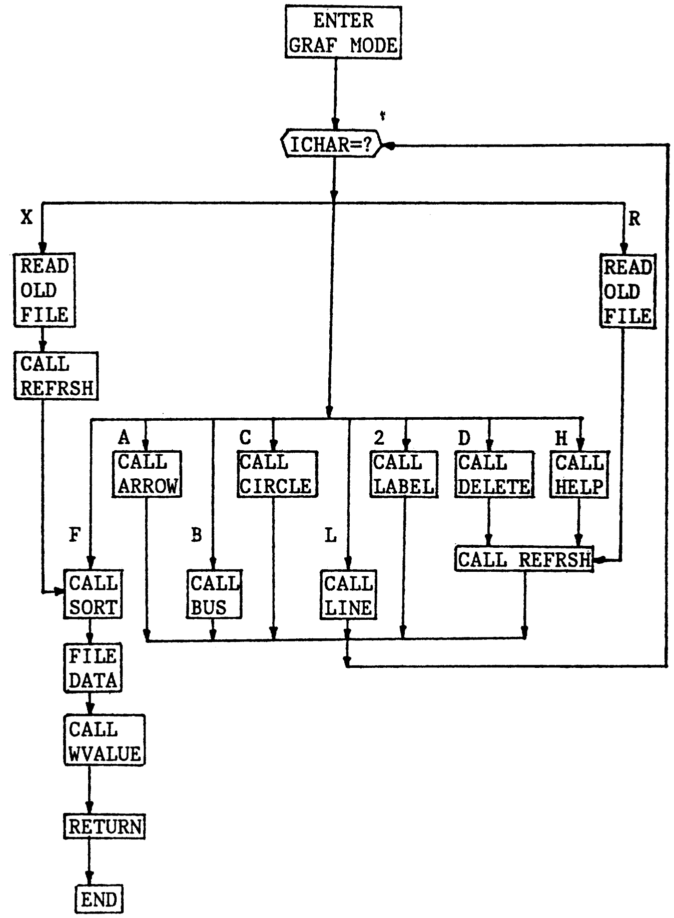


Figure 3. Flow chart of Manual Display Program

limits. Where limits are exceeded, adjustments can be made and the program run again to analyze the new situation.

The flow chart for this and the following programs are shown in Figures 5 through 8 of reference 12.

Voltage Level Control Program : Warning messages for overvoltage or undervoltage at any bus are presented. A capacitor can be added at the bus to improve voltage profile. The capacitor is added by moving the crosshair to that bus and pressing "C". The MVAR value is then requested from the terminal. Another possible method is switching off one end of a line; the capacitive capacity of this line then being applied to that bus so that the voltage may be improved. The load flow program is run again to enable the user to see if the situation has improved.

Economic Dispatch Program : Equal incremental cost is the basic criterion for the economic dispatch program. The Bisection method is used to find lambda. Transmission line losses are included. Calculations are summarized by the following equation:[10]

$$(IC)_i \,/\, (1-(ITL)_i) = \lambda \qquad (1)$$
for i=1,2...MB

where
$(IC)_i$ = Incremental cost $(\partial F_i/\partial P_i)$

λ = LaGrange multiplier

$(ITL)_i$ = Incremental Transmission Losses

$(\partial P_L/\partial P_i)$

The user is prompted to estimate the Lagrange multiplier lambda. The maximum and minimum limits of lambda are also requested. First degree incremental cost functions are programmed as shown in the following equation.

$$(IC)_i = A + B * PG_i \quad \text{(dollars/MWh)} \quad (2)$$

$$\text{for } i=1,2...MB$$

The user is prompted to input cost coefficients (A and B) for each generator; the economic dispatch program is executed; and the results are displayed.

Contingency and Planning Study : To simulate the event of a line outage, the user is prompted to input identification data for that line. The series impedance of the line is replaced by a very large number, say 9999 p.u., and the shunt admittance is set to zero. Then the load flow program is executed, and the results are displayed. A line can be added for planning study. The generation outage is simulated using the load and generation studies program by setting generated power equal to zero.

File Maintenance and Data Update : In the present system, all the computer programs are normally written onto the disk in separate files (FORTRAN source code). The programs are compiled and loaded prior to execution by the user. The power system analyzer allows data files to be edited during program execution. Basic data including system data are stored in File #1 and File #2. File #1 stores the old data while File #2 stores the new data entered from the terminal. Symbolic data are stored in File #8 and label data are stored in File #7. Data may be changed during the execution of the program, but the base case will remain unchanged for the next user.

The users' manual is given in Appendix B of reference 12.

SAMPLE RESULTS OF THE ANALYZER

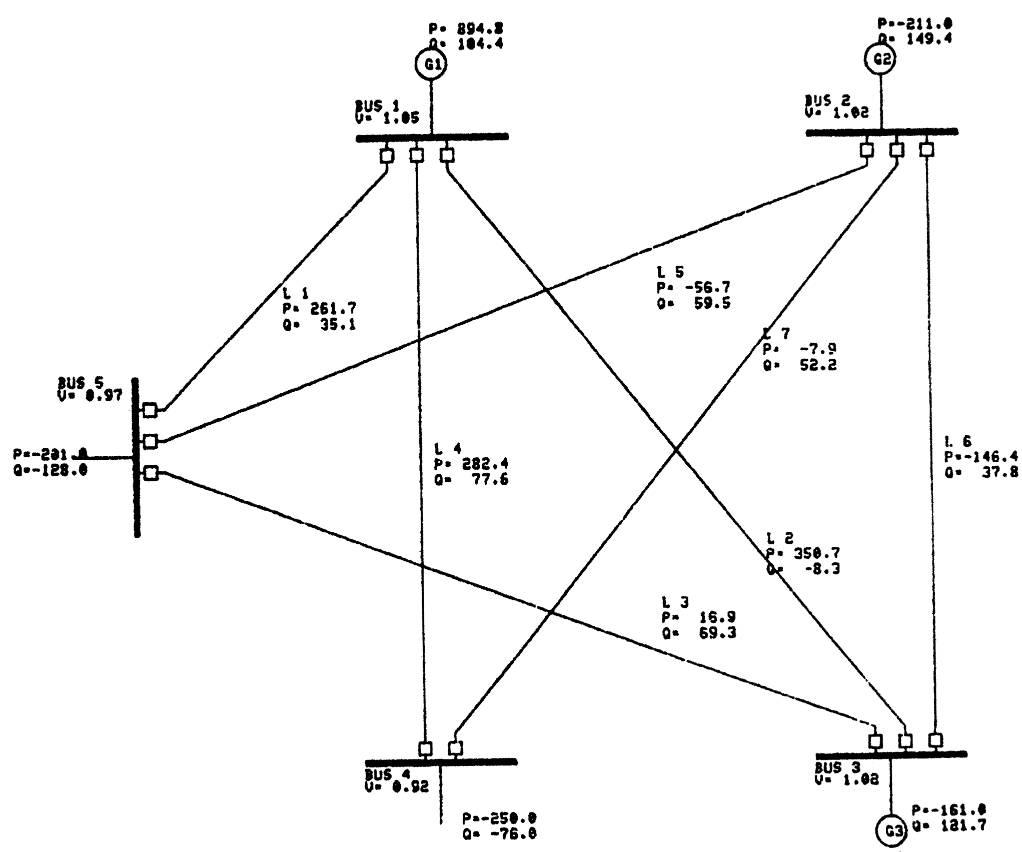
Example 1 - A 5-bus and 7-line system

A small system, of five buses and seven lines is selected as an example (see input data in Table IV of Appendix C of reference 12). Every change case is considered. It should be noted that the line flow is assumed "positive" when line flow is from the lower bus number to the higher bus number. The results of the load flow for the "base case" are presented in Figure 4, The total losses are 71.83 MW, and that the voltage of bus # 4 is under 0.95 per unit.

If it is desired to add some load in load/generation studies, this can be done as shown in Table I, where a load of 50 MW is added at bus #5. It was discovered that the losses increase to 81.05 MW as might be expected.

In voltage level studies, capacitors can be added to improve the low voltage problems such as that at bus #4. This is demonstrated in Figure 5, where 50 MVAR has been added there. Note that the voltage has been raised to 0.96 pu.

RESULTS OF BASE CASE



PRESS 'RETURN' TO CONTINUE Figure 4. Graphics Display for 5-bus and 7-line system. (Base Case)

Table I. **RESULTS OF LOAD/GEN STUDY**

LINE DATA

LINE	SB	EB	LENGTH	SHUNT ADMITTANCE		SERIES IMPEDANCE	
1	1	5	70.4	0.000	0.194	0.028	0.113
2	1	3	53.1	0.000	0.147	0.021	0.085
3	3	5	40.8	0.000	0.113	0.016	0.066
4	1	4	71.9	0.000	0.198	0.029	0.116
5	2	5	62.8	0.000	0.173	0.025	0.101
6	2	3	30.6	0.000	0.084	0.012	0.049
7	2	4	98.4	0.000	0.272	0.039	0.158

BUS ADMITTANCE MATRIX

6.8	-27.2	0.0	0.0	-2.7	11.0	-2.0	8.1	-2.1	8.3
0.0	0.0	8.5	-34.1	-4.7	19.1	-1.5	5.9	-2.3	9.3
-2.7	11.0	-4.7	19.1	11.0	-44.3	0.0	0.0	-3.6	14.3
-2.0	8.1	-1.5	5.9	0.0	0.0	3.5	-13.8	0.0	0.0
-2.1	8.3	-2.3	9.3	-3.6	14.3	0.0	0.0	7.9	-31.7

GAUSS-SEIDEL TECHNIQUE CONVERGED IN 20 ITERATIONS

BUS	VOLTAGE		MAGNITUDE	DELTA(DEGS)	REAL PWR(MW)	REACTIVE PWR(MVAR)
1	1.05	0.00	1.05	0.000	954.03	115.63
2	0.95	-0.38	1.02	-21.794	-211.00	157.57
3	0.97	-0.31	1.02	-17.427	-161.00	139.62
4	0.87	-0.29	0.92	-18.734	-250.00	-76.00
5	0.92	-0.30	0.96	-17.975	-251.00 *	-128.00

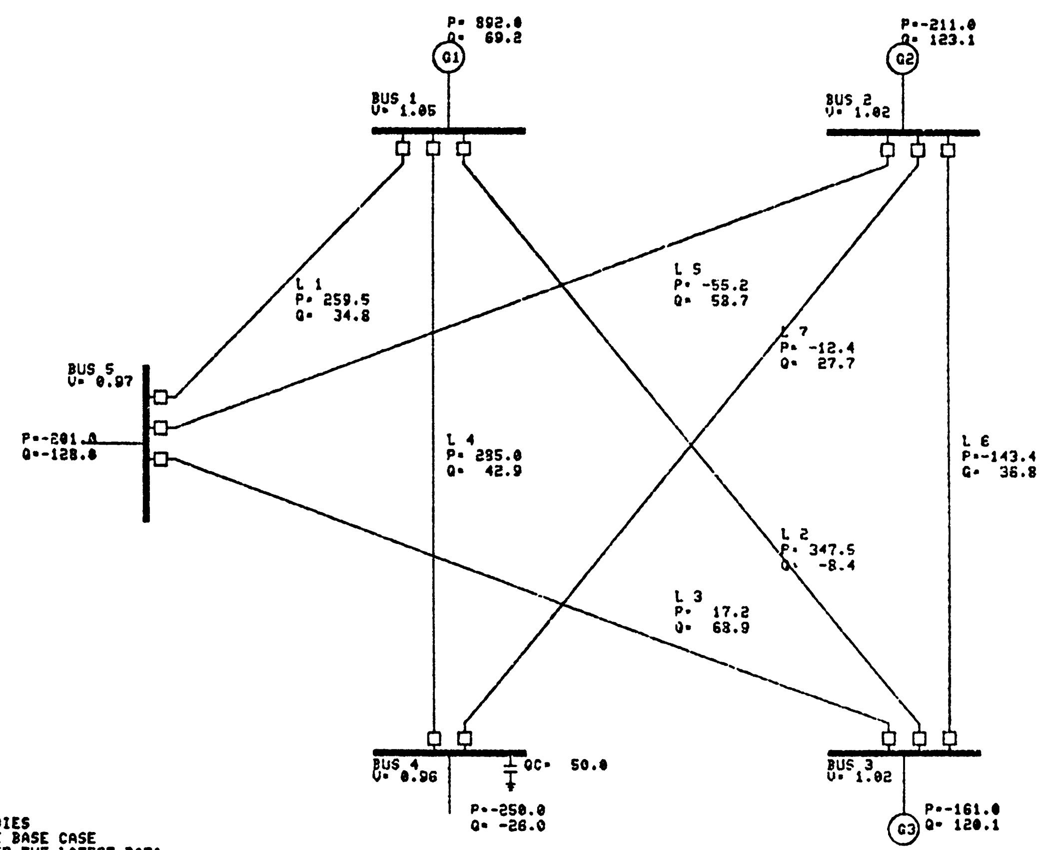
*50 MW load added at bus 5.

LINE FLOW

LINE	SB	EB	REAL POWER (MW)	REACTIVE POWER (MVAR)	LOSSES (MW)
1	1	5	288.31	42.40	21.95
2	1	3	375.46	-7.01	27.16
3	3	5	34.44	75.23	1.22
4	1	4	290.27	20.44	24.16
5	2	5	-46.78	62.95	1.78
6	2	3	-150.02	39.00	2.87
7	2	4	-14.22	55.66	1.92
				TOTAL LOSSES	81.05

PRESS 'RETURN' TO CONTINUE

RESULTS OF VOLTAGE LEVEL CONTROL



FOR FURTHER STUDIES
PRESS '1' TO USE BASE CASE
PRESS '2' TO KEEP THE LATEST DATA
?

Figure 5. Graphics display for 5-bus and 7-line system

Voltage level control

The Table II is also seen to be effective in displaying the improved situation after the economic dispatch program is run. The total losses drop to 17.52 MW, about 24 % of the base case losses.

For a contingency study, line #6 is removed (or switched out). The graphics display clearly confirms that the flow in that line is zero (Figure 6).

Example 2 - A 25-bus and 35-line system

The capabilities of this program in displaying larger systems and the high resolution of Tektronix terminal can be appreciated by analyzing a 25-bus and 35-line system[11] (see input data in Table V of appendix of reference 12). The graphics display of the load flow is shown in Figure 7. This example demonstrates the feasibility of presenting a 25-bus system on one page of graphics display.

CONCLUSIONS

A digital computer program has been developed especially to help students in the analysis of the following types of problems :

(1) Load flow
(2) Load and generation studies
(3) Voltage level control
(4) Economic dispatch
(5) Contingency and planning studies.

This program has been dimensioned for 30 buses and 50 lines. It has been tested on power systems of up to 25 buses and 35 lines. Programmers familiar with the FORTRAN language and the TCS instructions will have no difficulty in developing any additional software for the power system analyzer.

Finally, from a teaching point of view, the program can offer students a graphical presentation of more challenging power systems. The interactive features save time. The ability to display a 25-bus system on a screen will undoubtedly make those studies more effective and less limiting. With the support of the IBM system and the many Tektronix graphics terminals available, this program provides the university with a very useful teaching tool in power systems engineering.

Table II . RESULTS OF ECONOMIC DISPATCH

GAUSS-SEIDEL TECHNIQUE CONVERGED IN 18 ITERATIONS

BUS	VOLTAGE		MAGNITUDE	DELTA(DEGS)	REAL PWR(MW)	REACTIVE PWR
1	1.05	0.00	1.05	0.000	275.20	120.05
2	1.02	-0.04	1.02	-2.446	75.63	52.72
3	1.02	-0.02	1.02	-0.943	117.69	-17.22
4	0.92	-0.17	0.94	-10.345	-250.00	-76.00
5	0.98	-0.07	0.98	-4.062	-201.00	-128.00

LINE FLOW

LINE	SB	EB	REAL POWER (MW)	REACTIVE POWER (MVAR)	LOSSES (MW)
1	1	5	76.32	37.70	2.09
2	1	3	28.07	21.96	0.33
3	3	5	93.13	35.79	1.63
4	1	4	170.80	60.39	8.94
5	2	5	35.85	23.09	0.56
6	2	3	-52.00	9.24	0.34
7	2	4	91.74	20.42	3.64
				TOTAL LOSSES	17.52

LAMBDA = 11.718750

OPTIMAL GEN

GEN	MW
1	275.20
2	286.63
3	278.69

BIBLIOGRAPHY

(1) T.E. DyLiacco, M.K. Enns, M.D. Anderson, etal, "Considerations in Developing and Utilizing Operator Training Simulators", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 11, November, 1983, p. 3672-3679.

(2) R.E. Staponski, "Development of a Computer Based Simulator for the Training of Electric Utility Operators", M.S. Thesis, University of Missouri-Rolla, Rolla, Missouri, 1980.

(3) J.R. Liao, M.D. Anderson, E.F. Richards, "Developement of a Small Computer-Based Power System Simulator for Economic dispatch and Operator Training", Midwest Power Symposium, October 15-16, 1981, Urbana, Illinois.

(4) O.H. Yek, "Development of an Interactive Man-Machine interface for a Dispatcher Training Simulator", M.S. Thesis, University of Missouri-Rolla, Rolla, Missouri, 1982.

(5) M. Wei, "Fault Analysis in Power Transmission System Using Computer Methods with an Interactive Computer Graphics Display", M.S. Thesis, University of Missouri-Rolla, Rolla, Missouri, 1983.

(6) A.J. Wood and B.F. Wollenberg, "Power Generation, Operation, and Control", John Wiley & Sons, Inc., 1983, pp 33-36.

(7) "Tektronix 4014 Computer Display Terminal User's Manual," Tektronix, Inc.

(8) "Terminal Control System," Tektronix, Inc.

(9) O.I. Elgerd, Electrical Energy Systems Theory: An Introduction, Second Edition, McGraw-Hill Book Company, 1982, pp 252-253.

(10) G.W. Stagg and A.H. El-Abiad, Computer Methods in Power System Analysis, McGraw-Hill Book Company, 1968.

(11) R.B. Gungor, N.F. Tsang and B. Webb, "A Technique for Optimizing Real and Reactive Power Schedules." IEEE Transactions on Power Apparatus and System, Vol. PAS-90, pp 1781-1790, Jul./Aug. 1971.

(12) C.H. Lo, "An interactive Power System Analyzer With Graphics Display For Educational Use", M.S. Thesis, University of Missouri-Rolla, Rolla, Missouri, 1984.

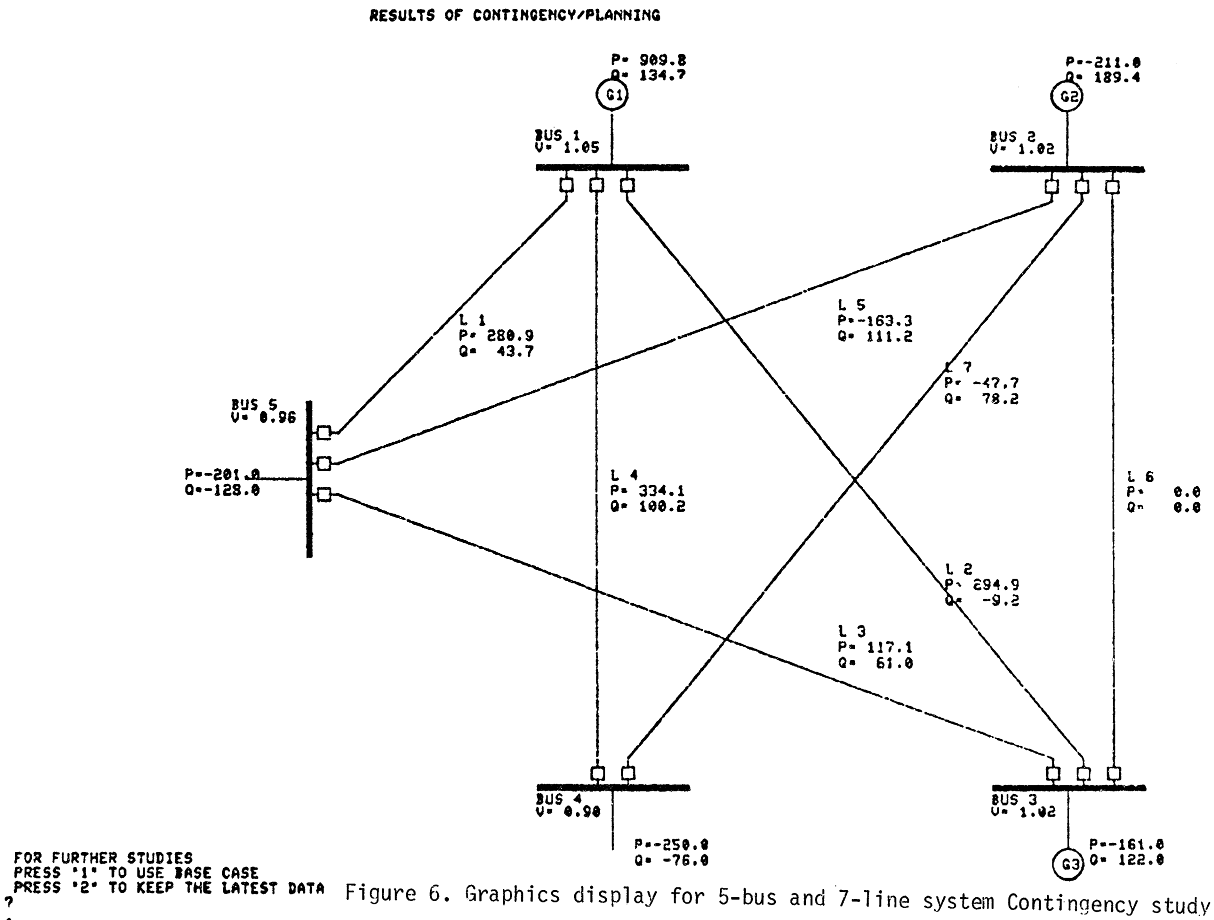


Figure 6. Graphics display for 5-bus and 7-line system Contingency study

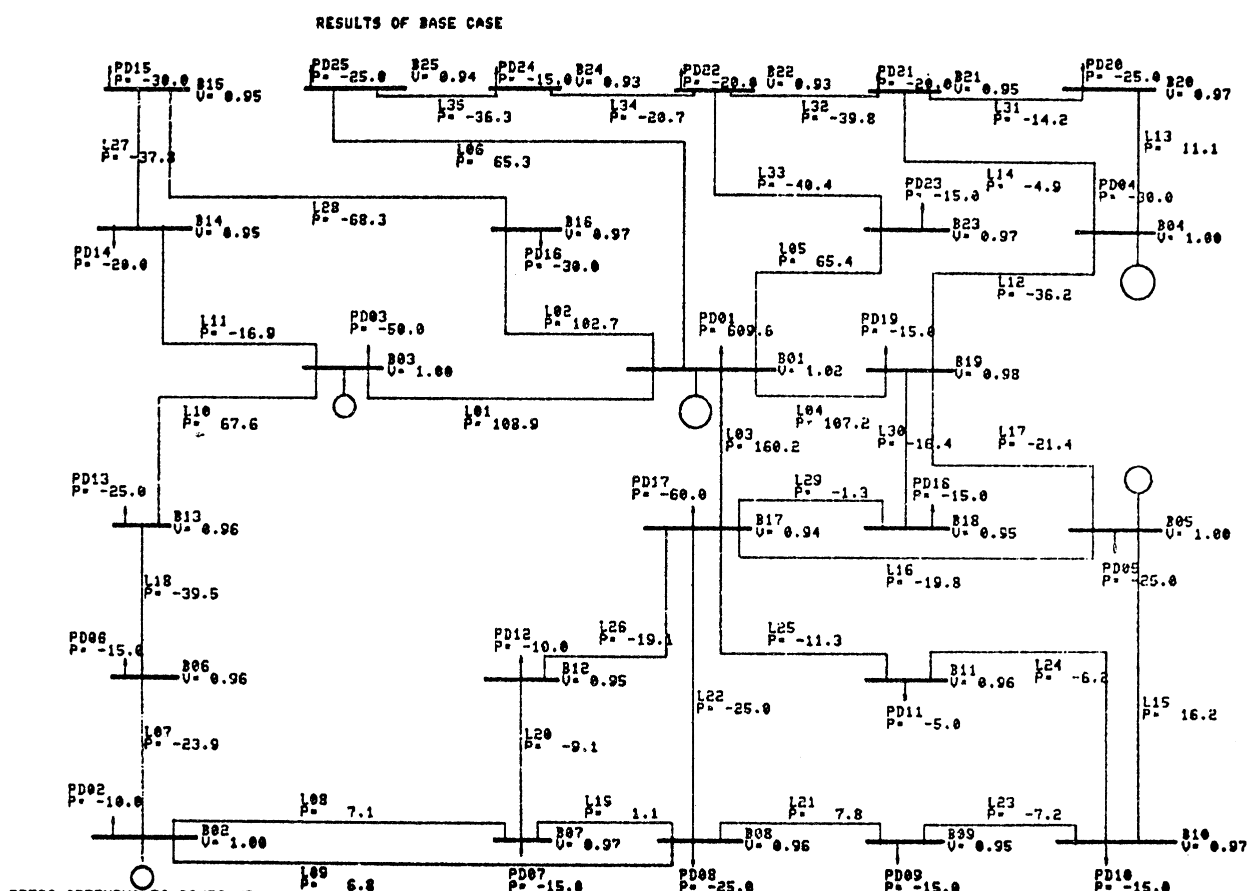


Figure 7. Graphics display for 25-bus and 35-line system Load flow