SPREADSHEET HELP FOR THE PROTECTION ENGINEER

By
A. F. Elneweihi
and C. F. Henville

BC Hydro
Vancouver, B. C.
Canada

Presented to the

Sixteenth Annual Western Protective Relay Conference
Spokane Washington
24-26 October, 1989

SPREADSHEET HELP FOR PROTECTION ENGINEERS

INTRODUCTION

A spreadsheet is an electronic worksheet where information is organised in rows and columns. A little effort spent in learning to use a spreadsheet can pay handsome dividends in productivity, accuracy and job satisfaction for the protection engineer. Modern Spreadsheets are user friendly and often include tutorials to make them easy to learn.

Early spreadsheet use focused on financial and business applications. They answered the "what if?" questions to examine the effect of variations in factors such as interest rates on financial performance and the like. In recent years, a growing number of scientific and technical applications have materialised. These started to grow when scientists and engineers became aware of the various features available in spreadsheets that make their use for a wide variety of these applications both attractive and easily attainable (References 1 and 2).

Spreadsheets may be used for simple as well as complex applications, depending on the familiarity of the user with the wealth of commands, formulas and features available. Novice users can quickly develop productive applications using basic functions and simple formulas. They may find then that progression to more advanced applications is relatively easy.

More sophisticated applications are possible with the aid of programming languages available with modern spreadsheets. Whether called Macros, as in Lotus and VPP, or a programming language, as in the Smart package (all explained in Appendix I), these features make it possible to use the spreadsheet for applications that previously were only possible through programming languages such as Basic or Fortran. Spreadsheets have an edge over these languages in the areas of easy and speedy design of user interface. Using the programing capabilities of spreadsheets requires an experienced user with some knowledge or desire to learn the syntax of the programming language of the spreadsheet. If this person is available, programs could be developed for use by others who are not familiar with computers, programming or spreadsheets.

This paper will discuss applications covering all these ranges of spreadsheet use to demonstrate some of the technical applications of spreadsheets in B C Hydro.

The spreadsheets described in this paper were produced using Lotus 1-2-3 (Lotus), VP-Planner Plus (VPP) or SmartWare (Smart). It is probable that other spreadsheet programs in the market could similarly be used to get the same results.

BASIC PRINCIPLES

A spreadsheet is a structured format designed to handle data and formulas. This structured format makes it easy to identify an entry and organise and manipulate information. Preparing a large worksheet on paper may not be so bad if one has to do it only once. Any changes, however, will be awkward to effect as it would require rewriting the entire sheet. With an "electronic" worksheet on the other hand, changes and manipulation of information in the sheet can be easily and swiftly made . In a spreadsheet, the intersection of a row and a column is called a cell. A cell is identified (addressed) by its row and column number. Any cell can hold a number, a text, a formula or a date.

A simple example is shown in Figure 1a, a table of test results for a time overcurrent relay. The column headings are text entries. The injected current, time dial settings and actual ("Meas.") operating times are numbers, and the mulptiples of pickup, expected ("Exp.") operating times and errors are formulas. Though the table could have been created manually, the "electronic" nature of the sheet makes changes simple. For example, only a few keystrokes would be required to enter a new column, "Pick Up Setting" on the left side, to allow variations in that number.

The ability to enter a formula in a cell is an important advantage of spreadsheets. It relieves the individual from the task of doing repetitive calculations. For example, in the VITOTEST (Figure 1a) spreadsheet, one can enter a formula in cell F10 to calculate the error in measured operating time. If the measured operating time changes (say during a later test), the error is automatically recalculated when the new time is entered. Moreover, with the "COPY" command, one only has to make a single entry of each type of data or formula. For example, all data and formulas in Figure 1a, except the injected current and measured operating times were only entered once, in row 10. Row 10 was then copied into the following rows in less than ten seconds. The ease with which formulas may be entered and copied could result in a spreadsheet that is not necessarily elegant or computationally efficient. But, this is not a problem in small spreadsheets.

Formulas may be as uncomplicated as simple addition and subtraction or as complex as to include trigonometric functions such as COS, ATAN2, Transcendental functions such as EXP, LN, SQRT or Statistical functions such as FACTORIAL, STD, MIN. Formulas could also use decision making functions such as IF-THEN-ELSE using comparison expressions such as ">" "<" "="...etc.

The ability to enter formulas in the spreadsheet cells opens the door for a wide variety of application to facilitate "what if" kind of investigations. This type of application is enhanced by the interactive nature of the spreadsheet. The results of changing data or formulas are seen immediately, without re-running or re-compiling a program. The HUCALCS spreadsheet shown in Figure 2 depends strongly on the interactive response to changing data. This will be explained further under "Applications".

Though not primarily data base programs, many spreadsheets have powerful data handling capabilities. For example, the sort command can be used to organise information for a variety of projects such as the relay replacement project shown in Figure 3.

The ability to graph information in rows and columns, makes it possible to convert numbers into pictures that make it easier to identify relationships and trends. The graphical output is used in several examples in this paper.

Programming in conjunction with the spreadsheet has many advantages. Designing attractive-to-use input screens and output formats with any programming language (such as BASIC or FORTRAN) is ,at best, a slow and tedious process. Using a spreadsheet, one can design and change the formats of the input and the output at will with "what-you-see-is-what-you-get" approach. The input-screen would simply be a section of the spreadsheet that the program would bring to the user to input his information. Similarly the output would be another portion of the same spreadsheet that the program would print upon the request of the user.

APPLICATIONS

VITOTEST- A Table for Overcurrent Relay Test Results

The layout and typical formulas for VITOTEST are shown in Figure 1a. Note the $ signs in the formula in cell B10 (for "Multiples of Pickup") make the cell reference "fixed" so that it is not adjusted when it is copied to cells in lower rows. Columns D and F have been formatted to show a fixed number of decimal places, and column F is also formatted in percent. In this example, the expected operating time has been calculated from a formula, but it could also be derived from a manufacturer's curve, and entered manually as a separate piece of data in each row.

Figure 1b shows a plot of the data which was generated by Figure 1a. The data in column D, "Expected Operating Time", was plotted with connecting lines, and with unmarked data points. The data in column E, "Measured Operating Time", was plotted without connecting lines, and with visible data points.

HUCALCS- An Aid for Setting Transformer Differential Relays

This spreadsheet is useful for optimising settings for type HU, or BDD transformer differential relays. The results of changing CT ratios or relay taps on the mismatch and sensitivity of the relay can be instantly seen. Figure 2 shows the layout of the sheet. The formula in column H is interesting. It uses a conditional IF...THEN... ELSE function to determine the current into the relay by checking whether the CT is connected wye or delta. Note that the sheet does not calculate CT ratios or relay taps, it only shows the results of various combinations. It would be possible to design a spreadsheet to do such calculations, but the results would be independent of the engineer's judgement of factors such as CT performance, and acceptable sensitivity. Since HUCALCS may be used by engineers other than the designer, most of it is protected against accidental change. The unprotected areas where data may be entered, are circumscribed on Figure 2.

HCB Replacement Spreadsheet

This is an example of the use of spreadsheets for handling a small relay data base. The HCB spreadsheet does not include any formulas. Figure 3 is a partial list that include all the columns but not all the rows of this spreadsheet.

As shown in Figure 3, the columns are labelled : DIV, for the division (area) of the BC Hydro system where the circuit is located; the circuit number;

the station name; the protection set (primary or standby) where the HCB relay is applied; the protection speed requirement for the replacement scheme; and the circuit length. The latter column was added since fibre optics-based schemes were considered for HCB replacement. As the project was reviewed by all the concerned departments in the company, many changes had to be made to the list. For example, circuits were added or deleted and the protection requirements were, in some cases, changed. Revisions to the sheet were done with the ease of pushing a few keystrokes. Also sorting was done on the list in more than one way, in order to meet different needs. For instance, the list sent to the Area Transmission Planning department was sorted by division; the list sent to the Design department was sorted by circuit number; and the list to the Communications department was sorted on the protection speed column to extract a list of circuits that need communication channels. The list in Figure 3 is sorted on 5 columns in the following order; Protection speed, Circuit No., Division Name, Station Name and Protection Set.

SHPMPROG - Setting Calculations for SHPM Relays

Quadramho, manufactured by GEC, is a multi-zone distance relay with phase and ground elements. It is being used by BC Hydro for the protection of a number of circuits. After calculating the relay reach based on line data, and required zones of coverage, the protection engineer has to specify the relay's "K" factors. These are analogous to relay taps and are to be specified for each relay element (zone1, zone2..etc). Determining the "K" factors is a fairly tedious and time consuming process. It was, therefore, logical to develop a computer program to perform it.

GEC, having recognised this, introduced a computer program using the BASIC language to calculate the "K" factor settings. This program did not meet all BC Hydro needs. For instance, the zone 1 reach for the ground element is often not set the same as the zone 1 reach for the phase element. The GEC BASIC program assumed the use of identical reaches for the phase and ground elements and offered no option for different setting selection for the latter. It was also desirable to have more detailed data in the output than provided by the GEC program. SHPMPROG was therefore developed, using the programming language of Smart in conjunction with the spreadsheet module of that product. The program was developed for use by engineers not familiar with programming or spreadsheets.

When the user invokes the program, an input-screen appears as shown in Figure 4a. The user would then input the data requested by the program, such as the positive and zero sequence impedances of the circuit and the desired reach of relay elements. On completion of the last entry, the user pushes a key to resume program execution. Within 3 seconds the program presents a summary of results and four choices for the user (see Figure 4b). If either "change input quantities", or "print results and do next circuit" option is chosen, the same input screen just filled would be presented. This would save the user having to re-enter all quantities if only a few entries need be changed. If "print results and do the next circuit" option is selected, printing will proceed while the user is entering data for the next circuit. Some users of this program have produced settings for four circuits in a few minutes with most of the time consumed in data entry and printing. A copy of the output is shown in Figure 4c.

Note that SHPMPROG is a combination of a program and a spreadsheet, with the feel of a program that has to be re-run with each set of data. It mainly uses the spreadsheet for easy formatting of the input screen and the hard copy output. Some formulas that were not related to the mainstream of the program were entered in the the spreadsheet cells (in the output area). This helps make the main program shorter and easier to debug. More details on the program are outlined in Appendix II.

SELMASK - To Record and Calculate SEL Relay Logic Mask Settings

Many Schweitzer Engineering Laboratory relays use logic masks to configure the connection of measuring elements to output relays. The settings of these masks are shown as two digit hexadecimal words. SELMASK is used to record the status of each measuring element with respect to each output relay and to calculate the appropriate hexadecimal words. As can be seen from Figure 5a, the binary description of each logic element is much more easily understood than the two digit words. Further the automatic calculation of the words reduces the chances of mistakes when applying the mask settings.

There is no function in the VPP spreadsheet to directly calculate hexadecimal numbers from binary numbers. SELMASK calculates the mask words by using a look up table. The table is shown in Figure 5b, and the formulas in cells E52 and F52 which lead to the derivation of word 4 for the MPT mask are also shown in Figure 5b. Note that the formulas in Row 52 and their results are normally hidden to enhance the appearance of the sheet. However, in Figure 5b, these results have been displayed to show the intermediate calculation.

FLTLOC- To Calculate Fault Location Correction Factors for Non Homogenous Lines

This spreadsheet calculates the correction factors to be applied to fault location estimates from a device that assumed the transmission line to be homogeneous, when in fact it was not. After the first manual calculation, the desirability of using a spreadsheet became obvious! Figure 6a shows the format of part of this sheet. Note that the correction factors for single line to ground faults and multi phase faults are calculated separately. This spreadsheet is designed for a user who need not be especially familiar with spreadsheets. Like HUCALCS, most of the sheet is protected against accidental change, and the circumscribed areas on Figure 6a show the regions where the user may enter data. The input screen of the sheet also tells the user how to invoke a macro to print out the correction factors.

Figure 6b shows a spreadsheet plot of the data of 6a. The plot is useful for showing whether it's worth using correction factors at all. As can be seen from Figure 6b, the correction factors in this case are so small, that their use is of questionable value. In fact the plots for multi phase faults cannot be distinguished from those for single line to ground faults. If the factors are to be used, they should be plotted manually, or using a more sophisticated plotting program for better resolution.

Double Ended Fault Location Calculations

Various fault location algorithms for double ended fault location have been put on spreadsheets, see figures 7 and 8.

Figure 7 shows the structure of a spreadsheet using multiple rows of data to make multiple estimates of the location. The calculations behind this spreadsheet are derived from Reference 3. The output of this speadsheet is approximately equivalent to the output of PROFILE (a double end fault locator program produced by Schweitzer Engineering Laboratories).

Figure 8 shows part of a spreadsheet program to calculate fault locations based on unsychronised fault information from both ends of a line. The data which must be entered manually is circumscribed. This program is based on the algorithm for single line to ground fault location estimation given in Reference 4.

MHOTEST 1- An Aid to Testing Distance Relays

MHOTEST 1 is an example of a spreadsheet used to calculate test quantities for a distance relay with a simple or offset mho characteristic. The layout is shown in Figure 9. This type of sheet was extensively used in distance relay tests reported in Reference 5. The difference between a spreadsheet approach and a BASIC program can be seen by comparing MHOTEST 1 with the program of Reference 6. While the BASIC program produces similar output, it must be re-run several times with different fault impedances to test different points on a mho characteristic. MHOTEST 1 is an example of a computationally inefficient program. The formulas to calculate test quantities for each fault angle are repeated in groups of three rows. To save disk space, only two sets of rows of formulas are stored. They are then copied into additional rows when required, to create test data.

Like HUCALCS (Figure 2), MHOTEST 1 is protected against accidental changes of formulas. The data that may be changed by the user are circumscribed on Figure 9.

SELANAL- To Analyze SEL Relay Reports

The data produced by Schweitzer Engineering Laboratories (SEL) relays event reports are ideal for spreadsheet analysis, due to their tabular format. SELANAL has been designed to do this analysis. A description of the sheet, and the instructions for its use, are given in Appendix III. Figure 10a shows the graphical plot of currents and voltages for a staged C phase to ground fault on a 500 kV line. Note that the currents have been scaled down by a factor of 100, to fit on the same graph as the voltages. While Figure 10a has some oscillographic value, it clearly does not have the same amount of information as a digital fault record of the same fault, as shown in Figure 10b. Figure 10a does clearly show the operation of the relay filters however, and gives useful insight into relay performance. Figure 10c gives somewhat different information, this time about the direction of the fault. In the case of phase relationships, the format of the data presention of Figure 10c is as useful, or more useful than the fault record of Figure 10b.

CONCLUSION

Spreadsheets have an important part to play in the daily work of the protection engineers. From helping in determination of settings to actual setting selection for relays, from use in organising information to the scheduling of projects, spreadsheets offer a rather easy, flexible and efficient tool that can be used to perform tedious, repetitive tasks. Their role in providing the programmer with a user interface that is easy to develop and change has also been recognised and utilised by the authors and explained in this paper. More spreadsheet applications are planned for use by protection planners in BC Hydro. All these efforts have one common goal, this is to increase the productivity and job satisfaction for the protection engineer.

ACKNOWLEDGEMENTS

Lotus and 1-2-3 are registered trademarks of Lotus Development Corporation.
VP-Planner Plus is a trademark of Paperback Software International.
SmartWare is a registered trademark of Informix Software, Inc.

REFERENCES

1 Orvis, William J., "1-2-3 For Scientists & Engineers", Paperback published by SYBEX, 1987.

2 Rao, Nutakki D., "Microcomputer Spreadsheet Calculations For Application in Power Systems", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, No. 9, September 1984, pp. 2537-2543.

3 Bartz, Robert C., and Schweitzer, E. O., "Field Experience With Fault Locating Relays", 13th Annual Western Protective Relay Conference, October 20-23, 1986.

4 Sachdev, M. S., and Agarwal, R., "A Technique for Estimating Transmission Line Fault Locations From Digital Impedance Relay Measurements", IEEE Transactions on Power Delivery, Vol. 3, Jan 1988, pp. 121-129.

5 Henville, C. F., "Type Tests on Distance Relays", 14th Annual Western Protective Relay Conference, October 20-22, 1987.

6 "Program to Compute Test Set Settings For Testing Distance Relays", A BASIC program available from Schweitzer Engineering Laboratories.

	A	B	C	D	E	F
1	Very Inverse Time Overcurrent Relay Test Results					
2						
3	Pickup Setting==>		2			
4						
5						
6	Injected	Multiples	Time	Operating Time (S)		
7	Current	of Pickup	Dial	------------------		
8	(A)			Exp.	Meas.	Error
9	----------	-------	-------	-------	-------	-------
10	3	1.5	1	27.000	30	11.1%
11	4	2	1	13.500	11	-18.5%
12	5	2.5	1	9.000	8	-11.1%
13	7	3.5	1	5.400	5	-7.4%
14	9	4.5	1	3.857	3.5	-9.3%
15	11	5.5	1	3.000	2.8	-6.7%
16	13	6.5	1	2.455	2	-18.5%
17	15	7.5	1	2.077	1.9	-8.5%
18	17	8.5	1	1.800	1.6	-11.1%
19	19	9.5	1	1.588	1.6	.7%
20	21	10.5	1	1.421	1.3	-8.5%
21	23	11.5	1	1.286	1	-22.2%

CELL	FORMULA	
B10	+A10/C3	
D10	13.5*C10/(B10-1)	
F10	(E10-D10)/D10	(Formatted in percentage)

Figure 1a - VITOTEST

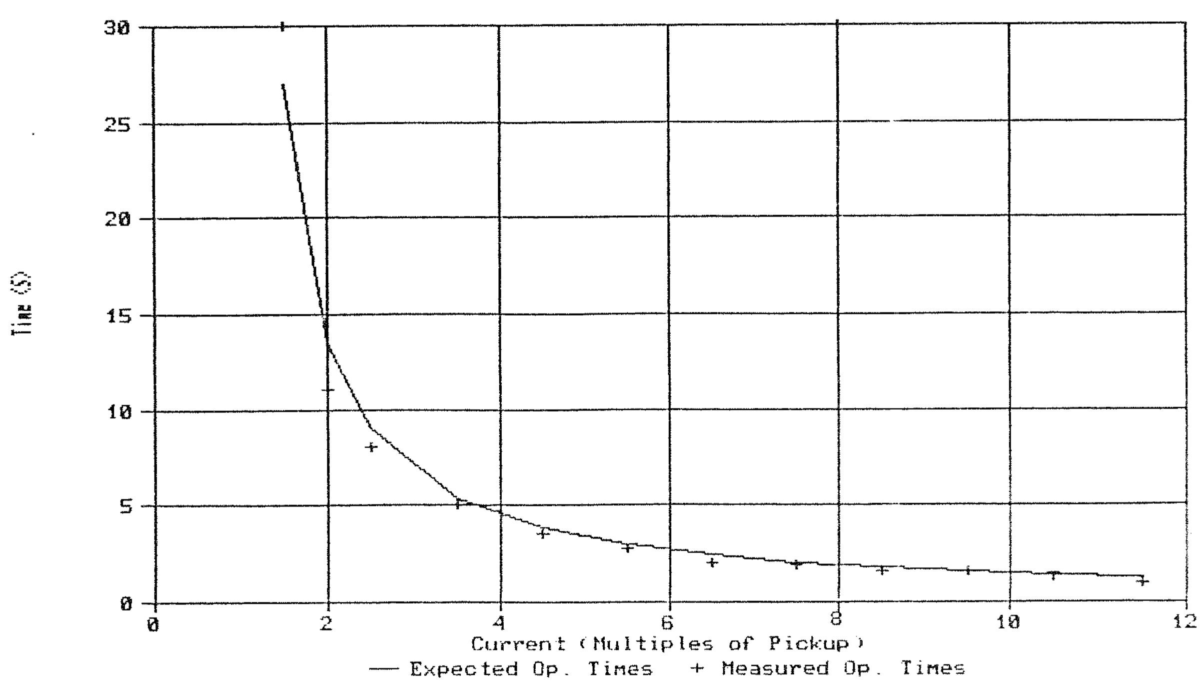


Figure 1b - Plot of VITOTEST Characteristics

	A	B	C	D	F	G	H	I	J
1	HU RELAY SETTING CALCULATIONS								
2	=================================								
3							LV Taps (%)		
4	Station=	GLD	Tformer=	T1&T4	Base		Max=>(+	12.5	
5			Device=>	87TS	M.VA===>	90	Min=>(-	12.5	
6									
7	Wdg.	Kv	Pri A @	CTR	Sec.	CT	Relay	Relay	%M
8			Base	(?-5A)	A	CONN	A	Tap	
9			MVA						
10		-------	-------	-------	-------	---	-------	-------	-------
11	HV	230	226	500	2.26	d	3.91304	4.2	
12	Tert	12.6	4124	5000	4.12	y	4.12393	4.6	-3.9%
13									
14	LV+	155.25	335	1200	1.39	d	2.41546	2.9	-11.9%
15	LV	138	377	1200	1.57	d	2.71739	2.9	.6%
16	LV-	120.75	430	1200	1.79	d	3.10559	2.9	14.9%
17									
18									
19	HU TAPS	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
20									
21	Sensitiviy Setting===>			30					
22	Sensitivity (% of Rating)				HV==>	56%			

FORMULA IN CELL H11==> @IF(G11="d",F11*@SQRT(3),F11)

Figure 2 - HUCALCS

HCB UPGRADE

LIST OF CIRCUITS THAT

REQUIRE A PROTECTION REVISION

DIV	CIRCUIT	STATION	PROT'N	PROT'N SPEED	CIRCUIT LENGTH (KM)
VI	1L12	GOW	PRI	F	6.42
VI	1L12	GTP	PRI	F	
SI	2L19	BR1	PN	F	1.63
SI	2L19	BRT	PRI	F	
LM	2L27	ING	PRI	F	5.00
LM	2L27	WHY	PRI	F	
LM	2L3	HPN	PRI	F	5.26
LM	2L3	WLT	PRI	F	
LM	2L53	MAN	PRI	F	7.29
LM	2L53	MAN	STBY	F	
LM	2L53	MUR	PRI	F	
LM	2L53	MUR	STBY	F	
LM	60L51	DGR	PRI	F	2.53
LM	60L51	DGR	STBY	F	
LM	60L51	MUR	PRI	F	
LM	60L51	MUR	STBY	F	
LM	60L28	GDK	PRI	S	2.75
LM	60L28	SPG	PRI	S	
LM	60L30	GDK	PRI	S	5.05
LM	60L30	KI1	PRI	S	
LM	60L31	KI1	PRI	S	15.51
LM	60L31	RYL	PRI	S	
LM	60L32	ANN	PRI	S	15.43
LM	60L32	KI1	PRI	S	
LM	60L36	BND	PRI	S	11.60
LM	60L36	NWR	PRI	S	
LM	60L39	BND	PRI	S	8.92
LM	60L39	HPN	PRI	S	
LM	60L40	BND	PRI	S	9.04
LM	60L40	HPN	PRI	S	
LM	60L77	NWR	PRI	S	3.17
LM	60L77	RYL	PRI	S	
LM	60L89	CYP	PRI	S	5.06
LM	60L89	HSB	PRI	S	
LM	60L97	JLN	PRI	S	3.27
LM	60L97	NOR	PRI	S	
SI	3L15	BR1	PN	S *	
SI	3L16	BR1	PN	S *	

* REMOVAL ONLY- NO REPLACEMENT; SEE NOTE **
** REPLACE HCB WITH IMPEDANCE RELAYS SET TO OVERREACH BR1&BR2

FIGURE 3

INPUT SCREEN FOR SHPM PROGRAM

```
ENTER CIRCUIT NUMBER ================================>      0000
ENTER STATION NAME ==================================>       AAA
ENTER CIRCUIT R1 IN OHMS ============================>      0.00
ENTER CIRCUIT X1 IN OHMS                                   0.00
ENTER CIRCUIT RO IN OHMS ============================>      0.00
ENTER CIRCUIT XO IN OHMS                                   0.00
ENTER CT RATIO TO ONE ===============================>      0.00
ENTER PT RATIO TO ONE ===============================>      0.00
ENTER DESIRED Z1 REACH IN PU OF CIRCUIT IMPEDANCE          0.00
ENTER REDUCTION FACTOR FOR Z1 GROUND (NORMALLY .06)        0.00
ENTER DESIRED Z2 REACH IN PU OF CIRCUIT IMPEDANCE          0.00
SET ZONE 3? (Y/N) ===================================>         A
ENTER DESIRED Z3 REACH IN PU OF CIRCUIT IMPEDANCE          0.00
ENTER ASPECT RATIO ==================================>      0.00
--------------------------------------------------------------
$$$ WHEN FINISHED DATA ENTRY PRESS FUNCTION KEY F8 TO PROCEED
--------------------------------------------------------------
```

FIGURE 4a

```
SUMMARY OF RESULTS:
------------------
DESIRED ZONE 1 REACH        =  85.0 %OF CIRCUIT
ACTUAL  ZONE 1 REACH        =  84.8 %OF CIRCUIT
DESIRED ZONE 1 GND REACH    =  80.2 %OF CIRCUIT
ACTUAL  ZONE 1 GND REACH    =  79.8 %OF CIRCUIT
DESIRED ZONE 2 REACH        = 198.1 %OF CIRCUIT
ACTUAL  ZONE 2 REACH        = 201.1 %OF CIRCUIT
DESIRED ZONE 3 REACH        = 311.0 %OF CIRCUIT
ACTUAL  ZONE 3 REACH        = 310.8 %OF CIRCUIT
===============================================

CHOOSE ONE OF THE FOLLOWING OPTIONS:

    1- PRINT DETAILED RESULTS AND QUIT
    2- PRINT DETAILED RESULTS AND DO NEXT CIRCUIT/STATION
    3- I WANT TO CHANGE MY INPUT QUANTITIES
    4- QUIT WITHOUT PROCEEDING ANY FURTHER

              ENTER 1, 2, 3 OR 4 AND PUSH RETURN     3
```

FIGURE 4b

SHPM RELAY SETTINGS

CIRCUIT: 60L2
STATION: SFL

TIME 18:09:07
DATE 16 Sep 89

CIRCUIT DATA

Z1= 5.89 +j 18.79 OHMS= 19.69 OHMS @ 72.6 DEG.
Z0= 13.28 +j 74.08 OHMS= 75.26 OHMS @ 79.8 DEG.
CTR= 160 -1 PTR= 600 -1

ZONE 1 SETTINGS

K1= 4 K2= 0.8 In = 5 Zph= 0.96 OHMS@ 75.0 DEG.
K11=4 K12=0.6 K13= 0.04 K14=1
DESIRED ZONE 1 MULTIPLIER= 4.649
ACTUAL ZONE 1 MULTIPLIER= 4.640
DESIRED ZONE 1 REACH = 85.0 %OF CIRCUIT
ACTUAL ZONE 1 REACH = 84.8 %OF CIRCUIT
= 16.70 PRI OHMS = 4.45 SEC OHMS @ 75.0 DEG.

COMPENSATOR SETTINGS

REDUCTION FACTOR SELECTED = 0.06
DESIRED K'n= 0.829 @ 10.5 DEG.
K4= 3 K5= 0.9 K6= 0.08
DESIRED Zn = 0.795 OHMS @ 85.5 DEG.
ACTUAL Zn = 0.796 OHMS @ 85.0 DEG.
ACTUAL K'n = 0.829 @ 10.0 DEG.
ACTUAL ZONE 1 GROUND REACH = 30.44 PRI OHMS@ 79.5 DEG.
= 79.8 % OF CIRCUIT = 8.12 SEC OHMS@ 79.5 DEG.

ZONE 2 SETTINGS

K21= 2 K22= 0.2 K24= 5
DESIRED ZONE 2 MULTIPLIER= 10.84
ACTUAL ZONE 2 MULTIPLIER= 11.00
DESIRED ZONE 2 REACH = 198.1 %OF CIRCUIT
ACTUAL ZONE 2 REACH = 201.1 %OF CIRCUIT
= 39.60 PRIMARY OHMS = 10.56 SECONDARY OHMS@ 75.0 DEG.

ZONE 3 SETTINGS

K31= 3 K32= 0.4 K33= 5
DESIRED ZONE 3 MULTIPLIER = 17.01
ACTUAL ZONE 3 MULTIPLIER = 17.00
DESIRED ZONE 3 REACH = 311.0 %OF CIRCUIT
ACTUAL ZONE 3 REACH = 310.8 %OF CIRCUIT
= 61.20 PRI OHMS= 16.32 SECONDARY OHMS @ 75.0 DEG.

ZONE 3 REVERSE SETTINGS

K33= 5 K35= 1 K36= 0.0 K37= 0.25
Z3 REV. REACH = 1.20 SECONDARY OHMS = 4.5 PRI. OHMS

MID POINT REACH

SELECTED ASPECT RATIO= 1.00
Ph-Ph REACH = 23.14 OHMS @ 25.8 DEG.

FIGURE 4c

SEL-121G MULTIFUNCTION RELAY LOGIC MASKS
====================================

DATE OF ISSUE=> 2 Dec. 1988

STATION=> DEMO
LINE====> 2L13 PRI or STBY===> PRI REV No.=> 0

WORD	ELEMENT	MASK MTU	MPT	MTB	MTO	A1	A2	A3	A4	RI	RC
1L	1ABC	1	0	0	0	0	0	0	0	0	0
1L	2ABC	0	1	0	1	0	0	0	0	0	0
1L	3ABC	0	0	0	0	0	0	0	0	0	0
1L	4ABC	0	0	0	0	0	0	0	0	0	0
1R	LOP	0	0	0	0	0	0	0	0	0	0
1R	50H	1	0	0	0	0	0	0	0	0	0
1R	50M	0	0	0	0	0	0	0	0	0	0
1R	50L	0	0	0	0	0	0	0	0	0	0
		MTU	MPT	MTB	MTO	A1	A2	A3	A4	RI	RC
2L	51NT	1	0	0	0	0	0	0	0	0	0
2L	67N1	1	0	0	0	0	0	0	0	0	0
2L	67N2	0	1	0	0	0	0	0	0	0	0
2L	67N3	0	0	0	0	0	0	0	0	0	0
2R	51NP	0	0	0	0	0	0	0	0	0	0
2R	Z1P	1	0	0	0	0	0	0	0	0	0
2R	Z2P	0	1	0	1	0	0	0	0	0	0
2R	Z3P	0	0	0	0	0	0	0	0	0	0
		MTU	MPT	MTB	MTO	A1	A2	A3	A4	RI	RC
3L	Z2PT	1	0	0	0	0	0	0	0	0	0
3L	Z3PT	1	0	0	0	0	0	0	0	0	0
3L	OSB	0	0	0	0	0	0	0	0	0	0
3L	3P50	0	0	0	0	0	0	0	0	0	0
3R	50MF	0	0	0	1	0	0	1	0	0	0
3R	RC	0	0	0	0	0	0	0	0	0	0
3R	RI	0	0	0	0	0	0	0	0	0	0
3R	DF	0	0	0	0	0	0	0	0	0	0
		MTU	MPT	MTB	MTO	A1	A2	A3	A4	RI	RC
4L	ALRM	0	0	0	0	1	1	1	0	0	0
4L	TRIP	0	0	0	0	1	0	0	1	0	0
4L	TC	0	0	0	0	1	0	0	1	0	0
4L	DT	0	1	0	0	1	0	1	1	0	0
4R	52BT	0	0	0	0	1	1	0	1	0	0
4R	52AT	0	0	0	0	1	1	1	0	0	0
4R	Z2GT	1	0	0	0	1	0	1	1	0	0
4R	Z3GT	0	0	0	0	0	0	0	1	0	0

HEX Nos.	MTU	MPT	MTB	MTO	A1	A2	A3	A4	RI	RC
Word 1	84	40	00	40	00	00	00	00	00	00
Word 2	C4	22	00	02	00	00	00	00	00	00
Word 3	C0	00	00	08	00	00	08	00	00	00
Word 4	02	10	00	00	FE	8C	96	7B	00	00

Note: Word "1L" means part of the left bit of the two bit hexadecimal number that makes up word 1. Similarly word "2R" means part of the right bit of word 2.

Figure 5a - SELMASK

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
42																									
43				MTU		MPT		MTB		MTO		A1		A2		A3		A4		RI		RC			
44	4L	ALRM		0		0		0		0		1		1		1		0		0		0			
45	4L	TRIP		0		0		0		0		1		0		0		1		0		0			
46	4L	TC		0		0		0		0		1		0		0		1		0		0			
47	4L	DT		0		1		0		0		1		0		1		1		0		0			
48	4R	52BT		0		0		0		0		1		1		0		1		0		0			
49	4R	52AT		0		0		0		0		1		1		1		0		0		0			
50	4R	Z2GT		1		0		0		0		1		0		1		1		0		0			
51	4R	Z3GT		0		0		0		0		0		0		0		1		0		0			
52			0	2	1	0	0	0	0	0	15	14	8	12	9	6	7	11	0	0	0	0			
53	HEX Nos.			MTU		MPT		MTB		MTO		A1		A2		A3		A4		RI		RC			
54	Word 1			84		40		00		40		00		00		00		00		00		00			
55	Word 2			C4		22		00		02		00		00		00		00		00		00			
56	Word 3			C0		00		00		08		00		00		08		00		00		00			
57	Word 4			02		10		00		00		FE		8C		96		7B		00		00			

Note: Word "1L" means part of the left bit of the two bit hexadecimal number that makes up word 1. Similarly word "2R" means part of the right bit of word 2.

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
67	HEX VALUES															
68	00	10	20	30	40	50	60	70	80	90	A0	B0	C0	D0	E0	F0
69	01	11	21	31	41	51	61	71	81	91	A1	B1	C1	D1	E1	F1
70	02	12	22	32	42	52	62	72	82	92	A2	B2	C2	D2	E2	F2
71	03	13	23	33	43	53	63	73	83	93	A3	B3	C3	D3	E3	F3
72	04	14	24	34	44	54	64	74	84	94	A4	B4	C4	D4	E4	F4
73	05	15	25	35	45	55	65	75	85	95	A5	B5	C5	D5	E5	F5
74	06	16	26	36	46	56	66	76	86	96	A6	B6	C6	D6	E6	F6
75	07	17	27	37	47	57	67	77	87	97	A7	B7	C7	D7	E7	F7
76	08	18	28	38	48	58	68	78	88	98	A8	B8	C8	D8	E8	F8
77	09	19	29	39	49	59	69	79	89	99	A9	B9	C9	D9	E9	F9
78	0A	1A	2A	3A	4A	5A	6A	7A	8A	9A	AA	BA	CA	DA	EA	FA
79	0B	1B	2B	3B	4B	5B	6B	7B	8B	9B	AB	BB	CB	DB	EB	FB
80	0C	1C	2C	3C	4C	5C	6C	7C	8C	9C	AC	BC	CC	DC	EC	FC
81	0D	1D	2D	3D	4D	5D	6D	7D	8D	9D	AD	BD	CD	DD	ED	FD
82	0E	1E	2E	3E	4E	5E	6E	7E	8E	9E	AE	BE	CE	DE	EE	FE
83	0F	1F	2F	3F	4F	5F	6F	7F	8F	9F	AF	BF	CF	DF	EF	FF

Cell Formulas
==============

```
E52===>  +F47+2*F46+2*F45+2*F44
F52===>  +F51+2*F50+2*F49+2*F48
F57===>  @INDEX($HEX-V,E52,F52)
         (Note, $HEX-V is the name of the range of cells containing
                the lookup table)
```

Figure 5b - Bottom of SELMASK, and lookup table.

FAULT LOCATION CALCULATOR FOR MULTI SEGMENT LINES

CIRCUIT NAME====> 60L210

	R1	X1	Ro	Xo	LL(km)
SETTINGS=>	35.36	50.91	53.14	177.98	100.05

PRESS ALT AND P KEYS TOGETHER TO PRINT OUT DATA FOR GRAPHICAL PLOT

LINE SEGMENT DATA TABLE

SEG	LENGTH	R1	X1	Ro	Xo	Act. km	Rep. km m-ph.	Rep. km 1-ph
						0	0	0
1	3.65	.69	1.81	1.34	5.99	3.65	3.56	3.55
2	2.74	.23	1.34	.93	4.48	6.39	6.19	6.25
3	1.72	.23	.95	.54	2.56	8.11	8.06	7.91
4	15.5	2.49	7.59	5.25	25.35	23.61	22.97	22.99
5	6.23	1	3.05	2.11	10.19	29.84	28.97	29.05
6	8.69	1.4	4.26	2.94	14.21	38.53	37.34	37.50
7	2.62	1.46	1.38	1.92	5.07	41.15	40.05	40.20
8	5.41	.87	2.65	1.83	8.85	46.56	45.26	45.46
9	2.51	1.4	1.32	1.84	4.86	49.07	47.85	48.04
10	2.99	.48	1.46	1.01	4.89	52.06	50.72	50.95
11	.8	.44	.42	.59	1.55	52.86	51.55	51.77
12	4.54	.73	2.22	1.54	7.43	57.4	55.91	56.18
13	42.65	23.72	22.45	31.3	82.55	100.05	100.03	100.08

Figure 6a - Correction Factors For Fault Location on Non-homogenous Lines

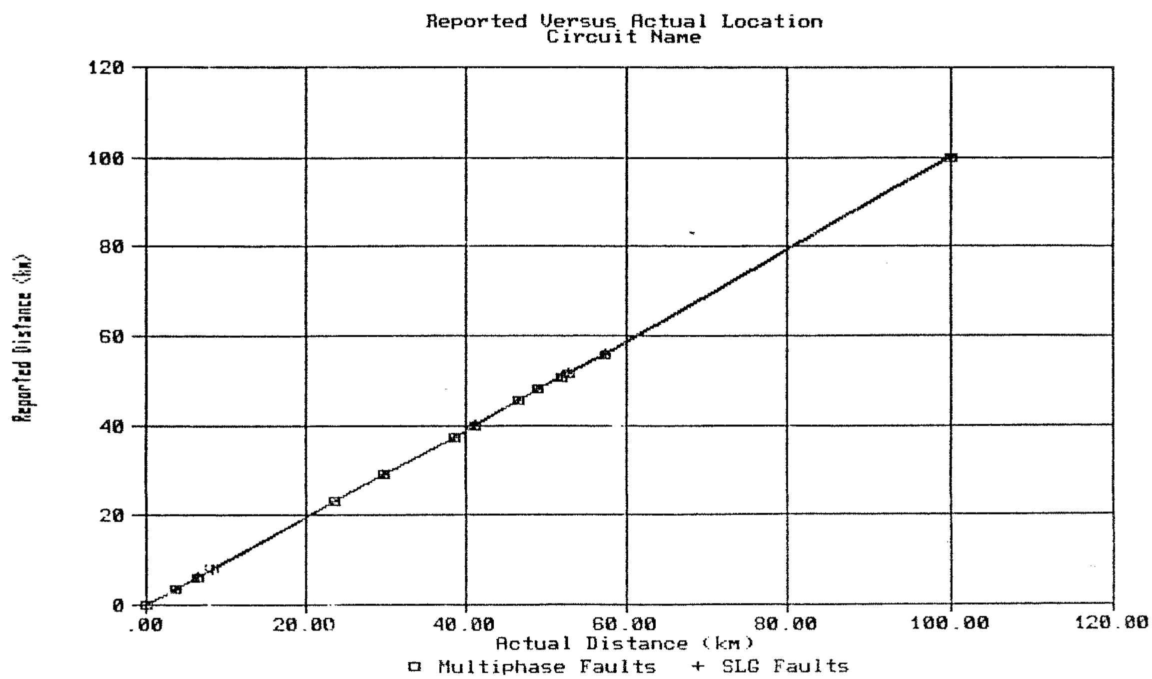


Figure 6b - Spreadsheet Plot of Correction Factors

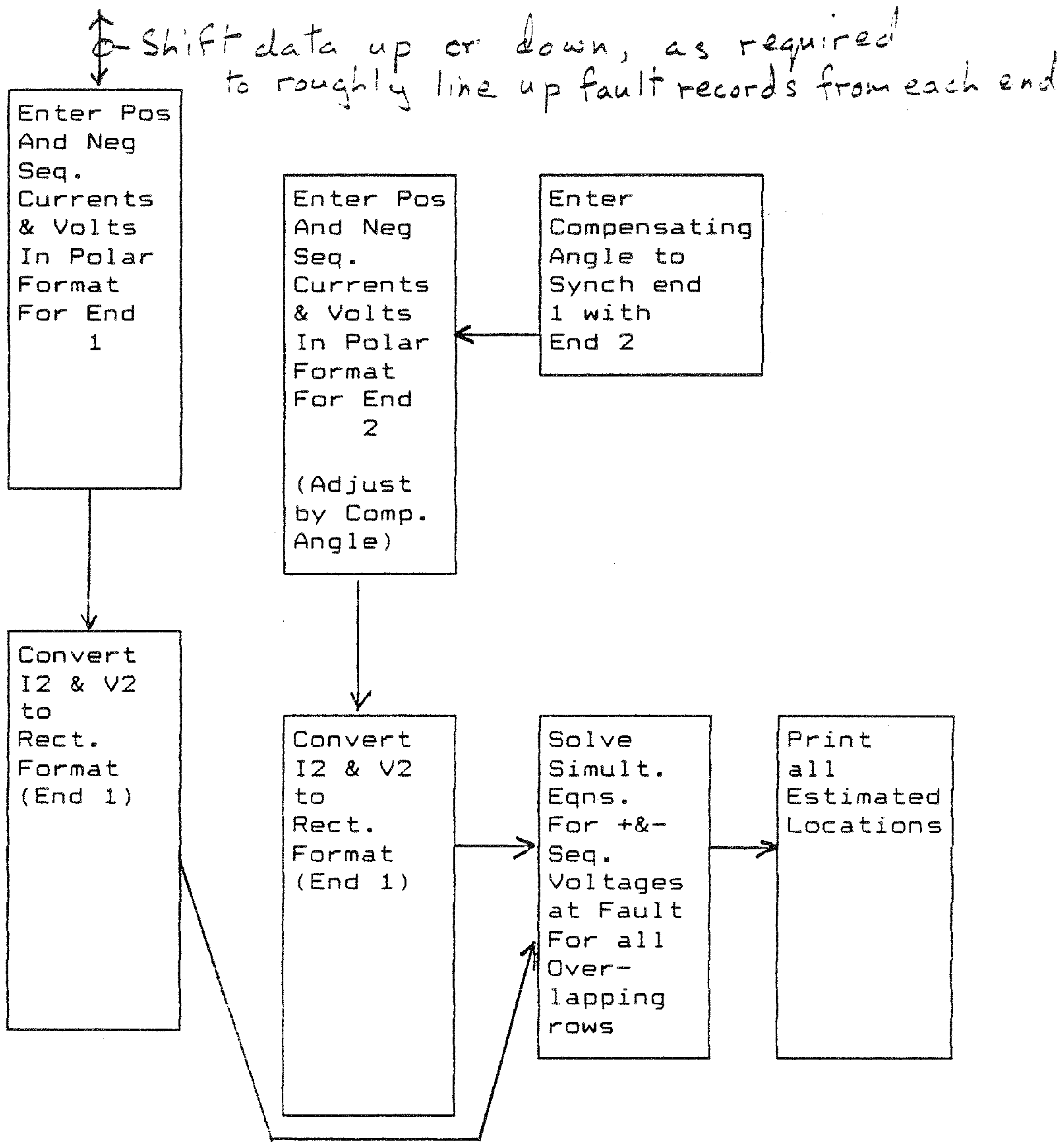


Figure 7 - Structure of double ended Fault Location Spreadsheet

FAULT LOCATION ESTIMATION BY SACHDEV SLG FAULTS

2L1 Fault 20 July 88

SENDING END =====> BRT (X) Fltd Ph=> 1 (1,2,3)

RECEIVING END ===> CKY (Y)

	Real	Imag.	Magn.	Angle
Z11=====>	11.72	70.04	71.0138	80.50054
Zo1=====>	36.1	207.6	210.7154	80.13536
Zo1-Z11=>	24.38	137.56	139.7038	79.94973
K=======>			.6557587	-.550807
Length==>	136.87	Y1====>	444	(Micromhos)

CALCULATED DISTANC
XXXXXXXXXXXXXXXXXX
FROM X =>43.41748
FROM Y=> 93.45252
"m"=====>.3172169

If Recalculation using line charging currents is desired ,
enter "m" here===> .317

Sending End Data (X END) Y1 at X=> 70.374 ERR

	Ir	Ia	Ib	Ic	Va	Vb	Vc
Magn.===>	787	982	230	218	135.1	138	143.9
Angle===>	-24	-19	-122	114	-9	-124	115
Real====>	718.9603	928.4992	-121.881	-88.6686	133.4367	-77.1686	-60.8148
Imag.===>	-320.102	-319.708	-195.051	199.1529	-21.1343	-114.407	130.4177

Receiving End Data (Y END) Y1 at Y=> 151.626

	Ir	Ia	Ib	Ic	Va	Vb	Vc
Magn.===>	346	185	216	204	132.5	136.7	136.5
Angle===>	5	-2	75	-59	12	-105	135
Real====>	344.6834	184.8873	55.90491	105.0678	129.6046	-35.3806	-96.5201
Imag.===>	30.15589	-6.45641	208.64	-174.862	27.5483	-132.042	96.52008

STEP 1

	(a1)	(b1)
Zx1+Zy1-Z3	86.9846	21.81643

STEP 2

p1===> .4396442
(mag Ioy/Iox)

STEPS 3-4 DELETED FOR BREVITY, IN THIS FIGURE
(This causes errors in steps 6 & 7)

STEP 6

Sin Theta	ERR
Rf1	ERR
Check Rf1	ERR

STEP 7

	Magn.	Angle	Real	Imag.
Z1xf===>			ERR	ERR
Z1yf===>			ERR	ERR

Figure 8 - Part of Spreadsheet
For Double End Fault Location

```
1PH-TEST
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                            Magnitud  Angle           Re Zs     Im Zs
SOURCE IMPEDANCEZ1s==>                   8        75          2.070552 7.72741
                                Zos==>                   8        75          2.070552 7.72741
=====================================================================
Zero Sequence Current Compensation Factor (Zo1-Z11)/3Z11
Kn ====>           1
---------------------------------------------------
         Magn.    Angle
          ------ ------- (enter Rev reach with
Z fwd===>        4  75.0001 positive magnitude
Z rev===>        4     -105 and true angle from ref)
=====================================================================
Enter Desired Angles of Fault Impedances ( -180<THETA<270 )
Enter Fault Type if not A-G (2 for B-G, 3 for C-G)
-------------------------------------------
```

THETA (Deg.)	Fault Type	Magn Va / Magn Ia	Ang. Va / Ang. Ia	Magn Vb / Magn Ib	Ang. Vb / Ang. Ib	Magn Vc / Magn Ic	Ang. Vc / Ang. Ic	Z1 Exp. / Z0 Exp.
75	1	34.7	0	69.4	-120	69.4	120	4.000
XXXXXXXXX		4.34	-75	.00	0	.00	0	16.000
XXXXXXXXX								
60	1	35.0	-8	69.4	-120	69.4	120	4.000
XXXXXXXXX		4.37	-68	.00	0	.00	0	16.000
XXXXXXXXX								

Figure 9 - MHOTEST 1

Figure 10a
Magnitudes of Currents and Volts

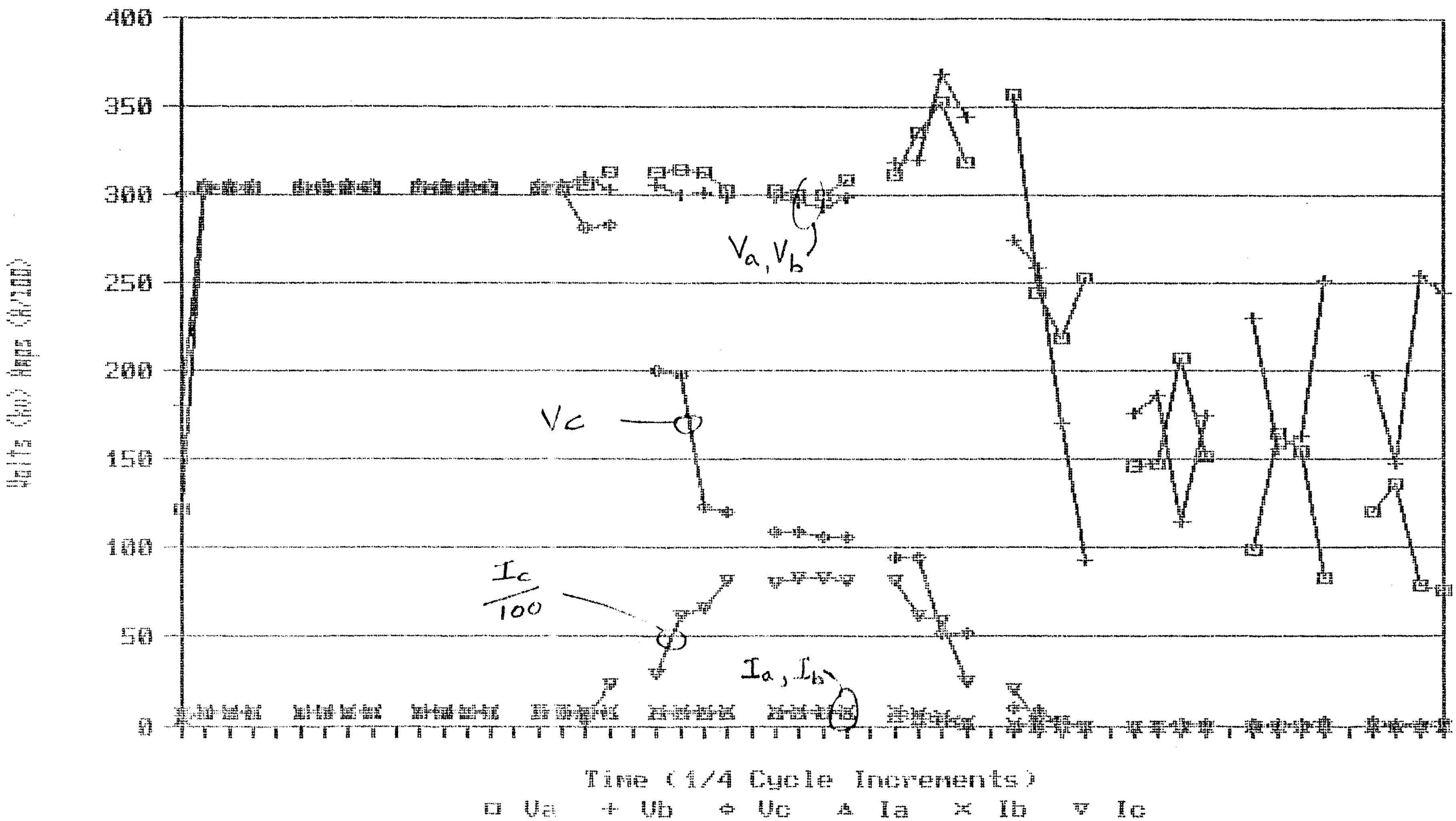


Figure 10a – 5L82 Staged Fault

5L82 STAGED FAULT TEST
SEPT. 20, 1988

<<< MICROSTORE DISTURBANCE RECORDER >>>

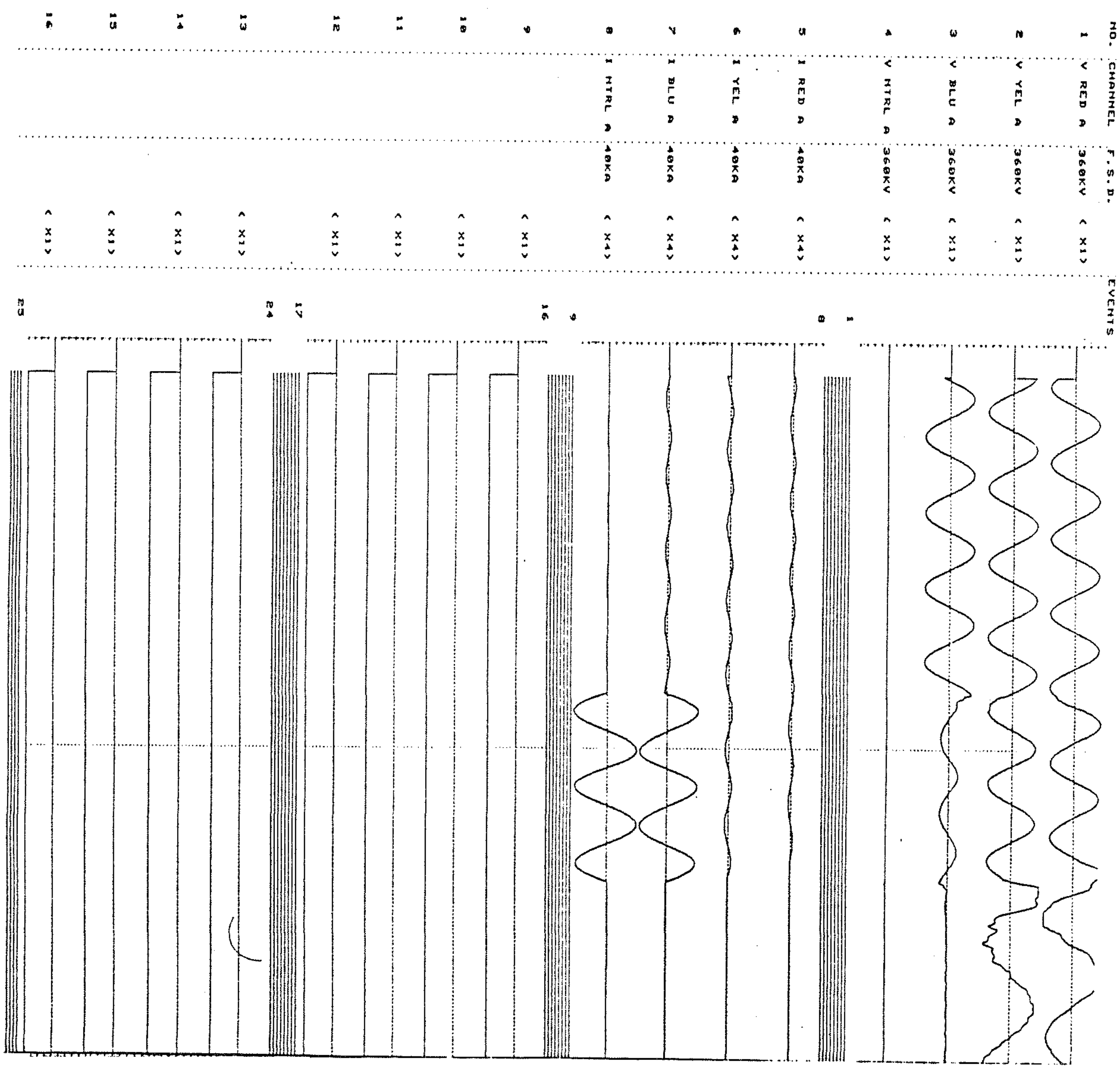
CIRCUITS & SYSTEMS DESIGN

B.C. HYDRO: VANCOUVER

IMS12 FAULT RECORDER/LOCATOR

```
HINE I.D. :- CSD BC HYDRO TEST UNIT 1
LOG TRIGGER MASK ( 16 - 1 ) :- OFF OFF OFF OFF 427% OFF OFF OFF + 5% +18% +18% +18% OFF OFF OFF OFF
.C. TRIGGER MASK ( 16 - 1 ) :- OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF OFF
NT TRIGGER MASK  ( 32 - 17 ) :- - - - - - - - - - - - - - - - -
                 ( 16 - 1 )  :- - - - - - - - - - - - - - - - -
LT NO.     :- 0029
E          :- 20 SEP 1988
E          :- 13:29:57.828 B
SE         :- OVER TRIGGER ON CHANNEL 08
PLE RATE   :- 4000HZ
```

NTS (32-25):-	EVENT 32	EVENT 31	EVENT 30	EVENT 29	EVENT 28	EVENT 27	EVENT 26	EVENT 25
NTS (24-17):-	EVENT 24	EVENT 23	EVENT 22	EVENT 21	EVENT 20	EVENT 19	EVENT 18	EVENT 17
NTS (16-9):-	EVENT 16	EVENT 15	EVENT 14	EVENT 13	EVENT 12	EVENT 11	EVENT 10	EVENT 09
NTS (8-1):-	EVENT 08	EVENT 07	EVENT 06	EVENT 05	EVENT 04	EVENT 03	EVENT 02	EVENT 01




```
** LINE #1  DISTANCE TO FAULT CALCULATIONS ARE:  SMALL DISTURBANCE CALCULATION ABORTED  **
** LINE #2  DISTANCE TO FAULT CALCULATIONS ARE:  SMALL DISTURBANCE CALCULATION ABORTED  **
** LINE #3  DISTANCE TO FAULT CALCULATIONS ARE:  SMALL DISTURBANCE CALCULATION ABORTED  **
V RED A  (01)  PREFAULT SIGNAL LEVEL :- 083.4 KV  POSTFAULT SIGNAL LEVEL :- 082.3 KV
V YEL A  (02)  PREFAULT SIGNAL LEVEL :- 083.2 KV  POSTFAULT SIGNAL LEVEL :- 078.7 KV
V BLU A  (03)  PREFAULT SIGNAL LEVEL :- 082.4 KV  POSTFAULT SIGNAL LEVEL :- 028.9 KV
V NTRL A (04)  PREFAULT SIGNAL LEVEL :- 000.3 KV  POSTFAULT SIGNAL LEVEL :- 000.8 KV
I RED A  (05)  PREFAULT SIGNAL LEVEL :- 000.5 KA  POSTFAULT SIGNAL LEVEL :- 000.6 KA  FAULT CURRENT DURATION :- 0000 MS
I YEL A  (06)  PREFAULT SIGNAL LEVEL :- 000.6 KA  POSTFAULT SIGNAL LEVEL :- 000.6 KA  FAULT CURRENT DURATION :- 0000 MS
I BLU A  (07)  PREFAULT SIGNAL LEVEL :- 000.6 KA  POSTFAULT SIGNAL LEVEL :- 006.0 KA  FAULT CURRENT DURATION :- 0040 MS
                                                  POSTFAULT SIGNAL LEVEL :- 006.7 KA  FAULT CURRENT DURATION :- 0040 MS
```

Figure 10b. — Oscillographic Record of 5L82 Staged Fault.

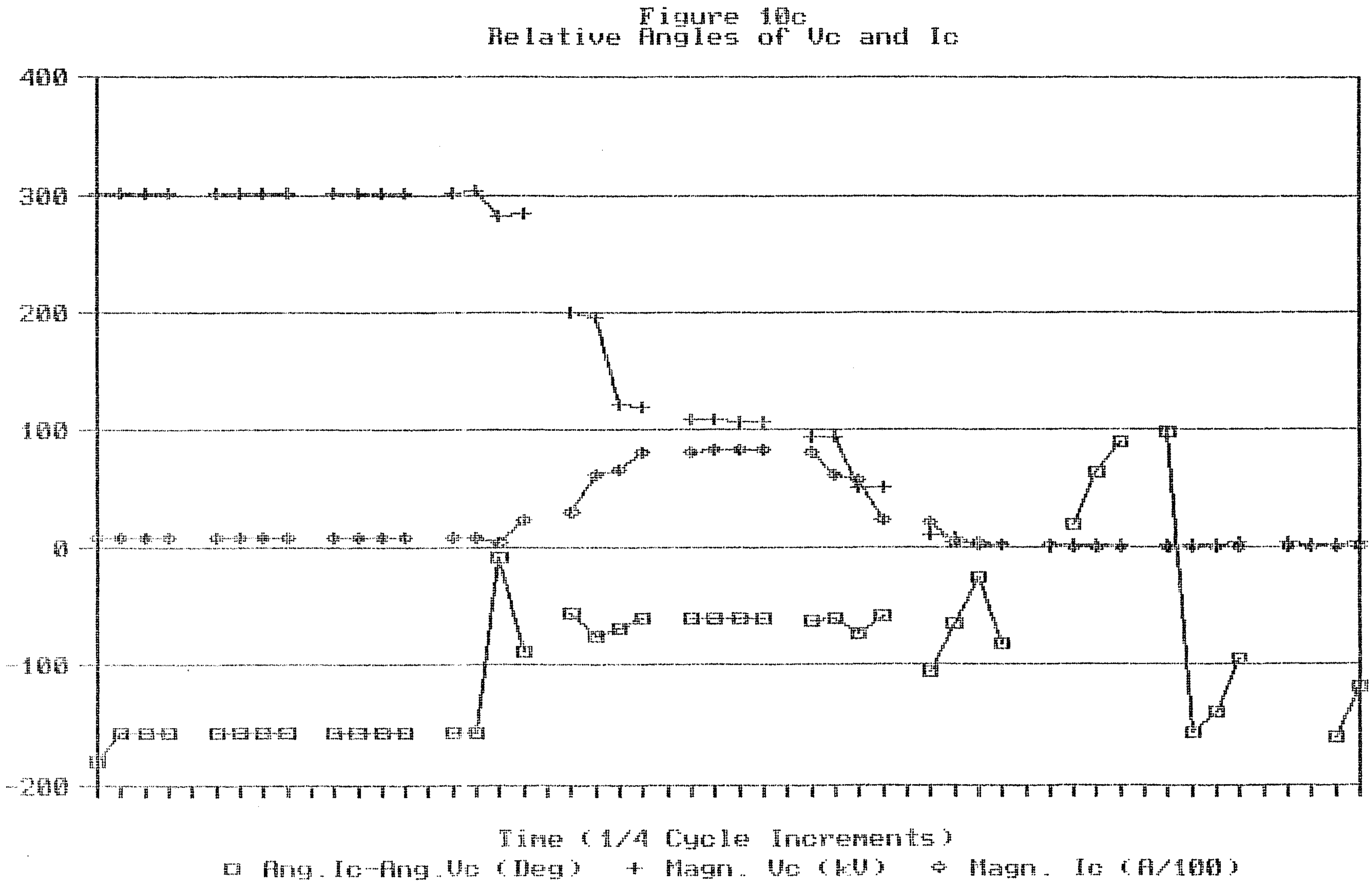


Figure 10c - 5L82 Staged Fault.

APPENDIX I

Stand-Alone Spreadsheets And Integrated Packages

A- Introduction

In this appendix, the broad similarities and differences between Lotus , VPP and Smart will be explored. Lotus and VPP are spreadsheet programs with some (limited) word processing and data base capabilities. The SmartWare package from Informix is an integrated package containing the following main modules : spreadsheet, data base, word processor, communications, and project processing. As with any integrated package of this type, each module can be used independently but data can also be moved from one module to another, e.g. from spreadsheet to data base or word processor (or vice-versa). It may then be more appropriate to compare Lotus and VPP with the spreadsheet module of Smart, rather than to the Smart package as a whole, and this in fact will be done for most of the discussions in this appendix. The authors decided, however, that it is also appropriate to discuss Smart as an integrated package for two reasons. First, Lotus and VPP have some word processing and data base capabilities. Second, it appears that at present, there is greater demand for integrated packages with consumers demanding ease of use, and at the same time, powerful modules within the integrated package.

B- Integrated Packages

In an integrated package such as Smart, movement of information between modules is very easy; requiring in most cases no more than selecting one command (SEND in Smart), and specifying the destination module and file name. Other stand-alone packages in the market, including Lotus and VPP, allow the importing and exporting of data to and from other programs such as word processor and data base programs, but the process could be time consuming and cumbersome. If this is the case, one might ask, why are not integrated packages such as Smart, Symphony or Framework as popular as stand-alone products. The answer is that for most integrated packages, each module is not as powerful as a stand-alone product. In the authors' experience, however this was not the case with the spreadsheet module of Smart. The comparison outlined later in this Appendix shows that, for the type of applications outlined in this paper, the Smart spreadsheet is as powerful and in some areas more powerful than many well known, stand-alone products.

C- Advantages and Disadvantages of Integrated Packages

The advantage of integrated packages is that they could open the door to a wider range of applications. For example, some engineering applications are better performed in a spreadsheet, others may be more easily and efficiently handled in a data base while some may need the use of both spreadsheet and data base with data moving between the two. Moreover, with a word processor being part of the integrated package, better "dressed-up" reports could be produced from the spreadsheet and the data base programs. This also means that graphs and spreadsheet tables could be produced in the body of the report, rather than as an attachment.

As previously indicated, Lotus and VPP spreadsheets include some data base capabilities. However, the data base is constrained by the fixed boundaries of the spreadsheet, i.e. rows and columns. This is not the case in the data base of an integrated package such as Smart. On the other hand, a user may be at a disadvantage using an integrated package if all that is needed is passing small amounts of data from the data base to the spreadsheet. In stand-alone products such as Lotus or VPP, the data base and the spreadsheet could be on the same page or screen, which could be advantageous for this limited use. When more powerful data base features are needed, however, integrated packages should be considered.

Similarities and Differences Between Lotus, VPP and Smart

The authors are aware of a few add-on packages, such as HAL and ALWAYS designed to enhance the performance of the Lotus Spreadsheet.In the following discussion, however, the "standard" program without any add-on packages will be compared. Recent updates for Lotus and Smart have been announced, but have not been reviewed yet by the authors. The products examined in this analysis are: Lotus 1-2-3 version 2.01, VPP+ version 2.0 and Smart version 3.1. The following comments are made to the best of the authors' knowledge, are directed at the technical applications discussed in this paper, and are not intended to be comprehensive. Further, some of the opinions expressed are subjective and based only on the authors' experience.

A- General Format

While all three spreadsheets have rows and columns, these rows and columns are not labelled the same way. For labelling, Lotus and VPP use letters for columns and numbers for rows. Smart use numbers for both rows and columns. Lotus and VPP's method makes it easier and faster for the user to enter and identify cell addresses.

B- Ease and Speed of Use

Even though the three products are relatively easy to use, some features in Smart are worth mentioning in this regard. One of these is the "Quick Keys". Normally, to issue a command, e.g. to retrieve or load a file, the user would have to go to the menu that includes that command and select it. In Smart, the "Quick Keys" enable the user to execute many of the most frequently used commands by pressing two keys together regardless of the menu the user is at. For example, "Alt" and "L" keys could be pressed together to load a file. Similarly, "Alt" and "S", when pressed, the worksheet would be saved. "Quick keying" could be done in Lotus and VPP only by programming Macros. In Smart, these Macros have been pre-programmed for the user.

Another attractive feature in Smart is that the last command or series of commands performed can be repeated by pressing the "F9" function key. Say there is a need to reformat a few cells identically (e.g., for values to have three-point precision instead of two), but the cells are not in a contiguous zone(i.e. cannot be included in one range of the worksheet). In Smart, one can reformat one cell , go to the next cell and press "F9" until all the cells have been reformatted as desired. With Lotus or VPP, to be as fast, the user would have to develop a Macro for formatting and call it at the desired cell locations.

C- Formulas

The three spreadsheets have almost the same facilities for ease of writing formulas, e.g. the user can point to a cell with the cursor instead of specifying its address. They differ, however in the maximum characters allowed per formula. In Lotus the limit is 240 characters while in Smart, up to 1000 characters are allowed. In Smart, a full screen is available for writing or editing a formula in a single-cell .

D- Sorting

Sorting is available in all programs but with varying degrees of flexibility. One can concurrently sort the rows of a spreadsheet on up to two keys in Lotus, four keys in VPP and 15 keys in Smart. Only in Smart can one also sort columns.

E- Graphics

All three programs have graphics capability, i.e. the capability to plot the data in the rows and columns into a graph. The power of this feature, however varies notably between them. In Lotus, graphs cannot be printed on hard copy from within the spreadsheet. In VPP and Smart, they can be. This makes the use of graphics in Lotus somewhat awkward. The graphics in VPP and Smart offer more features. In Smart, 3-D bar graphs with values displayed on top of the bars could be created.

F- Linkage Between Multiple spreadsheets

All three programs can combine or copy data from one or more spreadsheets to the sheet in current or active use. In Smart, data from other spreadsheets can be viewed, referenced, or printed without having to first combine them into the current spreadsheet as is required in Lotus and VPP.

G- Importing ASCII Files

All three programs can import data from ASCII formatted files. Lotus and Smart have a useful feature of being able to "parse" text into separate cells, with the spaces being used as data delimiters. This feature facilitates the import of tables from files generated by other programs. All three spreadsheets can "parse" numbers into separate cells. All text imported into VPP and Smart will go first into the first cell of each row, on a row by row format.

H- Matrices

In the Smart spreadsheet module, a variety of sophisticated calculations can be performed on matrices in a spreadsheet, including: calculation of the determinant, rank, and power of a matrix; calculations on diagonals; calculation of Eigenvalues and Eigenvectors ; inverting a matrix; multiplication of two matrices; and the ability to perform a multiple linear regression on values in a matrix. None of this is directly available in Lotus or VPP; though formulas could be written to do some of the mentioned functions.

I- Programming

In addition to their use in "what if" investigations, or in simple calculations, spreadsheets could also be used in a similar manner to programming languages such as Basic, Fortran ..etc. In Lotus and VPP, programming is done by using Macros. With Smart, an English-based programming language is provided. This programming language could be used independently in the project processing module or in conjunction with the spreadsheet module.

In Lotus, VPP and Smart, the term Macro means a "record" of keystrokes one would use to perform certain functions on the worksheet (e.g. insert, delete ...) This record is created and saved as a macro (after giving it a name). When called by the user, the macro would start executing the commands in its record. In Lotus and VPP, the macro language has been expanded to include not only the standard spreadsheet commands, but also special commands that can only be used in macros. In Smart, the same special commands were added, but included in what is called project processing which is actually an English-based programming language that could be designed and called for execution with or without any of Smart's modules. When used with a spreadsheet, the programming language (as well as the macros of Lotus and VPP) can get values from cells in the spreadsheet, manipulate them, and put the results back into the spreadsheet in the cells specified by the programmer.

With macros or project processing, an input screen (an interface) could be designed to prompt the users of the program to enter the values to be manipulated to produce the required results. An example in this paper shows how the programming language of Smart was used along with a spreadsheet to determine settings for QUADRAMHO relays, of GEC. The program was written so that it could be used by engineers not familiar with the basic concept of spreadsheets.

Preference for one programming language over the other is a personal issue. Some may find the syntax of the programming language of Smart easier to write and debug than the syntax of the Macro language of Lotus and VPP. On the other hand, those who are familiar with the macro language of Lotus or VPP may feel no need to learn the Smart programming language.

Common among the three products is a very useful programming feature. The programmers can have the macro or the project processing "record" theirs keystrokes while performing the actual steps they want the program to automate. The record could be later edited, if necessary. This feature makes it easier for the novice programmer to start and gain confidence quickly.

J- Data Base

The three products have data base capabilities but with varying power. The authors have not sufficiently explored this aspect to make an accurate comparison.

APPENDIX II

SHPM PROGRAM

In this appendix, more details about the SHPM program will be described in order to elaborate on the use of spreadsheets in conjunction with the programming language of Smart.

Figure II-1 shows the beginning of the program. When the user invokes the program, by pressing F8 and selecting SHPM, the commands shown will start execution. Command No. 2 will load the spreadsheet called "SHPMOUT" containing the input screen and the output form. Command 4 will put the cell with the address R1C15 at the top left corner of the screen so as to position the input screen for the user as shown in Figure 4a. With command No. 7 (Suspend), the program will be temporarily suspended to give the user the freedom of moving the cursor to change data and correct errors as required.

When the user is through with data entry, program execution can be resumed by issuing "Execute" command (Quick key F8). The program will then assign a name to each of the values entered. This is shown by commands 9 to 19. The result of these commands will be that the variable whose name is shown preceeded by the "$" sign, will acquire the value entered by the user in the cell whose address is shown on the right hand side of the equal sign. Note that instead of cell addresses, cell names are used. When creating the spreadsheet "SHPMOUT", these names were assigned to the cells where the user is to input his data. It is necessary in an interaction such as this between a spreadsheet and a program that the program points to cell names rather than cell addresses. If the cell location in the spreadsheet changes in the course of changing the input or the output form, the name definition of the cell will automatically change within the spreadsheet so that the name keeps pointing to the same piece of information. If instead cell address in rows and column numbers is used, the address in the program will have to be changed every time the cell location is changed.

Commands 20 to 135 are for manipulation of the data to determine the "K" factors settings for the relay. They contain a number of looping techniques and IF-THEN-ELSE statements, sometimes nested several levels. A portion of these commands is shown in Figure II-2.

Figure II-3 shows commands 136 to 177. When command 136 is executed, the user will have the screen shown in Figure 4b. Note that at this point, and unlike the case with the data input-screen, the program will not be suspended. It will stay in control, waiting for the user to select one of the options offered. When a selection has been made, commands 141 to 170 will process the user's instruction. Commands 171 to 177 are the subroutine for printing the output of the program.

Project file SHPMPROG

```
QUIET ON
LOAD SHPMOUT
GOTO SHPMOUT
GOTO R1C15
@R4C16 CURSOR TEXT
LABEL REDO
SUSPEND
$R1=RES
$X1=X1
$CTR=CTR
$RRZ1=REZ
$R=RED
$Z3ANS=Z3ANS
$PTR=PTR
$X0=X0
$R0=R0
$RRZ2=REZ2
$RRZ3=RRZ3
$AR=AR
```

FIGURE II-1

```
$Z1P=SQRT($R1^2+$X1^2)
$Z1S=($Z1P*$CTR)/$PTR
$RZ1S=$RRZ1*$Z1S
$K1=4
$K2=0.8
$ZPH=($K1+$K2)/5
$RZ1M=$RZ1S/$ZPH
WHILE $RZ1M<1
 $K2=$K2-0.2
 IF $K2<0
    $K2=0.8
    $K1=$K1-1
 ENDIF
 $ZPH=($K1+$K2)/5
 $RZ1M=$RZ1S/$ZPH
ENDWHILE
IF $RZ1M<=9.98
 $K14=1
 $K11=INT($RZ1M)
 $K12=(INT(($RZ1M-$K11)*10))/10
 $K13=(INT(($RZ1M-$K11-$K12)*100))/100
ELSE
 $K14=5
 $K11=INT($RZ1M/5)
 $K12=(INT((($RZ1M/5)-$K11)*10))/10
 $K13=(INT((($RZ1M/5)-$K11-$K12)*100))/100
ENDIF
```

FIGURE II-2

```
GOTO R68C1
LABEL OPTIONS
@OPTIONS CURSOR
@OPTIONS reformat block rc numeric normal nocommas precision 0
REPAINT ON
IF OPTIONS =1
  CALL PRINT
  UNLOAD SHPMOUT
  QUIT
ELSEIF OPTIONS=2
  CALL PRINT
  GOTO R1C15
  CURSOR DOWN
  CURSOR DOWN
  CURSOR DOWN
  CURSOR RIGHT
  JUMP REDO
ELSEIF OPTIONS=3
  GOTO R1C15
  CURSOR DOWN
  CURSOR DOWN
  CURSOR DOWN
  CURSOR RIGHT
  JUMP REDO
ELSEIF OPTIONS=4
  UNLOAD SHPMOUT
  QUIT
elseif options=5
  end
ELSE
  BEEP 2
  MESSAGE PRESS ENTER AND THEN 1,2,3 OR 4
  JUMP OPTIONS
ENDIF
END
PROCEDURE PRINT
IF UPPER($Z3ANS)="Y"
 report normal SHPMREP printer copies
ELSE
 REPORT NORMAL SHPMREP2 PRINTER COPIES
ENDIF
RETURN
```

FIGURE II-3

APPENDIX III

INSTRUCTIONS FOR SELANAL

A VP PLANNER PLUS SPREADSHEET FOR
ANALYZING SEL RELAY LONG FORM REPORTS

1.0 INTRODUCTION

The long form report of the SEL relay shows the sampled voltages and currents as instantaneous values in quarter cycle increments. The SEL instruction manual shows how these values can be treated as the rectangular coordinates of a series of phasors. The values can be converted to polar coordinates fairly simply, and are easier to analyze in polar form. Since there are 8 columns and 44 rows of data, an engineer analyzing the report usually only converts selected values to polar coordinates. The conversion to polar format becomes tedious after only a few samples are converted. The SELANAL spreadsheet converts all samples to polar format, and further, derives the sequence components of the phase currents and voltages in a few seconds.

The following instructions describe the structure of SELANAL, and show how to use it. The instructions assume the operator is familiar with the use of the spreadsheet program VP Planner Plus.

2.0 INPUT AND OUTPUT

This spreadsheet uses the 8 x 44 reported instantaneous currents and voltages in the SEL relay long form report, as input data. The data could be typed in manually from a report printed on hard copy. However, an easier, more error-free method, is to import the complete report from an ASCII file to a temporary spreadsheet, and then to copy the appropriate part of the report into SELANAL.

SELANAL uses the input data to calculate on a quarter cycle by quarter cycle basis, the magnitudes and angles of the reported polarizing current, residual current, phase currents, and phase voltages (see Fig. III-1). It further analyses the phase currents and voltages to report the magnitudes and angles of their positive negative and zero sequence components. The sequence components are also calculated on a quarter cycle by quarter cycle basis. The calculated currents and voltages can be printed or plotted to assist in analysis of the reported event. The calculated angles of the various phasors can also be printed or plotted. since the angle of the steady state phasor increases by 90 degrees at every sample, the angular information is most useful when reported with respect to the angle of another phasor in the report, or with respect to another arbitrarily selected phasor rotating with constant velocity.

3.0 STRUCTURE

SELANAL is split into several different ranges, as shown in Fig. III-2.

A5..H58 is the input range into which the raw data is input. This data is in rectangular format, with the data in any given row being the real components of phasors, which have as imaginary components the data in the row above. Note that the blank spaces between every four rows of data are ignored. These blank spaces only make it easier to identify each cycle of a given event record.

I5..X58 is the range where the magnitudes and angles of the phasors of the sampled data are calculated. This range uses the input data as a source. Note that the very top row of data in this range is meaningless, since there is no preceding row in the input data to give the imaginary components of the phasors.

The four ranges in the area K82..AM128 are where the phasors rotated through 120 degrees (a*(DATA)) and 240 degrees (a^2*(DATA)) are calculated and stored. These data are more easily multiplied in polar format, and added in rectangular format. Hence the ranges store the data in both formats. Ranges K82..X138 and Z82..AM138 get their data from range I5..X58. Ranges K162..X218 and Z162..AM218 get their data from the ranges directly above them.

Y5..AV58 is the range where the sequence components (referred to A phase) are calculated. These components are calculated from the formulae:

$$I_1 = (Ia + a * Ib + a^2 * Ic)/3$$

$$I_2 = (Ia + a^2 * Ib + a * Ic)/3$$

$$3Vo = (Va + Vb + Vc)$$

$$V_1 = (Va + a * Vb + a^2 * Vc)/3$$

$$V_2 = (Va + a^2 * Vb + a * Vc)/3$$

Note that 3Vo is calculated, instead of Vo, which is different from all the other sequence components. The sequence components are shown in rectangular and polar coordinates in this range. The polar format is useful for event analysis. The rectangular data is shown only as an intermediate step towards derivation of the data in polar format.

To the right of the range Y5..AV58 is an area into which selected data may be copied for scaling, or combination with other data for plotting or printing. This is called the output range. The first column in the output range is a series of angles in 90 degree increments. This column is supposed to represent a constantly rotating vector, and these angles can be subtracted from the angles of any other vector, to show shifting of the angle of that other vector over the period of the report.

Just below the input range is the listing of two small macros. The first macro may be used after the data is read in, to delete all formulae, and to condense the spreadsheet. Deleting the formulae speeds up calculations of formulae added during processing. Condensing the worksheet reduces its size from about 200 kB to less than 100 kB.

The second macro is useful to delete formulae from cells in the output range where these cells are in blank rows.

Note that the automatic recalculation feature of VPP is turned off in SELANAL. Whenever formulae are changed or added, the spreadsheet should be recalculated by pressing the F9 key.

4.0 USAGE

(a) Entering Data

The best way to enter the data is electronically. However, it is possible to type the data into the input range manually.

For electronic entry, the extraneous data from the SEL report (column headings, introduction, targets, summary and settings) have to be stripped away. All numbers from the long form report should be read into a temporary worksheet, using the commands / File Input Numbers (Filename). Where (Filename) is the name of the ASCII file containing the SEL relay long report. The range of cells containing the currents and voltages should then be named. This range is 8 columns wide and 54 rows long. Note that although there are only 44 rows of numbers, there are 10 blank rows (in between each cycle of data) included in the range. To name the range, move the pointer to the top left cell in the range, and use the commands / Range Name Create. Name the range DATA when prompted, and move the pointer to the bottom right cell of the range when prompted for the range to be named. Save the worksheet with a suitable name (such as TEMP.WK1) with the commands / File Save TEMP.

(b) Before Using SELANAL

Ensure the PC has sufficient memory by checking the number shown in the bottom left corner of the screen while in VP Planner Plus, with no worksheet present. Use the commands / Worksheet Erase Yes. There should be at least 200 k of memory available. If sufficient memory is not available, it will be necessary to delete some background programs (such as PC tools) which may be present in the PC.

(c) Loading SELANAL and Raw Data

Retrieve the worksheet by using the commands / File Retrieve SELANAL.WKS. Note that this worksheet will already have raw data in it, from some unrelated previous event. This previous data will be overwritten when the new data is read in.

Move the cursor to cell A5, and read in the data from the temporary worksheet. Use the commands / File Copy Combine Named range DATA, and give the appropriate worksheet name when prompted (e.g. TEMP.WK1). Observe the new data written into the raw data area.

Press the F9 function key to recalculate the output values from the new data.

If desired, to speed up future calculations, press the ALT and C keys together to invoke the macro that condenses the sheet and deletes the formulae. DO NOT SAVE THIS CONDENSED SHEET UNDER THE NAME SELANAL, since it will be of no use for future analyses with different raw data. The benefit of this macro is to speed up calculations using the existing data. These calculations may be required to scale certain magnitudes, or to compare angles of certain vectors for plotting or printing.

(d) Using and Saving Analyzed Data

When the output data has been calculated, it can be analyzed on the screen by looking at the numbers, or by being plotted.

Use the commands / Graph Type Line to start the plotting. Select the current or voltage magnitudes of interest by defining the data ranges A, B, C, D, E, or F as appropriate. Up to six ranges can be plotted on the same graph. Use the Options command within the graphing facility to add titles, legends, grids, etc. as desired to the graph. Fig. III-3a is an example of the type of plot that can be produced.

When plotting magnitudes, it is sometimes helpful to scale the plotted quantities. For instance, it can be seen that most of the plots are cramped at the bottom of Fig. III-3a. If all three currents are divided by 100, the plot of Fig. III-3b is obtained. The scaling was done by creating three new columns of data in the output range. The first cell of the first column was obtained by entering the formula + M5/100. Where the cell M5 refers to the cell containing the first value of Ia. The first cell was then copied into all 53 of the cells below it, to create a new column. The new column had zeroes in the cells which were in the rows with no original data. These zeroes should be erased to improve the look of the plot of this new column. There is a macro available to delete the zero in the blank rows. To invoke the macro, one should position the cursor on the top cell of the column to be corrected, then press the ALT and E keys together. The corrected column was then copied into two more new columns in the output range for Ib and Ic.

It is sometimes interesting to look at the relative angles of the various phasors. For instance, the maximum torque angle of the forward looking directional ground element occurs when the angle of the zero sequence current leads the angle of the zero sequence voltage by the maximum torque angle setting on the relay. One could create a column headed "AngIo-AngVo" in the output range. The first cell could contain the formula +AB5-AN5. Depending on the angles of Io and Vo, this formula could come up with answers >180 or <-180 , and the plotted angles could be confusing, see Fig. III-4a. The plotted angles could be kept within ±180 by applying conditions to the formula. Assume the first cell in the column containing the formula +AB5-AB5 is AX5. Then a new column could be created containing in the first cell, a formula @ IF(AX5>180, AX5-360, @ IF(AX5<180, AX5+360, AX5)). The plot of this improved formula is shown in Fig. III-4b.

Analyzed data may be saved at any time by using the / File Save commands. The data should be saved under an appropriate file name to describe the event, and should not be overwritten on top of SELANAL.WKS (which will be the default file name offered for saving). The analyzed data should be condensed to reduce the size of the worksheet from about 180 kB to less than 100 kB, before being saved. The macro Alt. C will condense the worksheet.

It is not recommended that analyzed data be archived, because of the large volume of the worksheet. It is best to archive the raw data from the SEL report, then to analyze events as required by SELANAL.

CFH/wpc
7 Apr'89

INPUT DATA (not full length) Currents and Volts in Rectangular Format

ENTER RAW DATA HERE   LOOK TO THE RIGHT FOR ANALYSED DATA=>

IPOL	IR	IA	IB	IC	VA	VB	VC
0	26	30	196	-200	11.4	117.1	-128.1
0	-138	-366	121	102	-138.8	76.5	63.8
0	-26	-30	-196	204	-11.6	-117.1	128.1
0	146	374	-121	-106	138.8	-76.6	-63.8
0	27	30	196	-204	11.7	117.2	-128.1
0	-152	-381	121	106	-138.7	76.6	63.7
0	-29	-30	-196	200	-11.8	-117.2	128.2
0	159	385	-121	-102	138.5	-76.6	-63.6

OUTPUT DATA (Partial) Currents in Polar Format

Ipol		Ires		Ia		Ib	
Magn.	Ang.	Magn.	Ang.	Magn.	Ang.	Magn.	Ang.
-----	-----	-----	-----	-----	-----	-----	-----
0	ERR	26	0	30	0	196	0
0	ERR	140	169	367	175	230	58
0	ERR	140	-101	367	-95	230	148
0	ERR	148	-10	375	-5	230	-122
0	ERR	148	80	375	85	230	-32
0	ERR	154	170	382	175	230	58
0	ERR	155	-101	382	-95	230	148
0	ERR	162	-10	386	-4	230	-122

OUTPUT DATA (Partial) Voltages in Polar Format

Va		Vb		Vc	
Magn.	Ang.	Magn.	Ang.	Magn.	Ang.
-----	-----	-----	-----	-----	-----
11.4	0	117.1	0	128.1	180
139.3	175	139.9	57	143.1	-64
139.3	-95	139.9	147	143.1	26
139.3	-5	139.9	-123	143.1	116
139.3	85	140.0	-33	143.1	-154
139.2	175	140.0	57	143.1	-64
139.2	-95	140.0	147	143.2	26
139.0	-5	140.0	-123	143.1	116

Figure III-1 Partial Views of SELANAL Input & Output Data.

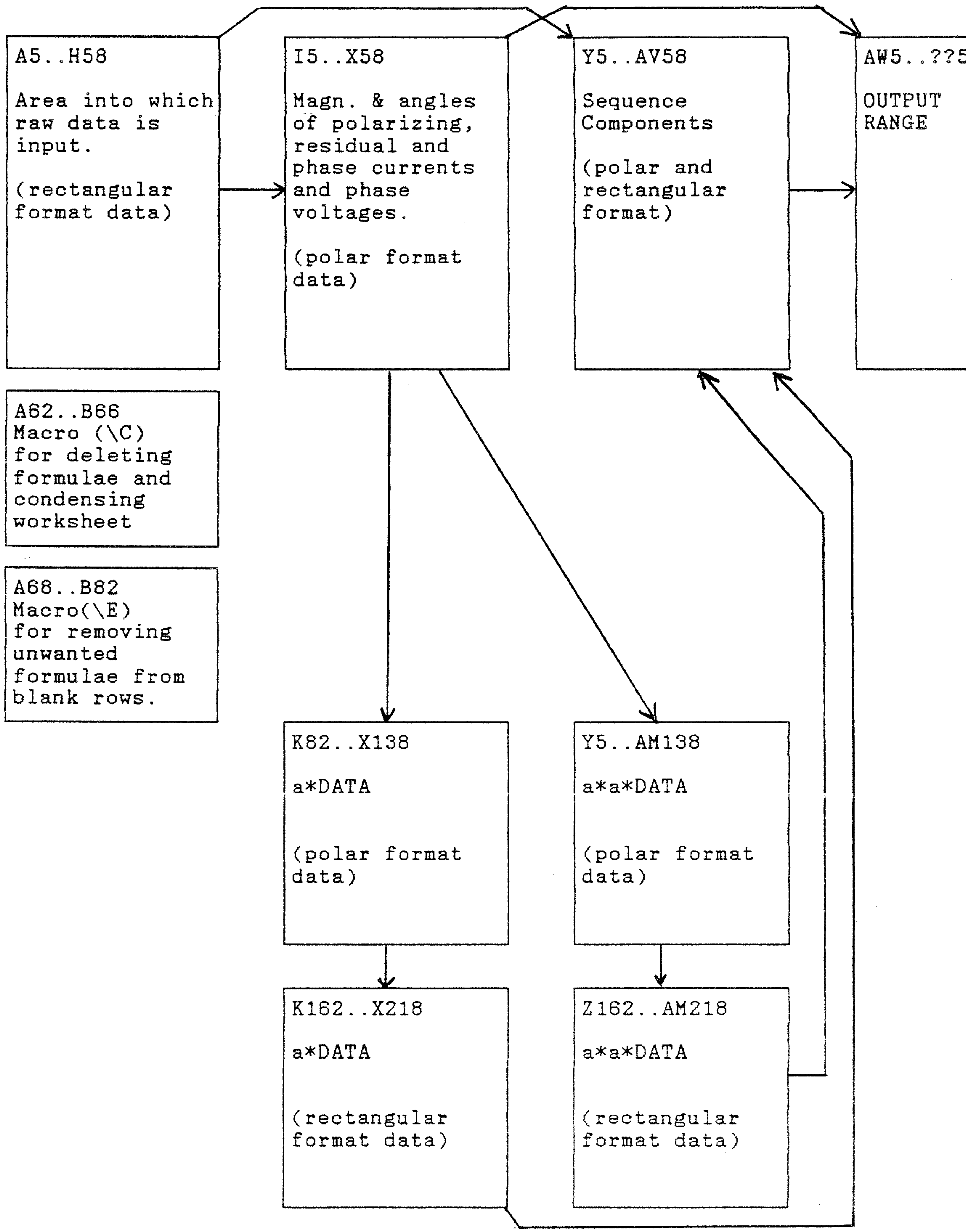


Figure II-2 Structure of SELANAL

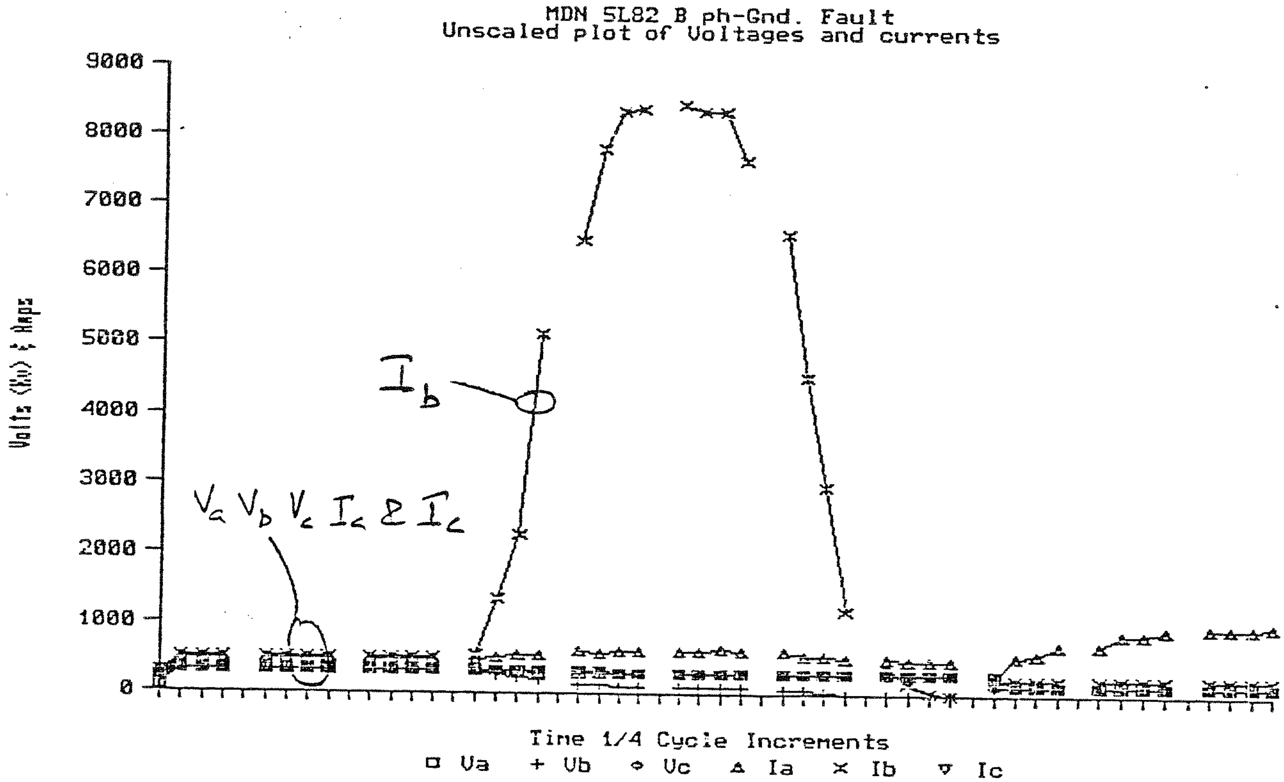


FIGURE III - 3a Unscaled Plot

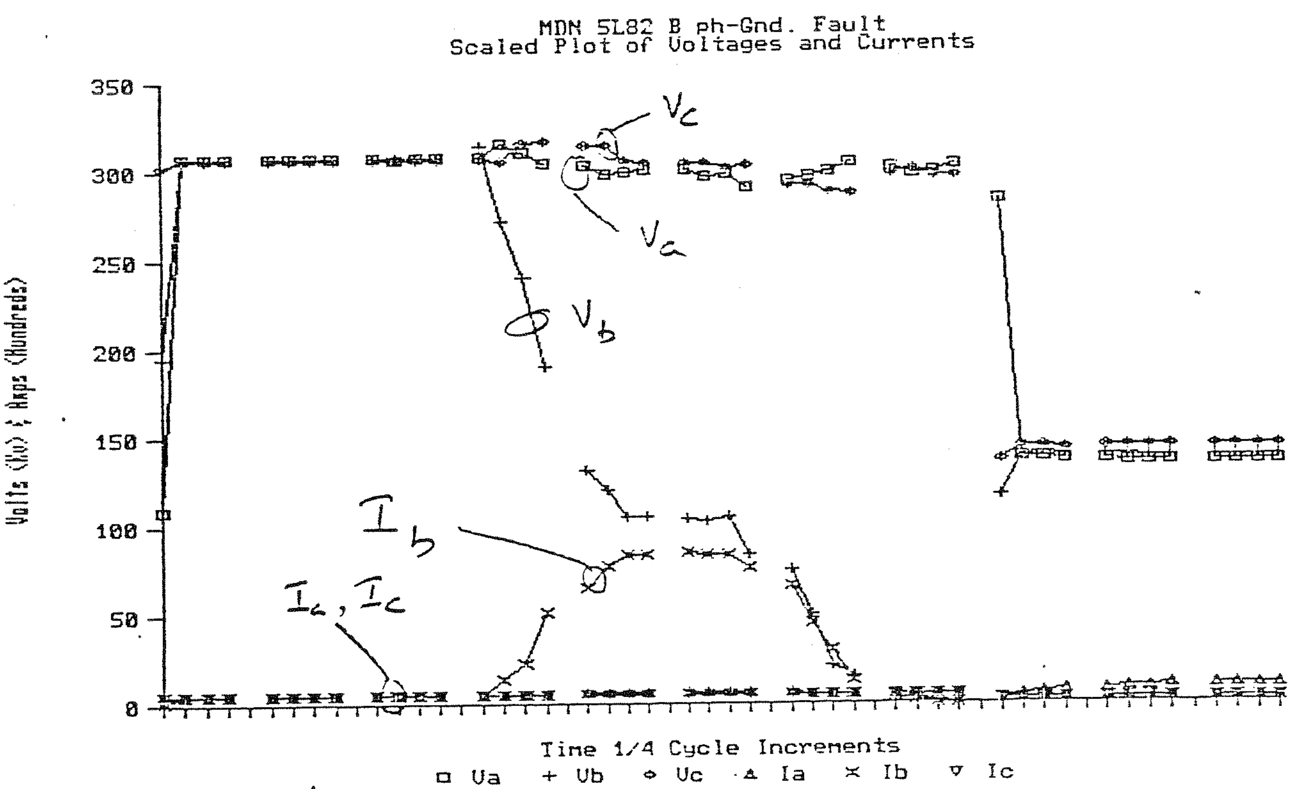


FIGURE III - 3b Rescaled Plot of same data.

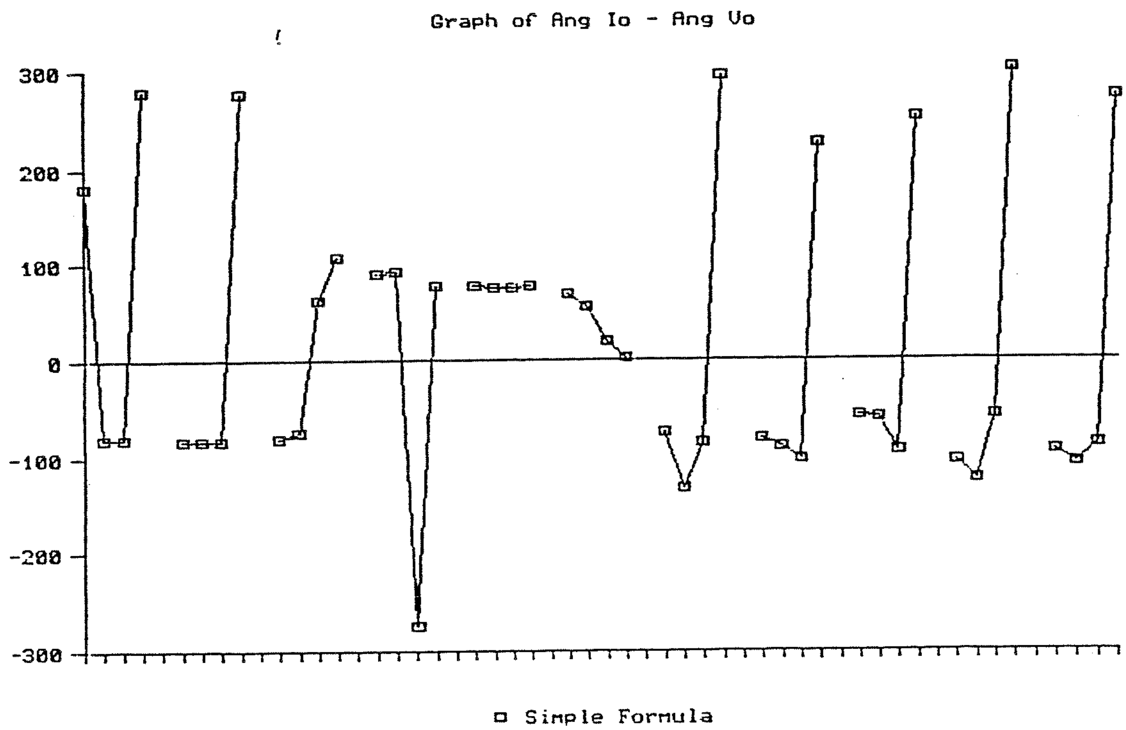


Figure III-4a

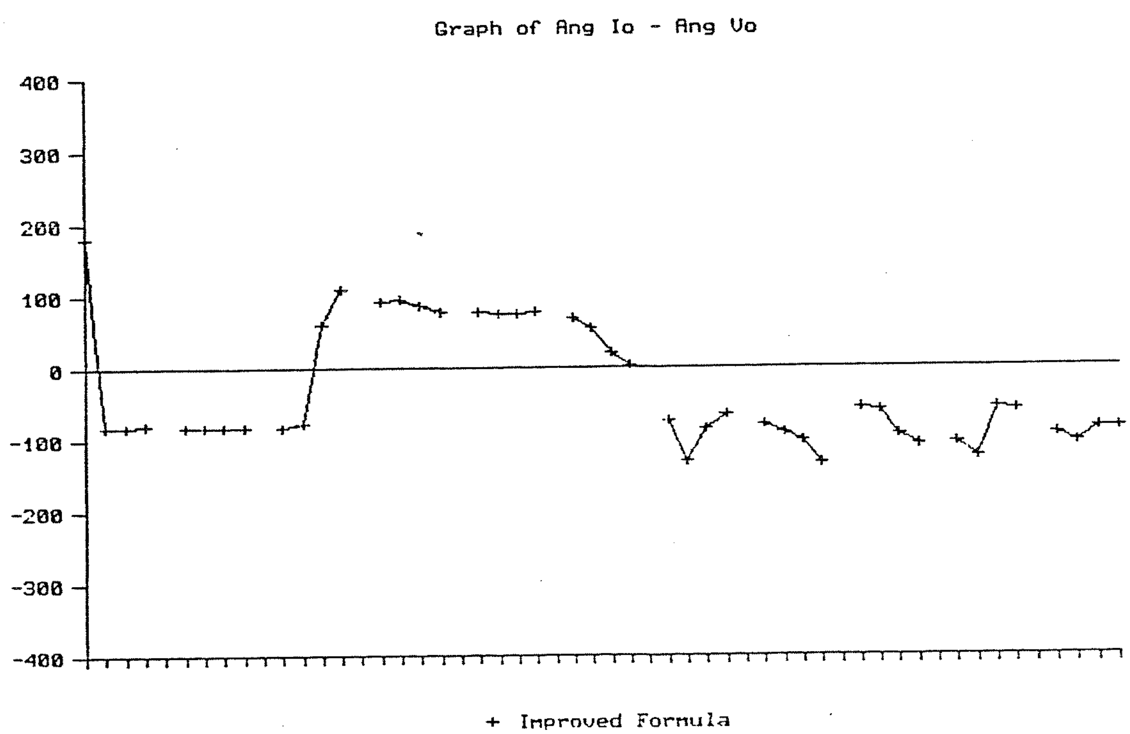


Figure III-4b