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# Comparison of Iowa State University harmonics program outputs to actual system data

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Comparison of Iowa State University  
harmonics program  
outputs to actual observed system data  
by  
John Henry Kremer, Jr.

A Thesis Submitted to the  
Graduate Faculty in Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE

Department: Electrical Engineering and Computer Engineering  
Major: Electrical Engineering

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Signatures have been redacted for privacy

Iowa State University  
Ames, Iowa  
1987

## TABLE OF CONTENTS

	PAGE
LIST OF SYMBOLS AND DEFINITIONS	v
ABSTRACT	vii
I. INTRODUCTION	1
A. Preamble	1
B. Review of Previous Work	2
C. Research Objective	3
D. Summary of Chapters	4
II. HARMONIC MEASUREMENTS AND PROGRAM MODIFICATIONS	5
A. Discussion of Measurements	5
B. Program Modifications	6
III. ASSEMBLING THE SYSTEM MODEL	8
A. The Electrical System	8
B. System Bases	8
C. Line Data	10
1. Normal	10
2. Circuits 13-A-12, 13, & 15	11
D. Two-Winding Transformers	12
1. Regular Transformers	12
2. Autotransformers	16
E. Three-Winding Transformers	16
1. Regular	16
2. Autotransformers	21
F. Scott Connected Transformers	21
G. Grounding Transformers	23
H. Power Capacitors	24

	PAGE
I. Power Reactors	26
1. Shunt Reactors	26
2. Series Reactors	27
J. Generators	28
K. Loads	28
IV. RESULTS	29
A. Entering Data Into Program	29
B. Actual Results	30
V. CONCLUSIONS AND RECOMMENDATIONS	33
A. Conclusions	33
B. Measurement Recommendations	36
C. Program Enhancement Recommendations	37
VI. REFERENCES	57
VII. ACKNOWLEDGEMENTS	59
VIII. APPENDIX A. CIRCUIT 13-A-12 TEST DATA AND REPORT	60
IX. APPENDIX B. SLIDE LISTINGS	82
X. APPENDIX C. MODIFIED HARMONIC LOADFLOW PROGRAM LISTING	92
XI. APPENDIX D. MODIFICATION MATRIX FOR PROGRAM	121
XII. APPENDIX E. TI-59 PROGRAM LISTINGS	151
XIII. APPENDIX F. THREE-WINDING TRANSFORMER EXAMPLE	179
XIV. APPENDIX G. THREE-TWO PHASE TRANSFORMER EXAMPLE	191
XV. APPENDIX H. GROUNDING TRANSFORMER EXAMPLE	199
XVI. APPENDIX I. REVISED HARMONIC ANALYSIS PROGRAM INSTRUCTIONS	203
XVII. APPENDIX J. SAMPLE PROGRAM OUTPUT	211



## LIST OF SYMBOLS AND DEFINITIONS

C	Capacitance
d	Diameter of Conductor
E	Voltage
$E_H$	Ideal Transformer High Side Voltage
$E_{L-L}$	Voltage (Line to Line)
$E_{L-N}$	Voltage (Line to Neutral)
$E_X$	Ideal Transformer Low Side Voltage
f	Frequency
GMD	Geometric Mean Distance
GMR	Geometric Mean Radius
H	Primary Winding
$H_1$	H Winding Lead
$H_2$	H Winding Lead
HVDC	High Voltage Direct Current
$I_C$	Core Resistance Current
$I_E$	Exciting Current
$I_H$	H Winding Current
$I_M$	Magnetizing Reactance Current
$I_{MAG}$	Magnetizing Current
$I_X$	X Winding Current
KW	Kilowatts
KVAR	Kilo-voltamperes

L	Inductance
MW	Megawatts
MVAR	Mega-voltamperes Reactive
n	Turns Ratio
$n_h$	Number of Turns on the H Winding
$n_x$	Number of Turns on the X Winding
$r_c$	a-c Resistance of Conductor
$R_C$	Core Resistance
$R_H$	Resistance of H Winding
$r_s$	a-c Resistance of Conductor Sheath
$R_X$	Resistance of X Winding
$R_0$	Zero Sequence Resistance
$R_1$	Positive Sequence Resistance
$R_2$	Negative Sequence Resistance
$S_B$	Base Voltamperes
$S_{BO}$	Voltampere Base (Old)
$S_{BN}$	Voltampere Base (New)
S	Spacing between Conductor Centers
$V_B$	Base Voltage
$V_{BN}$	Voltage Base (New)
$V_{BO}$	Voltage Base (Old)
$V_H$	H Winding Terminal Voltage
$V_X$	X Winding Terminal Voltage

$x_a$	Reactance of Conductor
$x_c$	Capacitive Reactance
$x_d$	Reactance Spacing Factor
$x_h$	Reactance of H Winding
$x_L$	Inductive Reactance
$x_m$	Mutual Reactance
$x_M$	Magnetizing Reactance
$x_S$	Reactance of Sheath
$x_X$	Reactance of X Winding
$Z_{Base}$	Base Impedance
$Z_H$	Impedance of H Winding
$Z_{HL}$	Impedance H Side to Low Side
$Z_X$	Impedance of X Winding
$Z_0$	Zero Sequence Impedance
$Z_1$	Positive Sequence Impedance
$Z_2$	Negative Sequence Impedance

## Miscellaneous

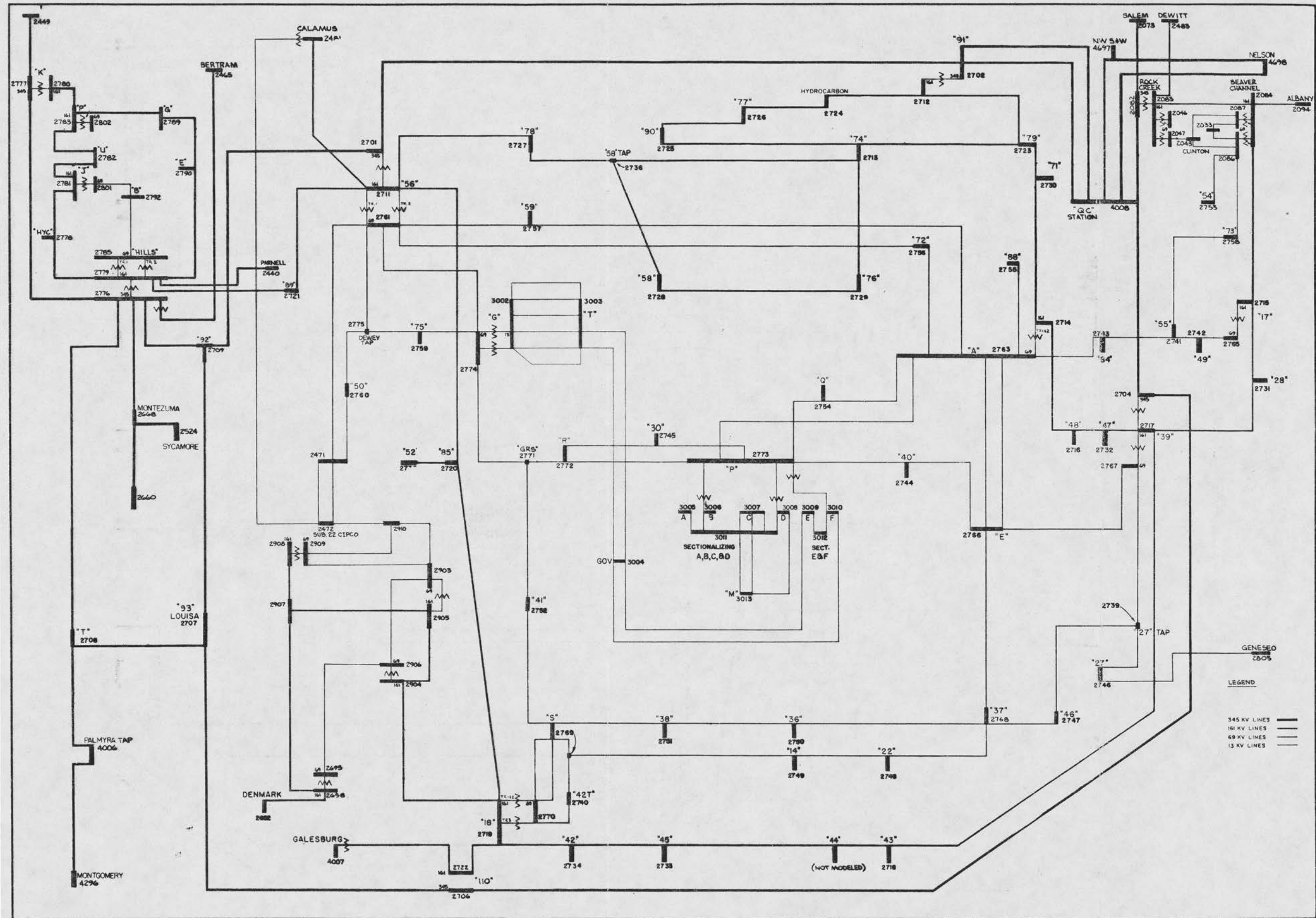
$\Delta$	Delta
$Y$	Wye

## ABSTRACT

The objective was to evaluate the Iowa State University Harmonic Loadflow Program to determine if it fulfilled the present need as an analysis tool for evaluating harmonic effects.

The material is arranged in the sequence of actual steps which occurred to accomplish the research objective. Most of the system as shown on the next page was modeled. Actual field measurements from this system were used to evaluate the program.

Results show the present program is useful for predicting harmonic effects to an existing system as a result of a single new source. Here, the program predictions match very close to measured values. The research also shows the present program is of very limited value for analyzing multiple harmonic sources on an existing system. Hence, it is recommended the program be enhanced to perform this function.



## I. INTRODUCTION

### A. Preamble

There is a general need both from the utility and industrial sectors for an analysis tool to evaluate the effects of harmonics. From the utility point of view an analysis tool is desired which can handle a multitude of harmonic sources all applied simultaneously. The tool needs to accept harmonic source inputs in a variety of forms. This variety should include various converter types, current and voltage waveforms in the form of oscillographs, and spectrum analyzer results in the form of photographs or computer recordings. The tool should be able to analyze existing as well as new sources.

Thus, this research focused on evaluating the Iowa State University Harmonic Loadflow Program to determine how many of these needs it fulfilled. It also examined the program's advantages and disadvantages. One of the goals of the research was to answer the management question concerning the allocation of manpower to use this particular program.

The program was known to have a lot of flexibility at accepting inputs. It appeared that the number of buses it

could handle could be easily expanded. It appeared to permit more detailed modeling of a system compared to other harmonic programs.

It was originally thought that the loadflow approach used by this program could be expanded to permit multiple sources on a system. This would permit determining harmonics at various buses throughout a system. No major documentation existed at the time this research commenced noting the actual limitations of the program and its use.

#### B. Review of Previous Work

The harmonics program under study is the Iowa State University Harmonic Loadflow Program. The program is a continuing refinement of R. D. Schultz's, "Harmonic Current Propagation on AC Systems Due to HVDC Links", Ph.D. dissertation from Iowa State University, dated 1979; K. H. Kuyper's, "Effects of Wind and Solar Converters on Utility Distribution Networks", Master's thesis from Iowa State University, dated 1980, and modifications to the aforementioned by Dr. A. L. Day, beginning June, 1982 to the present.

The program uses the bus impedance loadflow technique and the superposition principle for analyzing each harmonic

frequency separately. The types of sources that can be entered into the program include sampled harmonic voltage or current waveforms, AC-DC converters, and voltage or current harmonic magnitudes. The program was originally set up to accept up to 130 nodes, 475 elements, and a three digit bus number. When this research began, the program had only been used for the analysis of small systems (less than 20 buses).

### C. Research Objective

The research objective was to evaluate the Iowa State University Harmonic Loadflow Program to determine if it fulfilled the present need as an analysis tool for evaluating the effects of harmonics.

This was to be accomplished by comparing program output from measured voltage harmonic source values to the program output from measured current harmonic source values for the same harmonic source location. This would indicate if the program functioned correctly.

Following the initial verification, various other measured harmonic magnitudes, which were obtained throughout the system, would be entered into the program. This would then be used to determine if the program predicted what was



actually observed on the system. At this point, comparisons and conclusions concerning its use as an analysis tool should be possible and the appropriate recommendations could be made.

#### D. Summary of Chapters

The material is arranged in the sequence of actual steps which occurred to accomplish the research objective.

The test data that were used for input to the program were taken from actual field testing prior to this research. The data did have some deficiencies associated with them, but the majority of the data were quite usable.

The program was modified to accept up to 500 buses, 4000 elements, and use up to a four digit bus number. The research studies were run on an IBM 3083 Mainframe Computer. Several errors that existed in the original program were corrected.

Approximately 350 buses and their associated devices were modeled in the electrical system for this research. Examples and techniques to handle each device are included.

## II. HARMONIC MEASUREMENTS AND PROGRAM MODIFICATIONS

### A. Discussion of Measurements

The test data that were used for input to the program were taken from actual field tests (1). These test data are included in Appendix A and, a sequence of slides at the end of this thesis. A slide listing is also included in Appendix B. The slides show harmonics which were measured by a Hewlett Packard 3580A Spectrum Analyzer at various substations throughout the electrical system.

Appendix A includes a listing of all the test equipment. It also shows the current and voltage probes which were used. This same test equipment and probe set-up were used for every harmonic measurement taken and recorded via the slides.

The data included in Appendix B differ from those shown on the slides because of a scaling factor. The scaling factor resulted from the current probes that convert current to voltage. The Appendix B data are scaled correctly.

The current harmonic values which were measured and recorded in the sequence of slides, have no measurements of

the line current in amps. Therefore, there is no way to scale the line current magnitude to its appropriate per unit value. This lack of information limits the value of these measurements. The voltage harmonic values which are shown in the slides, can be scaled to correct per unit values and are quite usable.

#### B. Program Modifications

The harmonic loadflow program was modified to accept up to 500 buses, 4000 elements, and four digit bus numbers. Two unexpected logic errors in the original program were discovered and corrected during this research. These errors did not invalidate results obtained in previous research.

The listing shown in Appendix C is the present operating program. The first page of Appendix D shows a coded letter designator, followed by a corresponding program modification type. These letter codes are included in the program listing in Appendix D to indicate which lines must be changed to complete each type of modification.

For example, a voltage base modification is assigned the code letter "A" on the first page of Appendix D. Every line where the letter "A" occurs in the Appendix D

listing should be examined to determine if it should be changed.

### III. ASSEMBLING THE SYSTEM MODEL

#### A. The Electrical System

The electrical network under study is shown on the next page. This encompasses the major generation, transmission, and distribution systems and their components in a significant area in the eastern part of Iowa. A few of the buses in both the upper left and right hand corners of the network were not included in the harmonic analyses because of their remoteness to the harmonic sources.

Fossil, nuclear, and hydro generation, all at different voltage classes, are present on the system as well as combustion turbines. In addition, the system still has some two phase which had to be addressed and incorporated. The system also includes three-winding transformers, two-winding transformers (both regular and auto), grounding transformers, reactors (both series and shunt), capacitors, overhead lines, underground cables, major interconnections, urban areas, and rural areas.

#### B. System Bases

The harmonics program uses a 100 MVA voltampere base. Thus, all impedances, voltages, and currents were trans-



ferred to this base. To aid in base changes, some programmable calculator programs were written. Their listings appear in Appendix E. These programs were used to save time, to eliminate calculation errors, and to double check calculations.

### C. Line Data

#### 1. Normal

The line data for the model were taken from system data books covering 13.8 KV, 69 KV, 161 KV, and 345 KV lines. These books furnished any available data concerning circuit description, the length in miles, and the resistance, reactance, and susceptance values in actual quantities and in percent on 100 MVA base for positive, negative, and zero sequences. Some of the data were missing for the older lines because it was not required in an earlier era. In these cases, Anderson (2), the Westinghouse Electric Corporation reference books (3), (4), and the Electric Power Research Institute reference book (5) were utilized to estimate any missing data.

## 2. Circuits 13-A-12, 13, & 15

There are three circuits labeled 13-A-12, 13, and 15 that are cabled in such a way that they can be treated as an extension to the buses at Substation A. These circuits directly feed buses which power solid-state drives which, in turn, feed aluminum rolling mills. One of these aluminum mills is the largest of its kind in the world.

Because of the proximity of these circuits to a very large harmonic source, a more detailed model for them was developed. The only information available for these circuits were lengths and cable descriptions. One reason for this is that the present computer program used by the utility to calculate line data parameters cannot handle these cabling configurations and routings. The geometries become too elaborate with four conductors per phase. A second reason was that this modeling information was not required for any of the previous system studies performed by the utility. Hand calculations were made for detailed models of these circuits using references (2), (3), (4), and (5).



## D. Two-Winding Transformers

1. Regular Transformers

Assembling and incorporating transformer data into the program had to be one of the more interesting, but laborious facets of the modeling process. Each transformer test report had to be accessed and reviewed so the necessary parameters could be extracted. These consisted of:

1. type of construction, shell or core form
2. the number of windings
3. the voltamperes capability
4. the voltage transformation
5. the type of connections (i.e., delta, wye, etc.)
6. the impedances and their MVA base
7. the magnetizing current at 100% voltage and its MVA base
8. the no load loss at 100% voltage and its MVA base

Figures 1 through 6 show the two-winding transformer equivalents. In each succeeding figure, the model is further simplified. For these equivalents, all of the series resistance has been neglected. The magnetizing impedance has been assigned to the H or Primary Winding. The equivalent circuit shown in Figure 6 is derived by making the assumptions that  $RR_{1/2}$  is much, much less than  $RR_0$  and

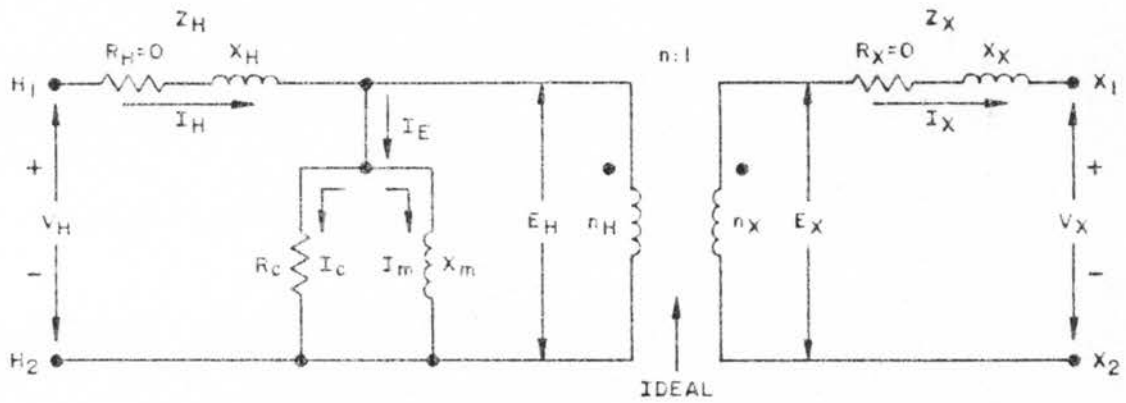
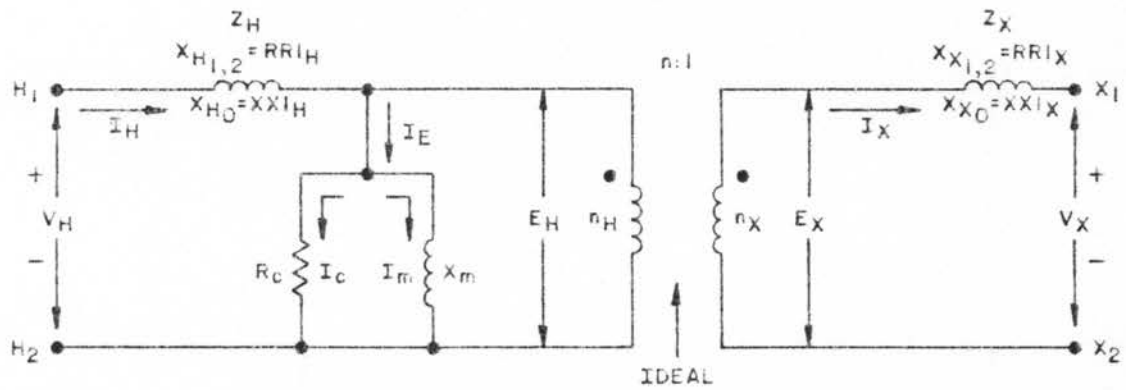


FIG. 1. EQUIVALENT IN SYSTEM QUANTITIES



WHERE:  $X_{m1,2} = X_{C1}$   $X_{m0} = X_{C0}$   $R_{c1,2,0} = R_{R0}$

FIG. 2. EQUIVALENT IN SYSTEM QUANTITIES SHOWING PROGRAM DESIGNATIONS

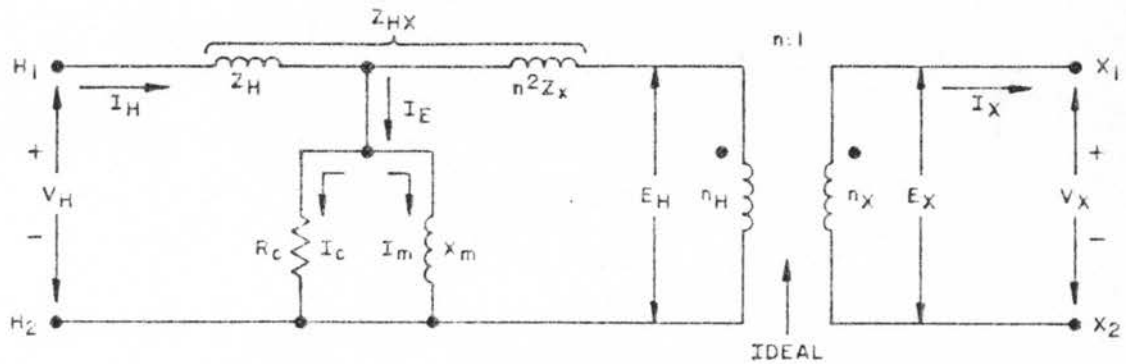


FIG. 3. EQUIVALENT WITH ALL SERIES IMPEDANCE REFERRED TO THE H WINDING

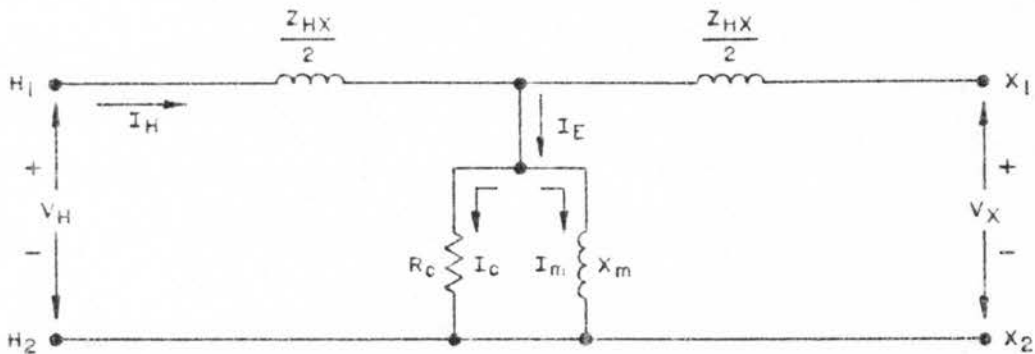


FIG. 4. P.U. EQUIVALENT

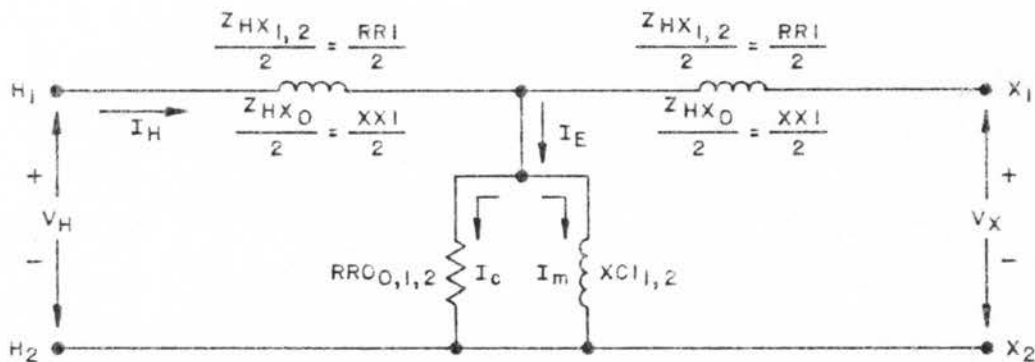


FIG. 5. P.U. EQUIVALENT SHOWING PROGRAM DESIGNATIONS

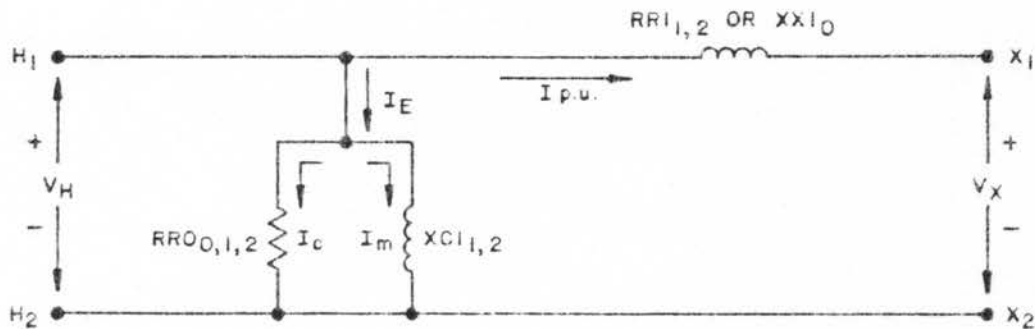


FIG. 6. MODIFIED P.U. EQUIVALENT SHOWING PROGRAM DESIGNATIONS

XX1/2 is much, much less than XC1. This is the model used in the Harmonic Loadflow Program.

The exciting current at 100% voltage obtained from the transformer test report is substituted into the following equation to determine the positive/negative sequence shunt reactance XC1.

$$\begin{aligned} XC1 &= \frac{\text{Voltage}}{\text{Magnetizing Current in \% @ 100\% Voltage}} \\ &= \frac{100\%}{I_{MAG}\%} \text{ pu} \end{aligned}$$

Similarly, the no load loss at 100% voltage obtained from the transformer test report is substituted into the following equation to obtain the positive/negative/zero sequence core loss resistance RR0.

$$RR0 = \frac{(\text{Voltage})^2}{\text{No Load Losses At 100\% Voltage}} \text{ ohms}$$

Next, divide RR0 by the base impedance and express it in percent. The positive, negative, and zero sequence series reactance values for RR1 and XX1 are all directly obtained from modern day transformer test reports.

However, there were many cases (due to the age of some of the transformers) where some of the parameters were not available. If the type of construction was unknown, a shell

design was assumed because a majority of large power transformers are shell type. If zero sequence information was unavailable, then the zero sequence impedance was assumed to be equal to the positive sequence impedance and the zero sequence equivalent was assumed to be the same as that developed for three single-phase units.

Appendix E includes a TI-59 Program Listing that was used to calculate the final transformer data values for direct entry into the system data.

## 2. Autotransformers

Two-winding autotransformers do not require any special treatment and are handled the same as a regular two-winding transformer. Thus, the same parameters are extracted from the transformer test report and the same process is utilized to determine the sequence shunt reactance  $X_{C1}$  and the sequence core loss resistance  $RR_0$ .

## E. Three-Winding Transformers

### 1. Regular

The program is not set up to accept three-winding transformers. To overcome this limitation, the appropriate

three-winding transformer model is selected and then transformed into an equivalent set of three separate two-winding transformers via a STAR to DELTA conversion.

The positive sequence impedances and voltampere ratings associated with each set of corresponding voltage levels are obtained from the transformer test report. These impedances are then transferred to the same voltampere base, normally that of the H, or Primary Winding. Next, the impedances are transferred to the equivalent per unit values. In this form, the model resembles the equivalent T model shown in Figure 10. A STAR to DELTA conversion is then made to transform the model to three two-winding transformers connected in a triangle configuration as shown in Figure 11. The equivalent circuits illustrating this modeling process are shown in Figures 7 through 11. The same technique is applicable for the negative and zero sequences. The zero sequence connection codes must be carefully selected to correctly model the zero sequence circuits. An example three-winding transformer model is developed in Appendix F.

For the X and Y windings, the no-load losses and magnetizing currents at 100% voltage are set to values approaching zero because the H winding already includes these quantities for all three windings. Thus, the values

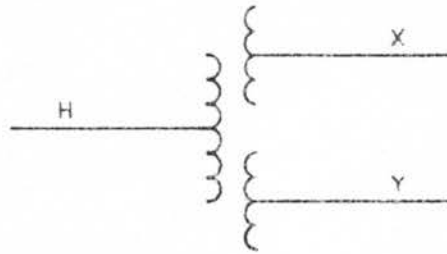


FIG. 7. SCHEMATIC OF A THREE-WINDING TRANSFORMER

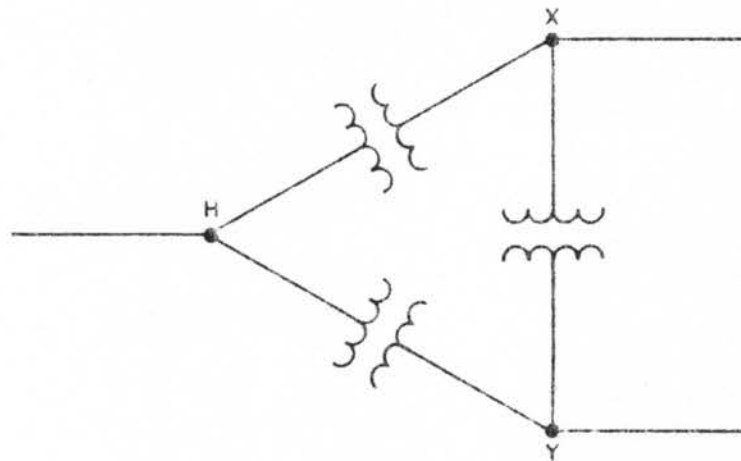


FIG. 8. SCHEMATIC OF THREE TWO-WINDING TRANSFORMERS CONNECTED IN A TRIANGLE

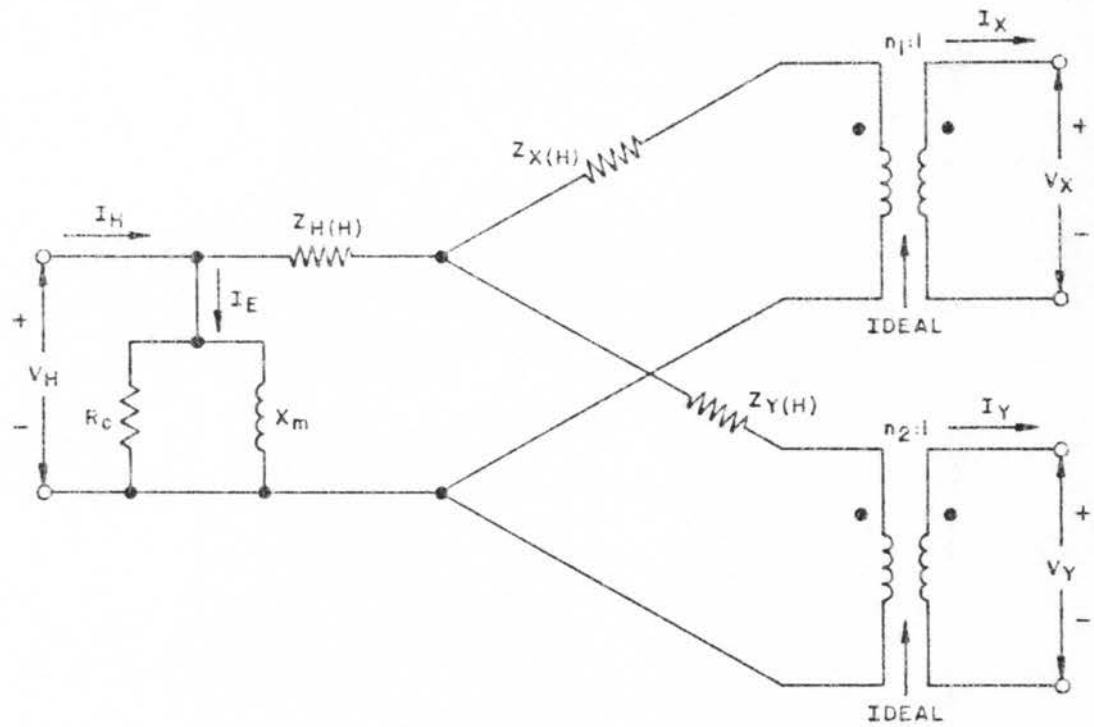


FIG. 9. EQUIVALENT FOR THREE-WINDING TRANSFORMER IN SYSTEM QUANTITIES WITH IMPEDANCES REFERRED TO THE H WINDING

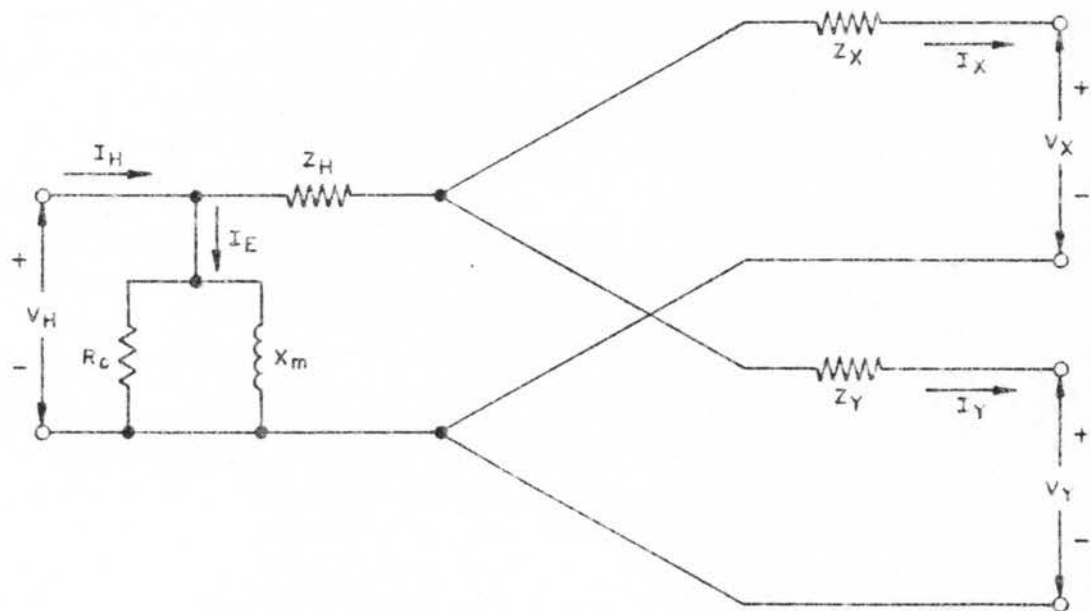


FIG. 10. EQUIVALENT FOR THREE-WINDING TRANSFORMER PER UNIT



WHERE:  $V_Y < V_X < V_H$

AND  $R_{cXY}$ ,  $X_{mXY}$ ,  $R_{cHY}$  AND  $X_{mHY}$  ALL APPROACH INFINITY

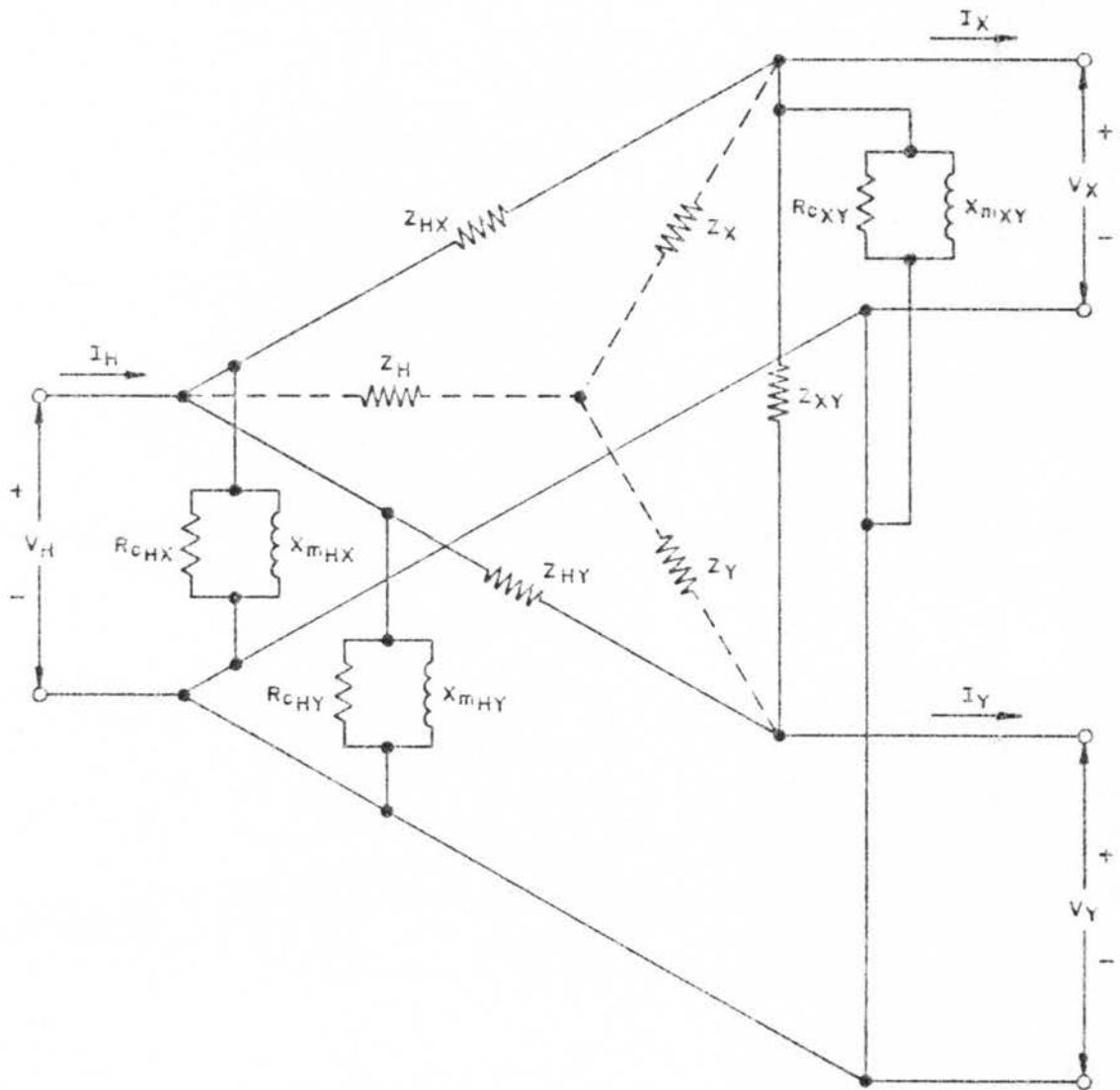


FIG. II. P.U. EQUIVALENT AFTER STAR TO DELTA CONVERSION ON A THREE-WINDING TRANSFORMER DEPICTING THREE SEPARATE TWO-WINDING TRANSFORMERS CONNECTED IN A TRIANGLE

for the sequence shunt reactance  $X_{C1}$  and the sequence core loss resistance  $R_{R0}$  for the X and Y windings approach open circuit conditions.

A TI-59 Program Listing for making the change to the per unit equivalent circuit values is shown in Appendix E. A TI-59 Program Listing to perform the STAR to DELTA conversion is also included in Appendix E.

## 2. Autotransformers

Three-winding autotransformers do not require any special treatment and are handled the same as the regular three-winding transformer. That is, the appropriate three-winding autotransformer model is chosen and then it is modeled as three separate two-winding transformers connected in a "triangle" configuration after a STAR to DELTA conversion is made.

### F. Scott Connected Transformers (Three to Two-Phase Transformers)

In reviewing Anderson (2, Chapter 1), we know for single-phase systems

$$Z = \frac{S}{V_{B-LN}^2} \text{ B - 1 phase (Z ohm) pu}$$

and

$$Y = \frac{V_{B-LN}^2}{S_{B-1 \text{ phase}}} \quad (\text{Y mho}) \text{ pu}$$

But using LL to indicate "line to line" and 2 phase for "two-phase", we write for a balanced system

$$V_{B-LN} = \frac{V_{B-LL}}{\sqrt{2}} \quad V$$

and

$$S_{B-1 \text{ phase}} = \frac{S_{B-2 \text{ phase}}}{2} \quad \text{VA}$$

Making the appropriate substitutions we compute

$$\begin{aligned} Z &= \frac{\frac{S_{B-2 \text{ phase}}}{2}}{\frac{V_{B-LL}^2}{(\sqrt{2})^2}} \quad (\text{Z ohm}) \text{ pu} \\ &= \frac{S_{B-2 \text{ phase}}}{V_{B-LL}^2} \quad (\text{Z ohm}) \text{ pu} \end{aligned}$$

and

$$Y = \frac{V_{B-LL}^2}{S_{B-2 \text{ phase}}} \quad (\text{Y mho}) \text{ pu}$$

Writing voltages in kV and voltamperes in MVA

$$Z = \frac{\text{Base MVA}_{2 \text{ phase}}}{(\text{Base kV}_{LL})^2} \quad (\text{Z ohm}) \text{ pu}$$

These equations are almost identical to those derived in Anderson for three-phase systems. In fact, if the arbitrary two-phase voltage and voltampere bases are equal to the arbitrary three-phase voltage and voltampere bases, then the results will be identical. Therefore, if the impedances are transferred to these bases, the program will handle both the two-phase and three-phase systems the same way.

An example of a three-winding, three-two phase transformer is included in Appendix G. The impedance values listed closely resemble those of the three-winding transformer values shown in Appendix F. The three-winding, three-two phase transformer parameters are determined in the same manner as for a regular three-winding transformer.

#### G. Grounding Transformers

Grounding transformers are modeled as linear elements connected from the bus to ground. The program will require three parameters to be entered consisting of  $RR1$ ,  $XX1$ , and  $XC1$ .  $RR1$  is the series resistance of the grounding transformer. If the resistance is to be neglected as it was for the other transformer models, then  $RR1$  can be entered as a zero value.  $XX1$  is the shunt reactance of the grounding transformer. The same technique used to calculate the shunt reactance for the other transformer models can be

used to calculate  $X_{C1}$ .  $X_{C1}$  is the zero sequence reactance of the grounding transformer. This reactance is equivalent to the series reactance of a conventional transformer. The same technique for calculating the series reactance of a conventional transformer will be used to determine values for  $X_{C1}$  in this model.

Appendix H shows an example of a grounding transformer modeling procedure.

#### H. Power Capacitors

Power capacitors are normally rated in three-phase kilovars. From elementary circuit theory we know:

$$X_C (\text{ohms})_{1 \text{ phase}} = \frac{E_{L-L}^2}{Q_{3 \text{ phase}}}$$

The program requires the capacitive reactance values to be entered on a per phase basis. Thus, knowing the three-phase line to line voltage and the three-phase kilovar rating (as furnished by the manufacturer), the capacitive reactance per phase can be easily determined. This value is entered into the Harmonic Loadflow Program as a linear element.

The kilovar manufacturing tolerance on power capacitors is minus zero and plus 15 percent. A normal dis-

tribution curve covering this variation is available from the various manufacturers. By taking this into account, more representative values of the actual KVAR capability can be entered into the program.

In the studies associated with this research, there was no allowance made for the manufacturing tolerances. In addition, the capacitors were all assumed to be located at the respective buses. This is in contrast to actual system conditions where the capacitors are usually located somewhere out on the line itself. To include the actual location of the capacitors in the model, the line lengths would have to be taken into account and appropriate corrections would have to be made.

If the program results identify a specific problem area resulting from capacitor resonance, then the additional modeling may be appropriate for the capacitors in that area.

Capacitor banks are often a major contributing factor to harmonic problems. Resonance at harmonic frequencies can cause overvoltage at the capacitor. In addition, since impedance of capacitors decreases with frequency, high harmonic voltages will result in high

current causing blown capacitor fuses, overheating, and possible failure. See references (4), (6), (7), (8), (9), (10), (11), (12), (13), and (14).

Appendix E includes a TI-59 Program Listing that was used to calculate the capacitive element reactances.

## I. Power Reactors

Power reactors are normally rated in three-phase kilovars. From elementary circuit theory:

$$X_{L1 \text{ phase}} (\text{ohms}) = \frac{(E_{L-L})^2}{Q_{3 \text{ phase}}}$$

The program requires the inductive reactance values to be entered on a per phase basis. Thus, knowing the three-phase line to line voltage and the three-phase kilovar rating (as furnished by the manufacturers) the inductive reactance per phase can be easily determined. This value is entered into the Harmonic Loadflow Program as a linear element.

### 1. Shunt Reactors

There were only five shunt reactors associated with the system studies. These were of 13.8 KV and 345 KV

classes. Their inductive reactance values in ohms were all determined in the manner just described. Then, these impedances were transferred into percent reactance on a 100 MVA base by utilizing the appropriate Z base.

## 2. Series Reactors

There were only six series reactors associated with the system studies. These were all located in the 13.8 KV network. Their inductive reactance values in ohms were determined by utilizing their respective test reports where the voltage drop across the reactor is given at rated current. Then using

$$E_L = I_L X_L$$

which is the voltage drop equation across the inductor yields

$$X_L = \frac{E_L}{I_L} \text{ (ohms)}$$

The impedance in percent is

$$Z(\%) = \frac{\frac{E_L}{I_L} (100)}{\frac{(V_B)^2}{S_B}}$$

where

$E_L$  = voltage drop across the inductor at rated current

$I_L$  = rated current of the inductor



$V_B$  = voltage base

$S_B$  = voltampere base

Appendix E includes a TI-59 Program Listing which can be used to calculate the inductive element reactance for shunt reactors.

#### J. Generators

Obtaining the necessary data for the generator model was fairly easy. Usually, good records are kept on these machines. There were twenty-four generators included in the system model ranging from generator voltages of 2400 Volts to 24 KV. A problem was encountered associated with four very old two-phase hydro units. These generators had been rewound, but no testing was performed. For these particular units, both references (2) and (9) were utilized to arrive at acceptable representative values.

#### K. Loads

Representative loads were obtained for the various substations for input into the model. These were obtained from utility company system studies. Depending upon the particular substation configuration, the loads were then apportioned to the various buses.

## IV. RESULTS

## A. Entering Data Into Program

Entering the harmonic magnitude values into the program from the slides is straightforward and is per the instruction sheet (see Appendix I). The particular harmonic magnitude value (in decibels) was read from the slide. The decibel equation is:

$$20 \log \left( \frac{V_1}{V_2} \right) = \text{db}$$

To transfer directly to per unit or percent values requires that  $V_2$  be chosen as 1 pu or 100% voltage. For voltage harmonics,

$$V_2 = \text{base voltage (volts)} = 100\% \text{ voltage} = 1 \text{ pu}$$

For the current harmonics measured as voltage equivalents,

$$V_2 = \text{base current (amps)} = 100\% \text{ current} = 1 \text{ pu}$$

Thus:

$$\frac{V_1}{1 \text{ pu}} = \frac{V_1}{100\%} = \text{antilog} \left( \frac{\text{db}}{20} \right)$$

which yields  $V_1$  directly in percent or per unit for that particular harmonic. This process is repeated for each successive harmonic until they have all been transcribed. See references (1), (10), (11), (12), (13), and (14).

Appendix E includes a TI-59 Program Listing which was quite useful to obtain the per unit voltage or current values from the harmonic measurements given in decibels. Appendix E also includes a TI-59 Program Listing which is useful for calculating harmonic distortion factors from the data obtained from the spectrum analyzer.

#### B. Actual Results

There were specific measured test data available only for Substations A, 36, 76, 78, 88, and 91. Of major interest to this research is Substation A. This particular substation supplies both arc furnace loads and solid-state converters for rolling mill drives. These loads combine into the dominant harmonic source in the area. The measurements at this substation and Substation 88 were used to verify that the Iowa State University Harmonic Loadflow Program functioned correctly.

The voltage harmonic distortion factor values for each bus in the system are printed at the end of the program output for each case. These values were used for the comparisons to actual measured data. A sample of the program output is shown in Appendix J. This sample output corresponds to the case where the harmonic source values are entered as the measured voltage harmonic values at Substation A.

The harmonic distortion factors at Substation 88 matched within .01 percent of the fundamental, with no unanticipated results. The program output showed that the effects of the harmonics produced by this source at Substation A could easily be observed as far away as Missouri. Voltage harmonic distortion factor contributions in the range of .3 percent are shown to exist on the 345 KV system in Missouri.

The measured system data at Substation 36, 76, 78, and 91 do not correlate to the Iowa State University Harmonic Loadflow Program output. This is because the test data which were taken reflects the actual system with a multitude of harmonic sources applied. There is no way the system harmonic measurements can be obtained with only one harmonic source present, which is the way the Harmonic Loadflow Program treats each case.

Measured test data from Substation A were entered to compare the program output from "measured voltage harmonic source values" to the program output from "measured current harmonic source values" for the same harmonic source location. Eighty-seven percent of the harmonic distortion factors showed less than one-half percent variation between the voltage and current cases. Ninety-eight percent of the harmonic distortion factors showed less than one percent variation. Some of the differences were the result of the system being

sensitive to resonance at different locations for different input harmonic frequencies. The measured current harmonic source data peaked at different harmonic frequencies than they did for the measured voltage harmonic source data. This is also covered in Appendix A.

A case was analyzed using the detailed line model for circuits 13-A-12, 13, and 15. The results from this case were compared to cases which did not include the detailed line model for these circuits. These comparisons showed essentially the same results, with or without the detailed line model.

The computation times for the actual system data consisting of approximately 350 buses were in a range of approximately five to fifteen minutes. For this system, harmonic source location appeared to play the major role in determining CPU time.

It should be noted that the printout will vary depending upon harmonic source location. The variations will be in the bus numbers included in the printout. The reason for this difference is directly attributed to the transformer connection codes. The program takes these into account and incorporates them directly into the printout.

In addition, if a converter input is used, the computer printout will only show certain harmonics. These will be determined by the formula  $h = pq \pm 1$ , where  $p$  equals the number of pulses and  $q$  is an integer. This is quite apparent in the printouts.

## V. CONCLUSIONS AND RECOMMENDATIONS

### A. Conclusions

The program is operating smoothly with an excess of 345 buses, a large number of linear elements, and four digit bus numbers. It can accept up to 500 buses, 4000 elements, and use four digit bus numbers up to 9,998. Expanding the dimensions of the program is fairly easy provided that the computer system is large enough to handle the increased array sizes. Using the techniques outlined in Chapter III, the unique system devices are easily incorporated.

The program, as it currently exists, appears to be useful only in analyzing new harmonic sources which are being added to the system. A program, as such, would give an indication of the percent harmonic distortion factor increase for the various buses on the system. The test data available support the fact that the program is functioning correctly and as designed.

There were differences in the harmonic distortion factor results between the cases that used measured voltage and measured current harmonic source values for the same circuit. These differences were attributed to

amplitude variations associated with select harmonic orders which were different for the voltage harmonic measurements than they were for the current harmonic measurements. Each study indicated that certain areas of the system were sensitive to resonance at different harmonic frequencies and at different locations. The suspected cause of the differences is that the phase angle differences between the voltages and currents were not included. Since the phase angle data were unavailable, then the procedure is to run analyses of both the current and voltage harmonics for the same circuit. This will indicate any specific resonance for each case.

Based on the closely matching comparisons of the cases with and without detailed line modeling for circuits 13-A-12, 13, and 15, the extra work involved in calculating the detailed models for bus extensions is not recommended.

The algorithms used in the program are not highly efficient in terms of CPU time and memory requirements. However, it was observed in this research that even when the program was used for a large system, it arrived at solutions in reasonable times. Modifications to reduce computational times is not recommended and are not seen as a major benefit. This recommendation is based upon the fact that most programs of this type are run during off-hours and weekends. During



these low use periods the computer time is discounted because, frequently, the computer is idle.

The harmonic source location affects the CPU time required for a program solution. However, it appears that reasonable solution times are obtained no matter where the harmonic source is located. There was no obvious advantage of using a voltage over a current input in the studies performed as they had essentially the same execution times for the same circuit.

One of the print options in the Iowa State University Harmonic Loadflow Program is "to print harmonic analyses of elements adjacent to the harmonic source bus only". Based on the results obtained during this research it is concluded that this is not a recommended option. It will overlook significant harmonic distortions located further out in the electrical system.

Based on the experience gained during this research, it would require about ninety man-days to model a 350 bus electrical system. This estimate includes the time required to gather the necessary system data, to make calculations for the device models, to enter the data into a computer file, and to verify the data.

This thesis provides the necessary assistance and guidance to others who will use the Iowa State University Harmonic Loadflow Program. It reduces the confusion associated with the modeling of the unique system elements and devices. Finally, it provides good insight to the limitations of the program and its advantages.

#### B. Measurement Recommendations

An additional effort should have been made to obtain measurements associated with phase angles. In addition, the daily and seasonal variation of harmonic levels should be considered when interpreting measured data.

For any measurements obtained, there is engineering judgement required to understand what they show and how they are associated with the Iowa State University Harmonic Loadflow Program. For many locations the measurements show the composite of all harmonics at a particular bus resulting from a multitude of harmonic sources. It is not feasible to have only one harmonic source connected to the system.

In summary, it is recommended that the measurement data obtained include at least as much data as that shown in Appendix A. Current and voltage waveforms should be

recorded in addition to photographs or computer recordings of the actual spectrum analyzer settings and traces. This will help answer questions involving the measurement data and provide for a cross-reference. Good communications between the parties obtaining the measurements and those requesting the measurements are also needed. This is to assure that pertinent details associated with the measurements are not overlooked.

#### C. Program Enhancement Recommendations

The program as designed, can only handle one source at a time. Its major intended use would be for analyzing new sources.

However, what is truly needed is a program which handles multiple harmonic sources derived from measured data. The program should resemble a true loadflow program in which multiple generators can arbitrary be connected to various buses. This would limit the number of locations where test data would need to be obtained. It would also permit analyses in areas where test data can not be obtained. It would overcome the obstacle of single source analysis that requires the removal of customers or systems from service to obtain harmonic source data.

The use of a multiple source program appears to be the logical solution. Entering harmonic measurements from key locations in the system would permit a complete harmonic picture of the overall system. The contribution from each customer's harmonic source could be determined.

In addition, the following modifications are recommended:

1. Modify the program to output a summary of the ten, twenty, or any assignable number of the largest bus harmonic magnitudes listed in descending order. This would greatly simplify review.
2. Modify the program to accept both alpha and numeric bus designations.
3. Modify the program to facilitate entering values directly from data sheets, test reports, etc.
4. Include an arc furnace harmonic source model (7).

## VI. REFERENCES

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## VII. ACKNOWLEDGEMENTS

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Finally, a special note of thanks is extended to my wife Connie, and our children, for their patience and encouragement. I also wish to thank my father, from whom I learned perseverance and determination.

VIII. APPENDIX

A. CIRCUIT 13-A-12 TEST DATA AND REPORT



Circuit 13-A-12 Test  
August 27, 1985

1. Personnel Present  
Davis, Coppens, Hender, Mathias
2. Equipment Used
  - A. Recording Voltmeters EM100, EM101, EM102
  - B. Bell and Howell Portable Oscillograph
  - C. Hewlett Packard 3580A Spectrum Analyzer
3. Equipment Calibration
  - A. Potential Transformers 7976/66.4 or 120/1
  - B. Current Transformers 2000/5
  - C. Potential Probe on Spectrum Analyzer x10.  
Voltages derived from an uncalibrated voltage divider.  
Voltage information is relative to 60 HZ fundamental.
  - D. Current Probes Bell clamp-on Hall effect - 1 volt equals  
10 amperes
  - E. Scale Settings indicated on oscillographs and  
photographs
4. Quantities Measured
  - A. 13 kV bus 1A volts phases 1, 2, 3
  - B. 13-A-12 currents phases 1, 2, 3
5. System Conditions
  - A. 161-69 kV transformers #1 & #2 OFF
  - B. 69-13 kV transformer #4 OFF
  - C. 69-13 kV transformer #5 ON
  - D. 69-13 kV transformer #6 ON
  - E. 25.2 MVAR 69 kV capacitor ON

## F. 13 kV capacitors

Test	C-156 5400 kVAR	C-326 4200 kVAR
1	OFF	ON
2	OFF	OFF
3	ON	OFF
4	ON	ON

Note: OCC would not permit tests to be done with only one 69-13 kV transformer in-service.

## 6. Test Results

## A. Recording Meters

Exhibits 1 and 2 show recording voltmeter charts on 8/27/85 and 8/28/85. Both of these charts are typical of the voltage variations recorded from 8/27/85 to 8/30/85 and from 9/3/85 to 9/6/85. The voltages were fairly flat during the Labor Day holiday weekend.

Some of the more severe voltage excursions are indicated on the exhibits. The worst is point "B" on Exhibit 1 which showed a dip from 14.0 to 13.3 kV. This represents a 5.3% change on a 13.2 kV base. Point "D" on Exhibit 2 shows an incident where the voltage dropped to 13.1 kV.

The frequency of the voltage dips ranged from about 35 to 60 occurrences per hour.

## B. Oscillograph

The portable oscillograph was used to record all three voltages and currents on circuit 13-A-12. When the paper feed was set at a low speed, the variations of voltage and current magnitudes can be seen. A fast

paper feed rate was used to monitor the individual waveforms to detect harmonic distortion.

Exhibit 3 graphically illustrates the varying current demands of the rolling mill at 12:05. The current varies rapidly from 353 to 990 amperes (rms). The voltages are also varying but the percentage change is too small to measure with this device.

Exhibit 4 is another slow speed run taken at 13:00. The maximum current spike was 1272 amperes. The voltage trace is very uneven.

A fast speed run done during test #1 is shown on Exhibit 5. The phase #1 current shows a definite harmonic content. The peaks of the current waveform have been "chopped" by operation of the solid state devices. The sides of the waves show when different pulses of the convertor are fired. The voltage waveform is more uniform but it definitely has a harmonic signal riding on top of the 60 HZ fundamental.

Exhibit 6 shows the waveforms during test #2 when there were no capacitors on. The harmonics in the current waveform are a little more pronounced.

Exhibit 7 was produced during test #3 when the 5400 kVAR capacitor bank C-156 was on-line. High frequency harmonics are very evident.

The presence of both capacitor banks in test #4 really emphasized the harmonic problem as shown on Exhibit 8. By looking at the entire oscillograph which includes several seconds of time, the following

observation was made. The worst harmonics appear to be generated when the mill is coasting down from a high current level to a lower one.

C. Spectrum Analyzer

The spectrum analyzer was used to resolve the voltage and current waveforms into their harmonic components. This device plotted the signal magnitude at a specific frequency on the vertical axis while it swept through the frequencies on the horizontal axis. The vertical axis was a logarithmic scale measured in dB. {A voltage ratio in decibels is equal to  $20 \log (V_1/V_2)$ } This allowed the small harmonic components to be shown on the same screen as the 60 HZ fundamental. The results were a percentage of the fundamental. The frequency sweep took about 20 seconds to complete. This introduced some error because the magnitude of the waveform was changing during the sweep.

Exhibits 9 and 10 show photographs taken of the spectrum analyzer screen. The locations of the 1st, 3rd, 5th, 7th, 9th, 11th and 13th harmonics are shown. These correspond to the signals at 60, 180, 300, 420, 540, 660 and 780 Hertz, respectively.

These pictures show that the predominant harmonics are the odd multiples of 60 HZ. Since these graphs are on a logarithmic scale, they are difficult to read. Therefore, the results will be summarized in Figure 1.

## SPECTRUM ANALYZER RESULTS

Test#	System Conditions			Quantity	Harmonics						DF %
	C156 5400 kVAR	C326 4200 kVAR			3rd %	5th %	7th %	9th %	11th %	13th %	
1	OFF	ON	V	.8	5.0	1.0	.4	.6	1.8	5.5	
1	OFF	ON	I	.6	1.6	.5	.1	.3	.5	1.9	
2	OFF	OFF	V	.8	4.0	2.5	.6	.6	.5	4.9	
2	OFF	OFF	I	.2	2.5	1.0	.2	7.9	.4	8.4	
3	ON	OFF	V	.3	5.0	.8	.2	1.0	1.6	5.4	
3	ON	OFF	I	.2	.9	.3	.0	.4	2.5	2.7	
4	ON	ON	V	.4	4.0	.8	.2	2.5	.4	4.8	
4	ON	ON	I	.5	1.3	.4	.0	.2	6.3	6.5	

V = Voltage I = Current DF = Distortion Factor

$$\text{Distortion Factor} = \sqrt{\frac{V_2^2}{V_1^2} + \frac{V_3^2}{V_1^2} + \frac{V_4^2}{V_1^2} + \dots + \frac{V_N^2}{V_1^2}}$$

where 1, 2, 3, and 4 refer to first, second, third and fourth harmonic

This analysis only included the odd harmonics from 3 to 11 for example.

$$\text{DF} = \left( \frac{0.8^2}{1.0^2} + \frac{5.0^2}{1.0^2} + \frac{1.0^2}{1.0^2} + \frac{0.4^2}{1.0^2} + \frac{0.6^2}{1.0^2} + \frac{1.8^2}{1.0^2} \right)^{\frac{1}{2}} = 5.5$$

The predominant harmonic in the voltage waveforms was the 5th. This 300 Hertz signal was 4 to 5 % in all four test cases. The switching of capacitors did not seem to affect it. The next worst at 2.5% was the 7th in case 2, the 11th in case 3 and the 13th in case 4. Increasing shunt capacitance tended to shift the second highest harmonic to a higher frequency.

The current waveforms exhibited different characteristics. The largest harmonic was the 11th at 7.9% in case 2 with no capacitors. The second largest was the 13th at 6.3% in case 4 with both capacitors on. The other two cases showed small harmonics.

## 7. Other Observations

### A. Recording Voltmeter

There is a recording voltmeter permanently attached to the 13 kV bus. This meter has an unknown calibration and it appears to be overly damped. However, it does allow a comparison between the voltage before and after the installation of the solid state drive.

Exhibit 11 shows the voltage record on June 12, 1985, which was the roughest observed on the June chart. This was before the mill drive was installed. The maximum voltage dip was about 250 volts or 2%.

Exhibit 12 shows the record made on August 13, 1985, by the same meter. This trace is much rougher. The maximum voltage dip approaches 500 volts or 4%. The

frequency is approximately 10 to 20 times per hour.

B. Operator's Digital Voltmeter

The 13 kV bus voltage at \_\_\_\_\_ is controlled by changing taps on 69-13 kV transformers #5 and #6. The tap changer control is located in the 800# boiler control room. The bus voltage is shown on a digital voltmeter that changes state about every second. The operator attempts to keep the voltage at 13.8 kV.

On August 27th, the operation of this digital voltmeter was observed. During a five-minute time span the meter varied from 14.1 kV to 13.3 kV. The right most two digits which represent the decimal parts of the kilovolt reading were very rarely the same each time the display was refreshed.

It is almost impossible for the operator to keep the voltage within tolerance. It moves so much he does not know whether to raise or lower at any given time. The best he can do is to limit the high voltage excursions and ignore the voltage dips.

8. Conclusions

The voltage flicker on the Sub A 13 kV bus exceeds the limits set forth in Planning Standard P820-200. In addition, the voltage dips may also put us in violation of voltage minimums at our other customers served at the end of Sub A 13 kV circuits. Comparison of the voltage conditions before and after the installation of the new mill drive indicates that it is the source of the problem.

The harmonic content of the voltages and currents measured at \_\_\_\_\_ also violates criteria. IEEE Standard 519-1981 lists the limits for voltage distortion factor as 5.0% for voltages from 2.4 to 69 kV and 1.5% for 115 kV and above. Figure 1 lists voltage distortion factors as high as 5.5%.

In addition, the presence of harmonic currents may be detrimental to the generating unit R-4 which is directly connected to the Sub A 13 kV bus. Harmonics can cause overheating of the rotor. Further research would be necessary to determine the extent of the problem.

In order to properly identify the new solid state drive as the source of the harmonic problem, it will be necessary to perform the harmonic tests with the mill not in service. Harmonic problems can show up at buses remote from their service. The harmonics measured at \_\_\_\_\_ could be coming from a number of sources inside and outside of \_\_\_\_\_.

#### 9. Possible Solutions

There are three possible solutions to the voltage flicker problem:

- A. Make adjustments to the solid state drive system controls
- B. Put \_\_\_\_\_ on its own separate transformer
- C. Install a static var generator

Possible solutions to the harmonic problem are:

- A. Put \_\_\_\_\_ on a separate transformer



B. Install tuned filters

Isolating on its own transformer would allow the application of the IEEE suggested limit of 8% for the voltage distortion factor. It would also place the customer on the lower impedance 161 kV system further away from other customers and generator R-4.

10. Recommendations

- A. A test should be coordinated with which would allow us to measure harmonics with the new mill drive on and off. This would positively determine if the new drive is the source of the harmonics.
- B. A meeting should be arranged with representatives of and (manufacturer of the solid state drive) to resolve the problem.

LTD:sjb  
09-09-85

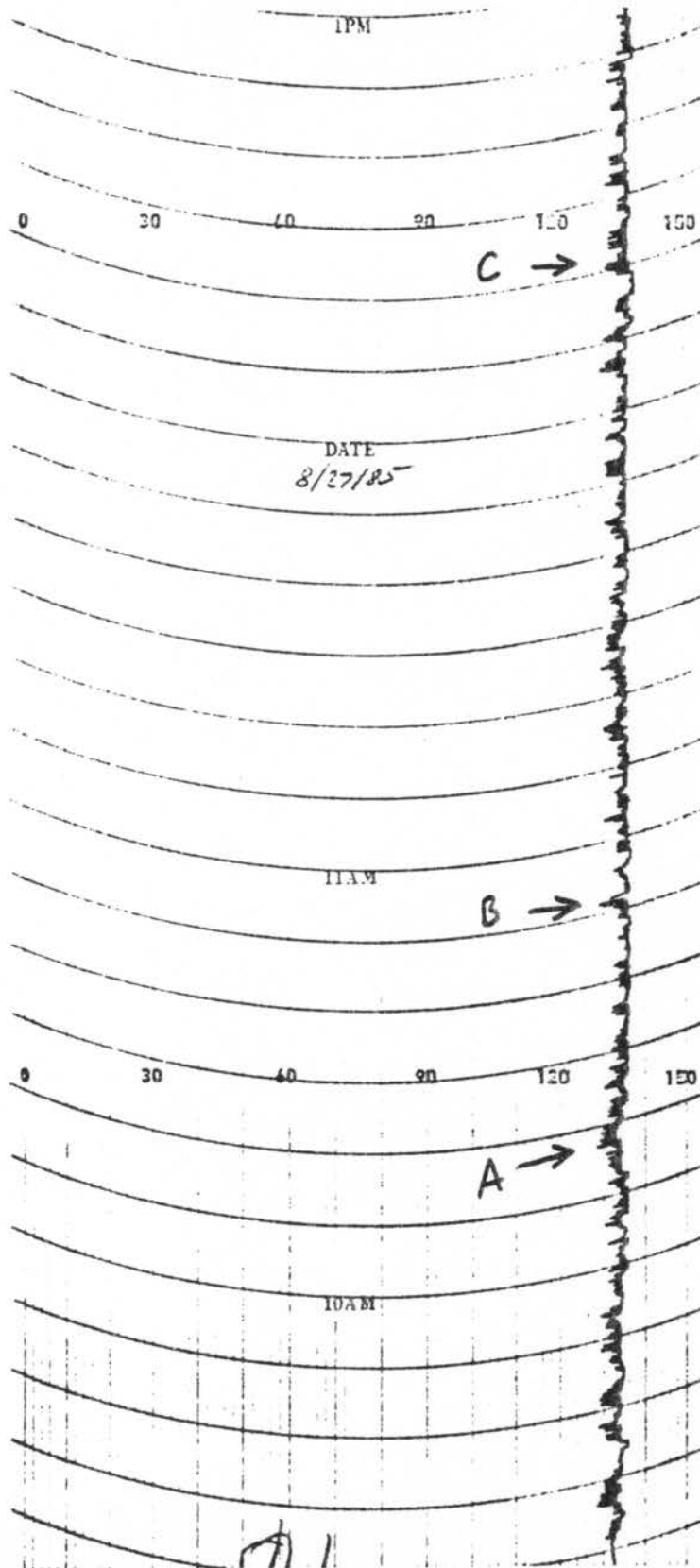


EXHIBIT 1  
BASE = 13.2KV

14.1 → 13.5 kV  
106.8% → 102.2%  
4.6%

Frequency  
36-60 per hour

GENERAL ELECTRIC

14.0 → 13.3 kV  
106.1% → 100.8%  
5.3%

13.8 → 13.2 kV  
104.5% → 100.0%  
4.5%

13-A-12  
φ1 VOLTS  
MULT = X60  
Correction  
-108V

RECORD PULL NO. A1A

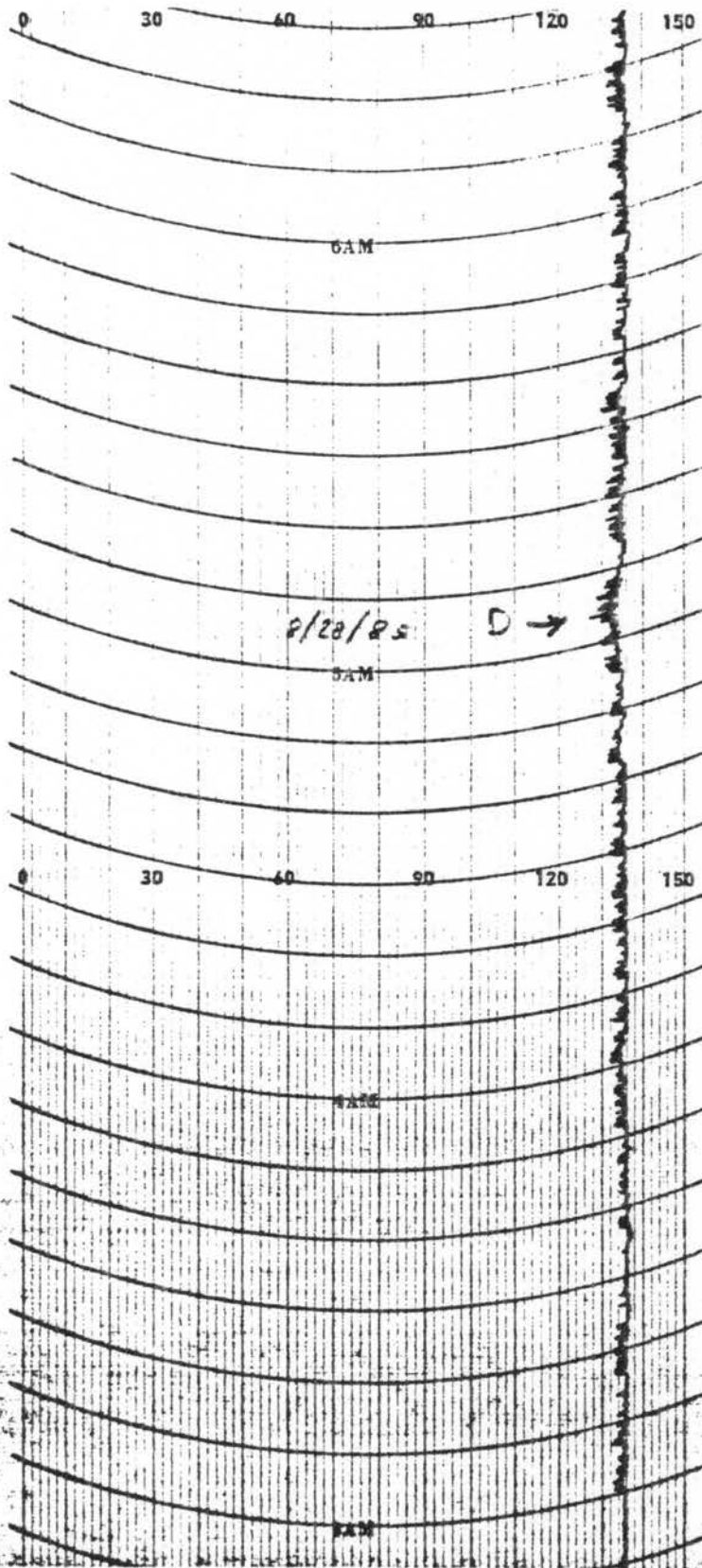


EXHIBIT 2  
 BASE = 13.2 KV

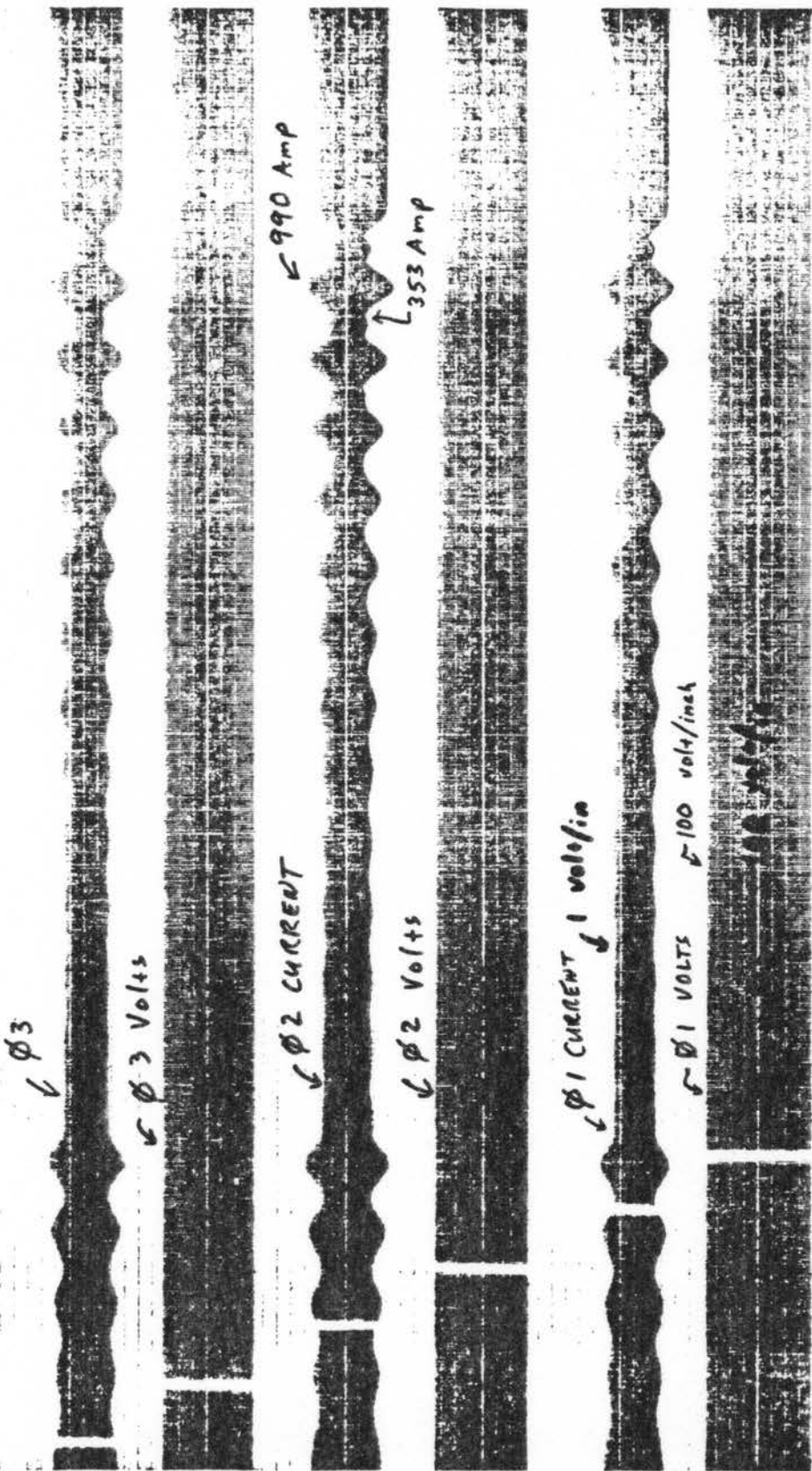
GENERAL ELECTRIC

13.8 → 13.1  
 104.5% → 99.2%  
 5.3%

8/28/25 D ->

RECORD ROLL NO. A1A3-3

13-A-12  
 φ Volts  
 MULT x60  
 Correction  
 - 108 V



9/27/85 12:05 C-156 OFF C-326 OFF 13-A-12

EXHIBIT 3

13-A-12

↓  $\phi 3$  current

←  $\phi 3$  Volt

↓  $\phi 2$  current

←  $\phi 2$  volt

←  $\phi 1$  current

100  $\mu$ /in

← PEAK CURRENT - 1272 Amp

8/27/85

←  $\phi 1$  Volt

18:00 C-156 ON C-326 OFF

EXHIBIT 4

4

13-A-12  
C-156 OFF  
C-326 ON

8/27/85 1020

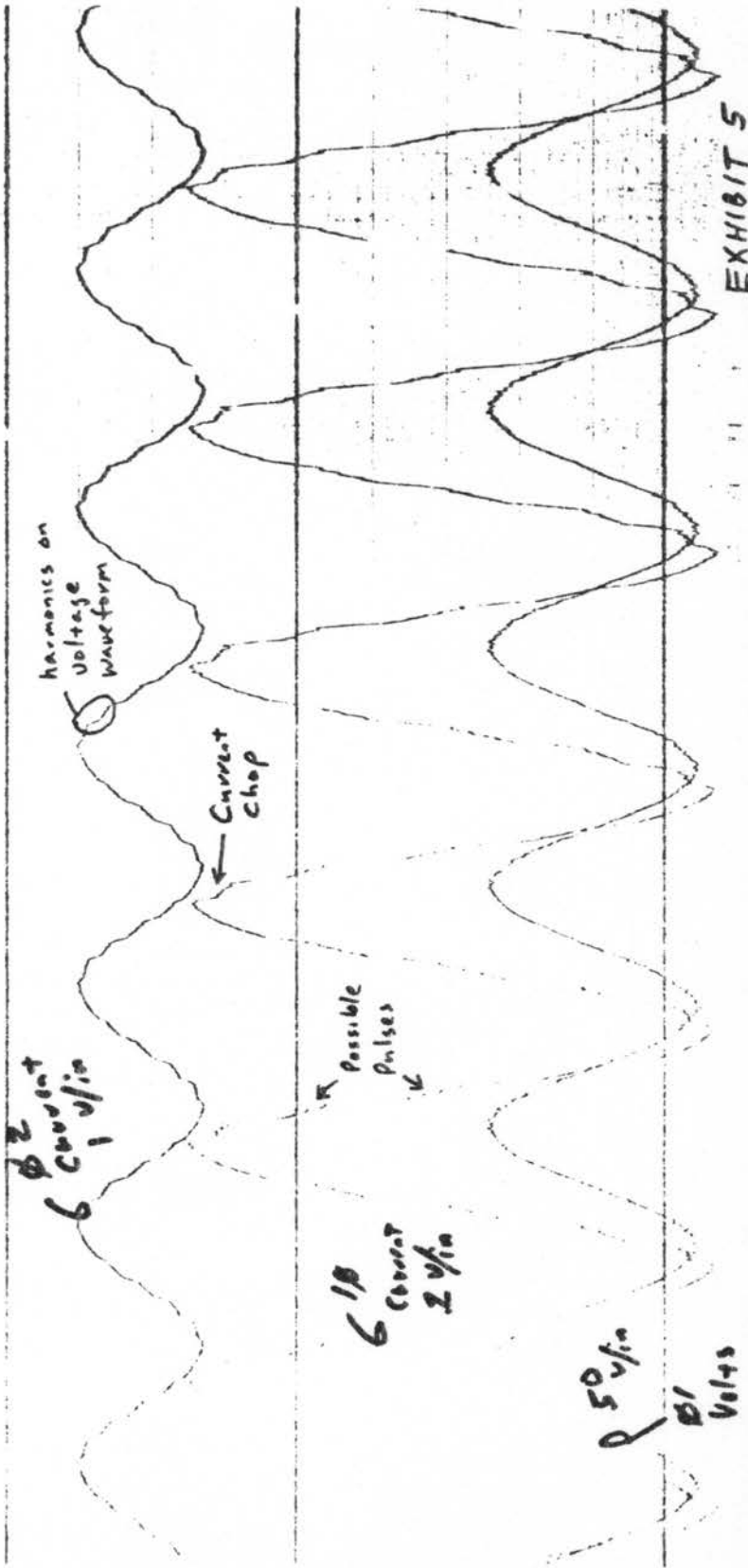
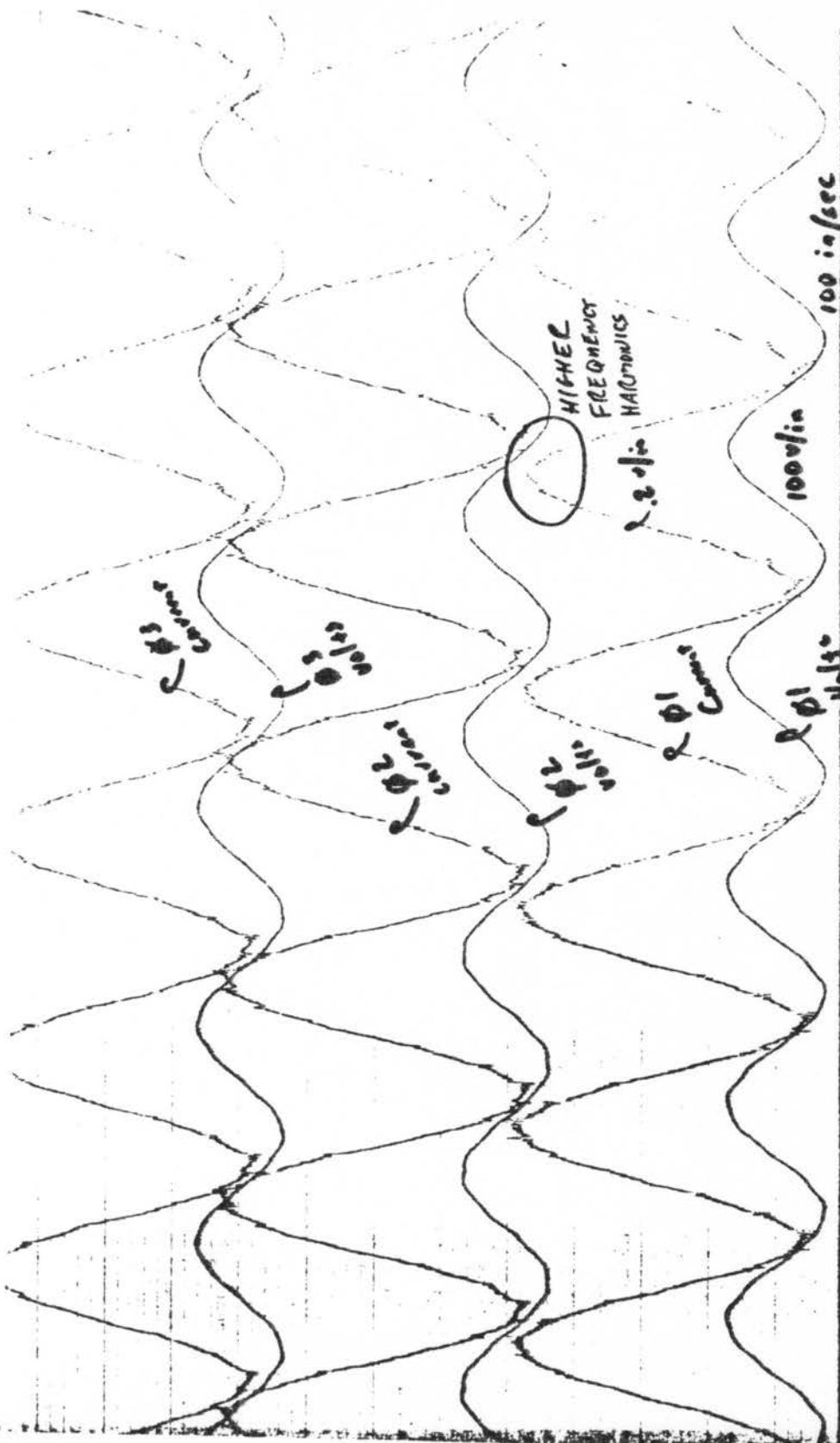


EXHIBIT 5





13-A-12  
 8/27/85 13:06 C-156 ON C-326 OFF  
 100v/in 100 in/sec

EXHIBIT 7

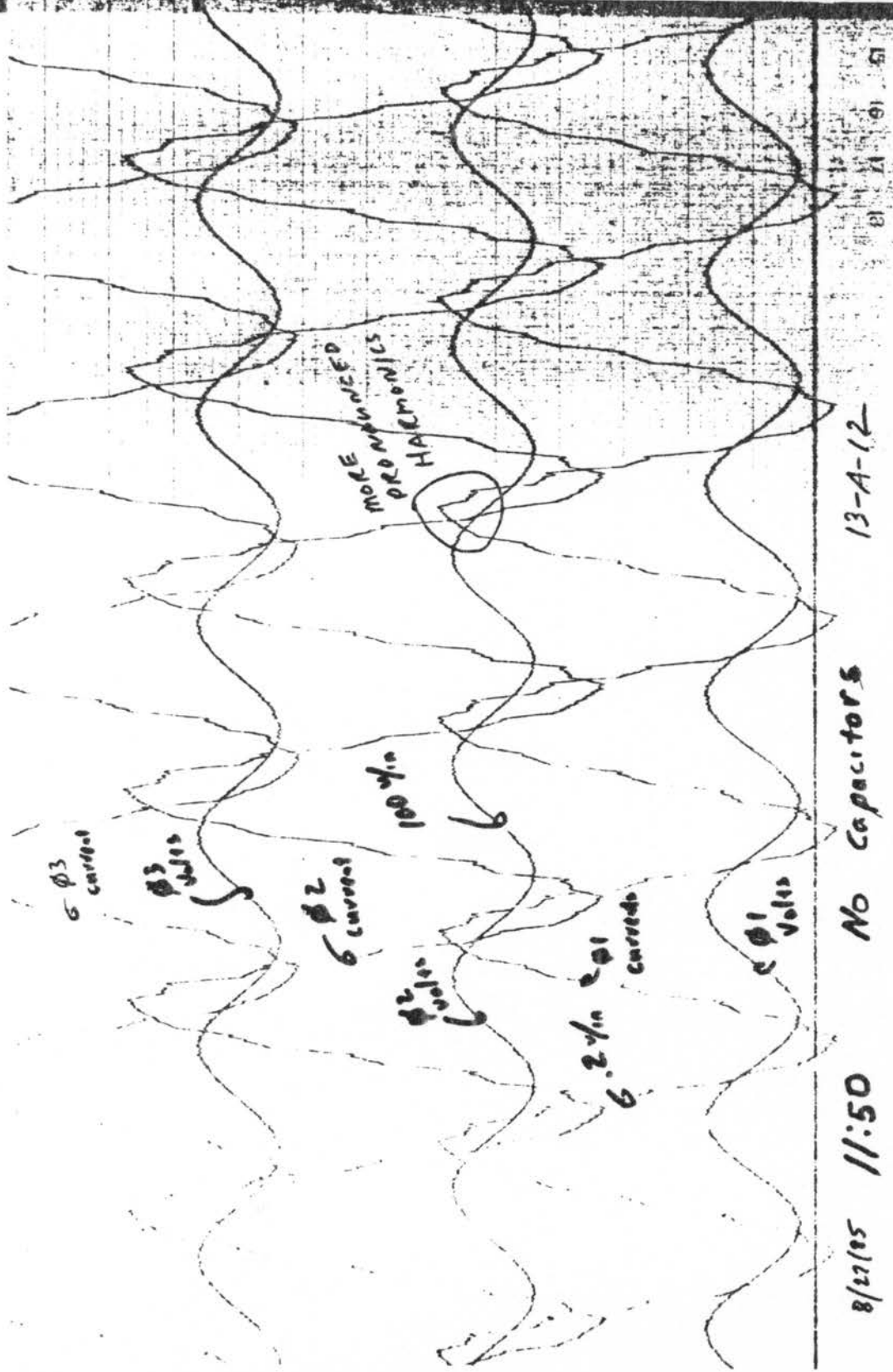
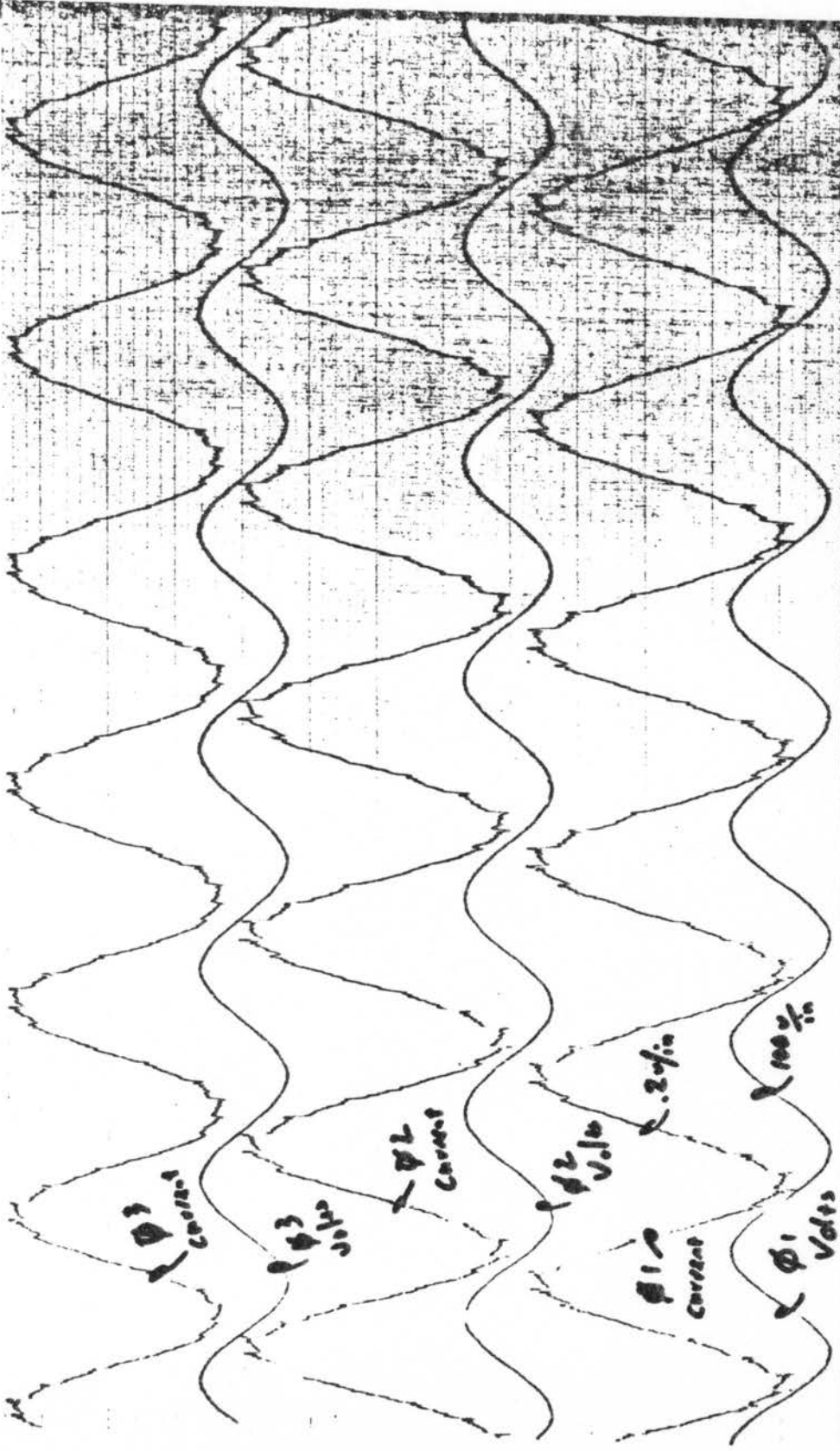


EXHIBIT 6





8/27/95 13:20 C-1560N C-3260N 13-A-12

EXHIBIT 8

SPECTRUM ANALYZER

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_

TEST

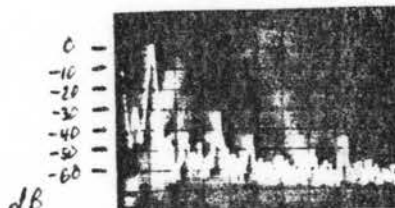
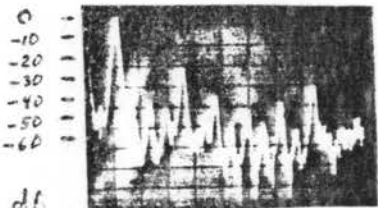
DATE 8/27/85 BY LTD

NOTE: POTENTIAL PROBE = 10X  
CURRENT PROBE = 1V = 10 AMPS

TEST #1

Sub A 13-A-12  
Voltage  $\phi 1$   
VERT  $30 \text{ dB/dv}$  H-20  
HORIZ 100 Hz/dv 11:25

Sub A 13-A-12  $\phi 1$   
Current  
Vertical  $0 \text{ dB/dv}$  0 dB 11:25  
HORIZ 100 Hz/dv 11:25



FORM CO-9L

TEST #2

Sub A 13-A-12 C3660  
Voltage C32601  
Vert 10 dB/dv  $\phi 1$   
HORIZ 100 Hz/dv H-25  
12:00

Sub A 13-A-12 -56 OFF  
Current C32602  
Vertical  $0 \text{ dB/dv}$  0 dB  $\phi 1$   
HORIZ 100 Hz/dv 12:00

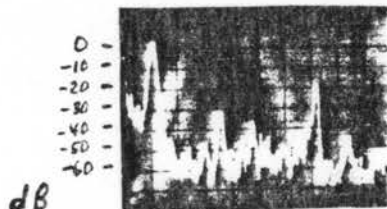
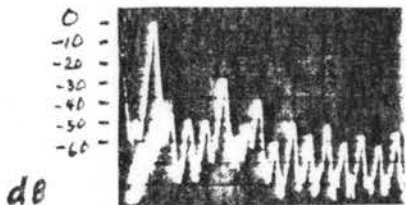


EXHIBIT 9

SPECTRUM ANALYZER

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_  
 DATE 8/27/85 BY LTD

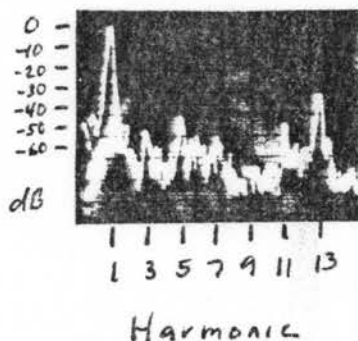
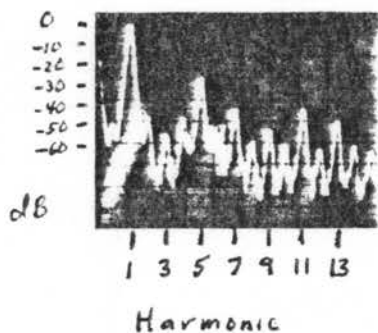
TEST

NOTE: POTENTIAL PROBE = 10X  
 CURRENT PROBE = 1V = 10AMPS

TEST # 3

Sub A 13-A-12 C156 ON  
 Voltage C326 OFF  
 Vert 10 dB/div 0.1  
 Horiz 100 ns/div 1256

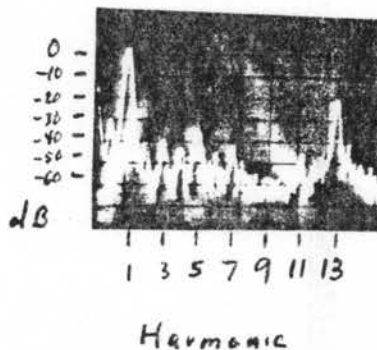
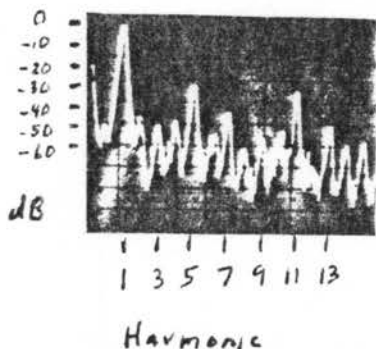
Sub A 13-A-12 C156 ON  
 Current C326 OFF  
 Vertical 10 dB/div 0.1  
 Horiz 100 ns/div 300



TEST # 4

Sub A 13-A-12 C156 ON  
 Voltage C326 ON  
 Vert 10 dB/div 0.1  
 Horiz 100 ns/div 1315

Sub A 13-A-1 C156 ON  
 Current C326 ON  
 Vertical 10 dB/div 0.1  
 Horiz 100 ns/div 1310



13 EV Bus Voltage  
6/12/85

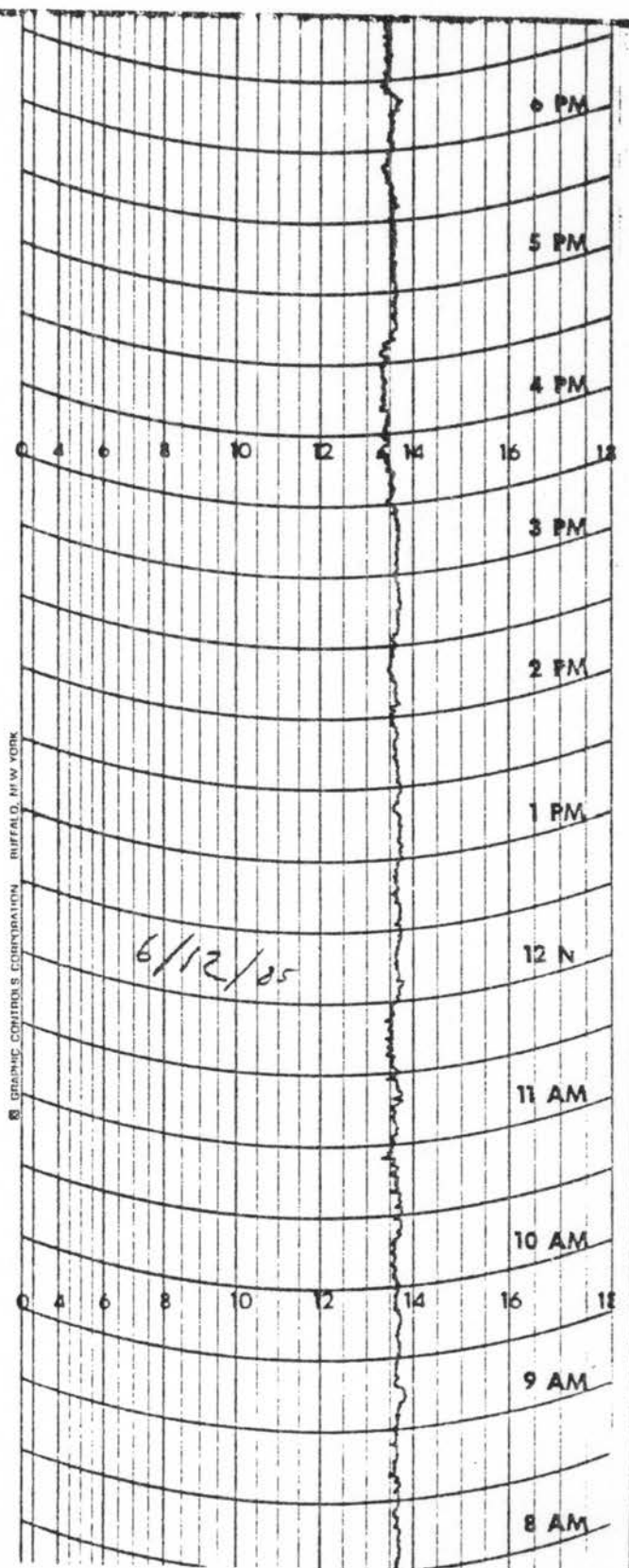


EXHIBIT 11

13 kV Bus Voltage  
8/13/85

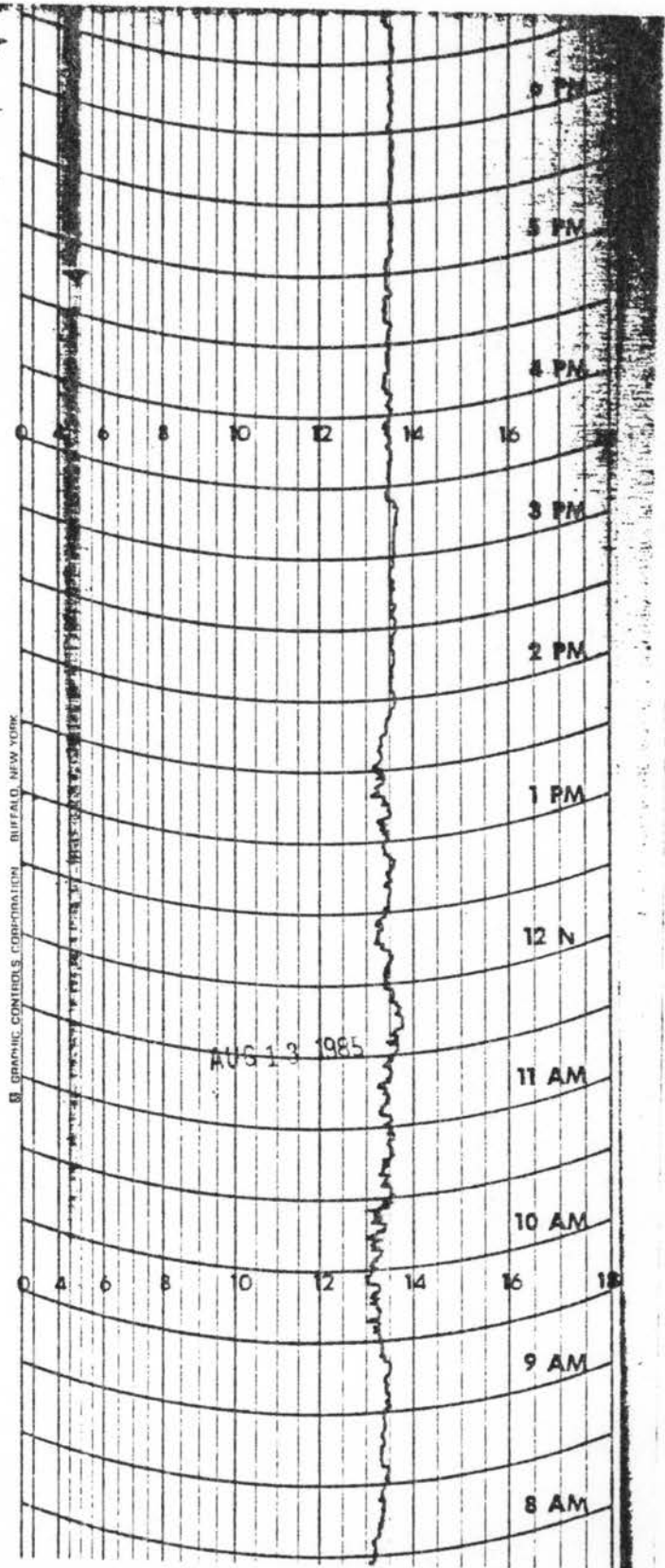


EXHIBIT 12

IX. APPENDIX

B. SLIDE LISTINGS

## SLIDE LISTINGS

1. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
2. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
3. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
4. SUB S TR #1  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles  
Phase 1
5. SUB S TR #1  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
6. SUB S TR #1  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
7. SUB S TR #1  
CURRENT - LOW SIDE (13 KV)  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
8. SUB S TR #1  
CURRENT - LOW SIDE (13 KV)  
Vert = 10dB/div  
Horiz = 100 cycles  
Phase 2
9. SUB S TR #1  
CURRENT - LOW SIDE (13 KV)  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
10. SUB S  
13 KV BUS 1 VOLTS  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
11. SUB S  
13 KV BUS 1 VOLTS  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
12. SUB S  
13 KV BUS 1 VOLTS  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
13. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
14. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
15. SUB S TR #1  
CURRENT - HIGH SIDE  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
16. SUB S TR #1  
CURRENT - LOW SIDE (13 KV)  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1

## SLIDE LISTINGS

(Continued)

- |  |  |
|--|--|
| <p>17. SUB S TR #1<br/>CURRENT - LOW SIDE (13 KV)<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 2</p> | <p>25. SUB 36 VOLTS - 13 KV<br/>13 KV BUS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p>         |
| <p>18. SUB S TR #1<br/>CURRENT - LOW SIDE (13 KV)<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p> | <p>26. SUB 36 VOLTS - 69 KV<br/>66-36-38-1<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p>        |
| <p>19. SUB S<br/>69 KV BUS 2 VOLTS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p>                | <p>27. SUB 36 VOLTS - 69 KV<br/>66-36-38-1<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 2</p>        |
| <p>20. SUB S<br/>69 KV BUS 2 VOLTS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p>                | <p>28. SUB 36 VOLTS 69 KV<br/>66-36-38-1<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p>          |
| <p>21. SUB S<br/>69 KV BUS 2 VOLTS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 2</p>                | <p>29. SUB 36<br/>CURRENT - 13 KV<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p>                 |
| <p>22. SUB S<br/>69 KV BUS 2 VOLTS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p>                | <p>30. SUB 36<br/>CURRENT - 13 KV<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 2</p>                 |
| <p>23. SUB 36 VOLTS - 13 KV<br/>13 KV BUS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p>         | <p>31. SUB 36<br/>CURRENT - 13 KV<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p>                 |
| <p>24. SUB 36 VOLTS - 13 KV<br/>13 KV BUS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 2</p>         | <p>32. SUB 36<br/>CURRENT - 69 KV<br/>69 Trans #1<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p> |



## SLIDE LISTINGS

(Continued)

33. SUB 36  
CURRENT - 69 KV  
69 Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
34. SUB 36  
CURRENT - 69 KV  
69 Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
35. SUB 36  
CURRENT - 13 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
36. SUB 36  
CURRENT - 13 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
37. SUB 36  
CURRENT - 13 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
38. SUB 76 VOLTS 161 KV  
161-76-58-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
39. SUB 76 VOLTS 161 KV  
161-76-58-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
40. SUB 76 VOLTS 161 KV  
161-76-58-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
41. SUB 76  
CURRENT - 161 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
42. SUB 76  
CURRENT - 161 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
43. SUB 76  
CURRENT - 161 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
44. SUB 76 VOLTS 13 KV  
13 KV BUS 2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
45. SUB 76 VOLTS 13 KV  
13 KV BUS 2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
46. SUB 76 VOLTS 13 KV  
13 KV BUS 2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3

## SLIDE LISTINGS

(Continued)

47. SUB 76  
CURRENT - 13 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
48. SUB 76  
CURRENT - 13 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
49. SUB 76  
CURRENT - 13 KV  
161 KV Trans #1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
50. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
51. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
52. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
53. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
54. SUB 78 Thu 6-21-84  
161-58-74-78-1 line  
current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
55. SUB 78 Thu 6-21-84  
161-58-74-78-1 line  
current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
56. SUB 78 Thu 6-21-84  
161-58-74-78-1 line  
current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
57. SUB 78 Thu 6-21-84  
161-58-74-78-1 line  
current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
58. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles  
Phase 1
59. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
60. SUB 78 Thu 6-21-84  
Tr #1 13 KV Current  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2

## SLIDE LISTINGS

(Continued)

- |  |  |
|--|--|
| <p>61. SUB 78 Thu 6-21-84<br/>Tr #1 13 KV Current<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 3</p> <p>62. SUB 78 Thu 6-21-84<br/>Tr #1 13 KV Volts<br/>Phase 1</p> <p>63. SUB 78 Thu 6-21-84<br/>Tr #1 13 KV Volts<br/>Phase 2</p> <p>64. SUB 78 Thu 6-21-84<br/>Tr #1 13 KV Volts<br/>Phase 3</p> <p>65. SUB 78 Thu 6-21-84<br/>161-58-74-78-1 line<br/>voltage<br/>Phase 1</p> <p>66. SUB 78 Thu 6-21-84<br/>161-58-74-78-1 line<br/>voltage<br/>Phase 2</p> <p>67. SUB 78 Thu 6-21-84<br/>161-58-74-78-1 line<br/>voltage<br/>Phase 3</p> <p>68. SUB 78<br/>161 BUS Volts<br/>Phase 1</p> <p>69. SUB 78<br/>161 BUS Volts<br/>Phase 2</p> <p>70. SUB 78<br/>161 BUS Volts<br/>Phase 3</p> | <p>71. SUB 78<br/>13 BUS 2 Volts<br/>Phase 1</p> <p>72. SUB 78<br/>13 BUS 2 Volts<br/>Phase 2</p> <p>73. SUB 78<br/>13 BUS 2 Volts<br/>Phase 3</p> <p>74. SUB 78<br/>Trans #2 13 Currents<br/>Phase 1</p> <p>75. SUB 78<br/>Trans #2 13 Currents<br/>Phase 1</p> <p>76. SUB 78<br/>Trans #2 13 Currents<br/>Phase 2</p> <p>77. SUB 78<br/>Trans #2 13 Currents<br/>Phase 3</p> <p>78. SUB 78<br/>161-58-74-78-1<br/>Phase 1</p> <p>79. SUB 78<br/>161-58-74-78-1<br/>Phase 2</p> <p>80. SUB 78<br/>161-58-74-78-1<br/>Phase 3</p> <p>81. SUB 78 - Volts - 13 KV<br/>13 KV BUS<br/>Vert = 10dB/div<br/>Horiz = 100 cycles/div<br/>Phase 1</p> |
|--|--|

## SLIDE LISTINGS

(Continued)

- |     |  |     |   |
|-----|--|-----|---|
| 82. | SUB 78 - Volts - 13 KV<br>13 KV BUS 1<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 2  | 90. | SUB 88<br>CURRENT - 13 KV<br>69/13 Trans #2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 1                             |
| 83. | SUB 78 - Volts - 13 KV<br>13 KV BUS 1<br>Vert = 10 dB/div<br>Horiz = 100 cycles/div<br>Phase 3 | 91. | No Title - Assumed to be<br>SUB 88<br>current - 13 KV<br>69/13 Trans #2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 2 |
| 84. | SUB 78 - Volts - 13 KV<br>13 KV BUS 2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 1  | 92. | SUB 88<br>CURRENT - 13 KV<br>69/13 Trans #2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 3                             |
| 85. | SUB 78 - Volts - 13 KV<br>13 KV BUS 2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 3  | 93. | SUB 88 - Volts - 13 KV<br>13 KV BUS 2 (Alcoa Pots)<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 1                      |
| 86. | SUB 78 - Volts - 13 KV<br>13 KV BUS 2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 3  | 94. | SUB 88 - Volts - 13 KV<br>13 KV BUS 2 (Alcoa Pots)<br>Vert = 10 dB/div<br>Horiz = 100 cycles/div<br>Phase 2                     |
| 87. | SUB 78 - Volts - 161 KV<br>161-74-78-1<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 1 | 95. | SUB 88 - Volts - 13 KV<br>13 KV BUS 2 (Alcoa Pots)<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 3                      |
| 88. | SUB 78 - Volts - 161 KV<br>161-74-78-1<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 2 | 96. | SUB 88<br>CURRENT - 69 KV<br>69/13 Trans #2<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 1                             |
| 89. | SUB 78 - Volts - 161 KV<br>161-74-78-1<br>Vert = 10dB/div<br>Horiz = 100 cycles/div<br>Phase 3 |     |   |

## SLIDE LISTINGS

(Continued)

97. SUB 88  
CURRENT - 69 KV  
69/13 Trans #2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
98. SUB 88  
CURRENT - 69 KV  
69/13 Trans #2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
99. SUB 88  
CURRENT - 69 KV  
69/13 Trans #2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
100. SUB 88  
CURRENT - 69 KV  
69/13 Trans #2  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
101. SUB 91 - Volts - 345  
345-QC-91-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
102. SUB 91 - Volts - 345  
345-QC-91-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
103. SUB 91 - Volts - 345  
345-QC-91-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
104. SUB 91 - Volts 161 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
105. SUB 91 - Volts - 161 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
106. SUB 91 - Volts - 161 KV  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
107. SUB 91  
CURRENT - 345 KV  
345-91-QC-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
108. SUB 91  
CURRENT - 345 KV  
345-91-QC-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
109. SUB 91  
CURRENT - 345 KV  
345-91-QC-1  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
110. SUB 91  
CURRENT - 161 KV  
345/161 Trans  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1

## SLIDE LISTINGS

(Continued)

111. SUB 91  
CURRENT - 161 KV  
345/161 Trans  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
112. SUB 91  
CURRENT - 161 KV  
345/161 Trans  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
113. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 On  
C326 On  
Phase 1
114. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 On  
C326 On  
Phase 1
115. SUB A 13-A-12  
CURRENT  
Vert = 20 volt/div  
Horiz = 100 cycles/div  
C156 On  
C326 On  
Phase 1
116. SUB A 13-A-1  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 On  
C326 On  
Phase 1
117. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
C156 On  
C326 On  
Phase 1
118. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 On  
C326 Off  
Phase 1
119. SUB A 13-A-12  
CURRENT  
Vert = 20 v/div  
Horiz = 100 cycles/div  
C156 On  
C326 Off  
Phase
120. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 On  
C326 Off  
Phase 1
121. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
C156 On  
C326 Off  
Phase 1
122. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 Off  
C326 Off  
Phase 1

## SLIDE LISTINGS

(Continued)

123. SUB A 13-A-12  
CURRENT  
Vert = 20 v/div  
Horiz = 100 cycles/div  
C156 Off  
C326 Off  
Phase 1
124. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
C156 Off  
C326 Off  
Phase 1
125. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
C156 Off  
C326 Off  
Phase 1
126. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
127. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
Phase 3
128. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
Phase 1
129. SUB A 13-A-12  
CURRENT  
Vert = .2 v/div  
Horiz = 100 cycles/div  
Phase 1
130. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
0 db Input  
Phase 1
131. SUB A 13-A-12  
CURRENT  
Vert = 20 v/div  
Horiz = 100 cycles/div  
Phase 1
132. SUB A 13-A-12  
CURRENT  
Vert = +30dB/div  
Horiz = 100 cycles/div  
Phase 1
133. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 1
134. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 2
135. SUB A 13-A-12  
CURRENT  
Vert = 10dB/div  
Horiz = 100 cycles/div  
Phase 3
136. Picture of Test  
Equipment
137. Picture of Test  
Equipment
138. Picture of Test  
Equipment
139. Picture of Test  
Equipment

X. APPENDIX

C. MODIFIED HARMONIC LOADFLOW PROGRAM LISTING





```

000670 C---          0=NO PLOTS
000680 C---          IVC=VOLTAGE OR CURRENT OR CONVERTER CODE
000690 C---          LESS THAN -1 = CURRENT HARMONIC MAGNITUDES GIVEN
000700 C---          -1=VOLTAGE HARMONIC MAGNITUDES GIVEN
000710 C---          0=VOLTAGE WAVEFORM
000720 C---          1=CONVERTER
000730 C---          ANYTHING ELSE=CURRENT WAVEFORM
000740 C---          IUNIT=OUTPUT UNITS
000750 C---          0=VOLTS
000760 C---          ANYTHING ELSE=PER UNIT
000770          READ(IPD,1000)N,VCBASE,LHARM,IPL0T,IVC,IUNIT
000780          1000 FORMAT(13,F10.2,4I3)
000790          WRITE(IWT,109)N,VCBASE,LHARM,IPL0T,IVC,IUNIT
000800          109 FORMAT(1X,'N = ',13.5X,'VCBASE = ',F7.2,5X,'LHARM = ',13,
000810          ' 5X,'IPL0T = ',13.5X,'IVC = ',13.5X,'IUNIT = ',13)
000820          IF(IVC.GE.0)GO TO 40
000830 C---          READ MEASURED HARMONIC VOLTAGES OR CURRENTS
000840 C---          IY=HARMONIC ORDER
000850 C---          VCM=HARMONIC VOLTAGE (CURRENT) MAGNITUDE
000860 C---          VCA=HARMONIC VOLTAGE (CURRENT) ANGLE
000870          IF (IVC.NE.-1) GO TO 28
000880          IVC=0
000890          GO TO 29
000900          28 IVC=2
000910          29 CONTINUE
000920          WRITE(IWT,1051)
000930          DO 31 IM=1,65
000940          31 VC(IM)=0.,0.)
000950          30 READ(IRD,600)IV,VCM,VCA
000960          IF(IV.EQ.999)GO TO 34
000970          WRITE(IWT,600)IV,VCM,VCA
000980          600 FORMAT(3X,13,2X,F10.8,2X,F12.8)
000990          IF(VCA.EQ.0.)GO TO 32
001000          IM=IV+1
001010          VC(IM)=CMPLX(-VCM,0.)
001020          GO TO 32
001030          32 IM=IV-1
001040          VC(IM)=CMPLX(VCM,0.)
001050          33 GO TO 30
001060          34 IF=65
001070          GO TO 308
001080          40 IF(IVC.NE.1)GO TO 301
001090 C---          READ CONVERTER DATA
001100 C---          POW=MW RATING OF CONVERTER
001110 C---          ALFA=DELAY ANGLE IN DEGREES (0-60)
001120 C---          OVLP=OVERLAP ANGLE IN DEGREES
001130          READ(IRD,302) POW,ALFA,OVLP
001140          302 FORMAT(3F10.2)
001150          WRITE(IWT,303) POW,ALFA,OVLP
001160          303 FORMAT(10POW = ',F10.2,5X,'ALFA = ',F10.2,5X,'OVLP = ',F10.2)
001170          ALFA=ALFA/RTD
001180          OVLP=OVLP/RTD
001190          GAM=ALFA+OVLP
001200          DO 304 IM=3,65
001210          304 VC(IM)=(0.,0.)
001220          WRITE(IWT,1051)
001230          DH=COS(ALFA)-COS(GAM)
001240          DO 305 IM=N,65,N
001250          IF(OVLP.NE.0.)GO TO 306
001260 C---          0.779697=SQRT(6)/PI
001270          SHAR1=0.779697/(IM-1.)
001280          SHAR2=0.779697/(IM+1.)
001290          GO TO 307
001300          306 SHM=SIN((IM-2.)*OVLP/2.)
001310          SHP=SIN(IM*OVLP/2.)
001320          F2=SQRT((SHM/(IM-2.))**2+(SHP/IM)**2-2.*SHM*SHP*

```

```

001330      1 COS(2.*ALFA+OVLP)/((IM-2.)*IM)
001340      SHAR1=0.779697*F2/((IM-1.)*DH)
001350      SHM=SIN(IM*OVLP/2.)
001360      SHP=SIN((IM+2.)*OVLP/2.)
001370      F2=SQRT((SHM/IM)**2+(SHP/(IM+2.))**2-2.*SHM*SHP*
001380      1 COS(2.*ALFA+OVLP)/(IM*(IM+2.)))
001390      SHAR2=0.779697*F2/((IM+1.)*DH)
001400 C---      2.5651=2*PI/SQRT(6)
001410      307 CR=2.5651*POW/((COS(ALFA)+COS(GAM))*100.)
001420      VCA=180.
001430      VCM=CR*SHAR1
001440      IY=IM-1
001450      VC(IM)=CMPLX(-VCM,0.)
001460      WRITE(IWT,106) IY,VCM,VCA
001470      VCA=0.
001480      VCM=CR*SHAR2
001490      IY=IM+1
001500      VC(IM+2)=CMPLX(VCM,0.)
001510      WRITE(IWT,106) IY,VCM,VCA
001520      305 CONTINUE
001530      IF=65
001540      GO TO 308
001550 C---      READ IN SAMPLED DATA WAVEFORM
001560      301 J=(N-1)/B+1
001570      DO 2 IB=1,J
001580      KI=B*(IB-1)+1
001590      KJ=KI+7
001600 C---      A=ARRAY OF N VALUES OF THE SAMPLED DATA WAVEFORM IN COSINE
001610 C---      FORM IN KV
001620      READ(IRD,1050) (A(K),K=KI,KJ)
001630      1050 FORMAT(BF10.2)
001640      9 CONTINUE
001650      WRITE(IWT,200)
001660      200 FORMAT(1H0.5X,'SAMPLED DATA POINTS'/1H0,'NUMBER',35X,'VALUES')
001670      DO 110 IB=1,J
001680      KI=B*(IB-1)+1
001690      KJ=KI+7
001700      WRITE(IWT,111) KI,(A(K),K=KI,KJ)
001710      111 FORMAT(1H0,I4,BF10.2)
001720      110 CONTINUE
001730      DO 300 IB=1,N
001740      300 VC(IB)=CMPLX(A(IB),0.)
001750 C---      FFTCC IS A SPECIAL PROGRAM FROM A LIBRARY NOT INCLUDED
001760 C---      THERE IS A DUMMY PROGRAM INCLUDED TO SATISFY EXTERNAL
001770 C---      REFERENCES
001780 C---      PERFORM FAST FOURIER TRANSFORM
001790 C---      IWK=INTEGER WORK ARRAY OF LENGTH 6N+150
001800 C---      WK=REAL WORK ARRAY OF LENGTH 6N+150
001810      CALL FFTCC(VC,N,IWK,WK)
001820 C---      RN=NUMBER OF SAMPLED DATA POINTS/2
001830      RN=N/2
001840      WRITE(IWT,1051)
001850      1051 FORMAT(1H-,'HARMONIC VALUES'/1HORDER',8X,'MAG',8X,'ANG')
001860      IZ=N/2
001870 C---      RESCALE TRANSFORM COEFFICIENTS
001880      DO 26 IM=1,IZ
001890      VC(IM)=CONJG(VC(IM))/(RN*VCBASE)
001900      VCM=CABS(VC(IM))
001910      VCA=ANGLE(VC(IM))*RTD
001920 C---      IY=HARMONIC ORDER
001930      IY=IM-1
001940 C---      PRINT HARMONIC VALUES
001950      WRITE(IWT,106) IY,VCM,VCA
001960      106 FORMAT(3X,I2,2X,F12.4,F12.2)
001970      26 CONTINUE
001980 C---      LLL=FIRST TIME THROUGH LOOP FLAG

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001990 C---      1=FIRST TIME
002000      IF=N/2+1
002010      308 LLL=1
002020      IF(IPL0T.EQ.0) IF=LHARM+1
002030 C---      INITIALIZE DC HARMONIC TO ZERO
002040      DO 167 IE=1,4
002050      167 SOURCE(1,IE)=(0.,0.)
002060 C---      BEGIN LOOP FOR HARMONIC ANALYSIS
002070 C---      JJ=HARMONIC ORDER + 1
002080      DO 27 JJ=3,IF
002090 C---      IW=HARMONIC ORDER
002100      IW=JJ-1
002110 C---      VCK=HARMONIC SOURCE VALUE IN PU
002120      VCK=VCF(JJ)
002130 C---      IDS=SEQUENCE CODE FOR HARMONIC (SEE LINEIN)
002140      IDS=0
002150 C---      IF HARMONIC INJEC NEGLBLE, DO NOT PERFORM HARMONIC ANAL
002160      IF(CABS(VCK).GT.0.0000001)GO TO 17
002170      DO 984 IE=1,4
002180      984 SOURCE(JJ,IE)=(0.,0.)
002190      GO TO 27
002200      17 IF(IW.GT.LHARM) GO TO 18
002210      GO TO 19
002220      18 WRITE(IWT,108) IW
002230      108 FORMAT('0XXX HARMONICS OF ORDER',3X,I3/)
002240      19 CONTINUE
002250 C---      LINEIN=SUBROUTINE FOR READING AND STORING LINE, TRANSFORMER,
002260 C---      GENERATOR, SHUNT CAPACITOR, AND LOAD DATA
002270 C---      IP=ARRAY CONTAINING EXTERNAL 'FROM' BUS #'S
002280 C---      IQ=ARRAY CONTAINING EXTERNAL 'TO' BUS #'S
002290 C---      ICT=ARRAY CONTAINING ELEMENT CIRCUIT #'S
002300 C---      R,X=ARRAYS CONTAINING ELEMENT RESISTANCE AND REACTANCE
002310 C---      NB=ARRAY CONTAINING CONVERSION OF EXTERNAL TO INTERNAL
002320 C---      BUS #'S
002330 C---      NLB=ARRAY CONTAINING THE # OF ELEMENTS TO A BUS
002340 C---      NBE=ARRAY CONTAINING CONVERSION OF INTERNAL TO EXTERNAL
002350 C---      BUS #'S
002360      CALL LINEIN(IP,IQ,ICT,R,X,NB,NLB,NBE,ILIN,Z0,GAML,&2,&500)
002370 C---      ORDER=SUBROUTINE FOR ORDERING AND INDEXING SYSTEM TOPOLOGY
002380 C---      JP1=POINTER ARRAY FOR 'FROM' BUS TO ELEMENT #
002390 C---      JP2=POINTER ARRAY FOR 'TO' BUS TO ELEMENT #
002400 C---      KP1=POINTER ARRAY FOR 'FROM' BUS (ONE ELEMENT # TO NEXT)
002410 C---      KP2=POINTER ARRAY FOR 'TO' BUS (ONE ELEMENT # TO NEXT)
002420 C---      ISC=ARRAY CONTAINING THE ORDERING SCOPE OF THE BUS
002430 C---      ILO=ARRAY CONTAINING THE ELEMENT ORDER
002440 C---      IBO=ARRAY CONTAINING THE BUS ORDER
002450      2 CALL ORDER(IP,IQ,NLB,JP1,JP2,KP1,KP2,ISC,ILO,IBO,&4,&500)
002460 C---      ZBUS=SUBROUTINE FOR CALCULATION OF IMPEDANCE MATRIX
002470 C---      RBUS=ARRAY CONTAINING REAL PART OF BUS IMPEDANCE MATRIX
002480 C---      XBUS= ARRAY CONTAINING IMAGINARY PART OF BUS IMPEDANCE Matri
002490 C---      RL=ARRAY CONTAINING ELEMENT RESISTANCE
002500 C---      XL=ARRAY CONTAINING ELEMENT REACTANCE
002510      4 CALL ZBUS(IP,IQ,R,X,ILO,IBO,ISC,REBUS,IBUS,RL,XL,NBE,&6,&500)
002520 C---      HARMJ=SUBROUTINE FOR HARMONIC ANALYSIS
002530      6 WRITE(IWT,107)IW
002540      107 FORMAT('1XXX HARMONICS OF ORDER',3X,I3/)
002550      CALL HARMJ(IP,IQ,ICT,R,X,KP1,KP2,NB,NBE,JP1,JP2,ISC,REBUS,IBUS,RL,
002560      1XL,ILIN,Z0,VMSQ,VVM1,GAML,&7,&500)
002570      7 CONTINUE
002580      LLL=2
002590      27 CONTINUE
002600 C---      COMPUTE HARMONIC (VOLTAGE) DISTORTION FACTOR
002610 C      IF(IOPT.EQ.0) GO TO 470
002620      WRITE (IWT,450)
002630      DO 400 J=1,NB#
002640 C      J=EXTERNAL BUS#

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002650 C      KP=INTERNAL BUS #
002650      KP=NB(J)
002670 C      BUS EXISTS?
002680      IF(KP.EQ.0)GO TO 400
002690      IF(IUNIT.EQ.0)GO TO 430
002691      IF(VVM1(J).EQ.0.)VVM1(J)=1.0
002700      HDF(J)=(VMSG(J)**0.5)*100./VVM1(J)
002710      GO TO 440
002720 430 IF(VVM1(J).EQ.0.)VVM1(J)=VCBASE*1000./SQRT(3.)
002730      HDF(J)=(VMSG(J)**0.5)*100./VVM1(J)
002740 440 WRITE(1,460)J,HDF(J)
002750      400 CONTINUE
002760 450 FORMAT(11'HARMONIC DISTORTION FACTOR'//6X,'BUS',12X,'HDF (%)')
002770 460 FORMAT(6X,14,8X,F10.4)
002780      IF(IPL0T.EQ.0) GO TO 500
002790      IVCO=1
002800      IF(IVC.EQ.0) IVCO=2
002810      IF(IVC.EQ.1) N=128
002820      J=(N-1)/4-1
002830      IC=N/2-1
002840      DO 37 IE=1,J,JJ
002850      WRITE(6,220) IE
002860 220 FORMAT(1H1,5X,'WAVEFORM FOR HARMONIC SOURCE NUMBER',15)
002870      DO 47 IG=1,IC
002880      IA=IG+N/2+1
002890      IB=N/2+1-IG
002900 47 SOURCE(IA,IE)=CONJG(SOURCE(IB,IE))
002910 C---      FFTCC IS A SPECIAL PROGRAM FROM A LIBRARY NOT INCLUDED
002920 C---      THERE IS A DUMMY PROGRAM INCLUDED TO SATISFY EXTERNAL
002930 C---      REFERENCES
002940      CALL FFTCC(SOURCE(1,IE),N,IKW,WK)
002950      DO 57 IA=1,N
002960      SOURCE(IA,IE)=SOURCE(IA,IE)/2.
002970      A(IA)=REAL(SOURCE(IA,IE))
002980 57 X(IA)=(IA-1.)*1000./((60.*N)
002990      DO 67 IB=1,J
003000      KI=4*(IB-1)+1
003010      KJ=KI+3
003020 67 WRITE(6,210) KI,(SOURCE(I,IE),I=KI,KJ)
003030 210 FORMAT(1H0,14,BF10.5)
003040 C---      THIS CALLS IOWA STATE UNIVERSITY'S VERSION OF CALCOM
003050 C---      THIS MAY NOT WORK WITH STANDARD CALCOM
003060      CALL GRAPH(N,X,A,4,103,12.,9.,1.5,0.,0.,0.,'TIME (MS):',
003070      1 YLAB(1,IVCO),GLAB(1,IVCO),DATLAB(1,IE))
003080      37 CONTINUE
003090 500 STOP
003100      END
003110      SUBROUTINE LINEIN(IP,IQ,ICT,R,X,NB,NLB,NBE,ILIN,Z0,GAML,*,*)
003120 C---      READ AND STORE LINE, TRANSFORMER, GENERATOR, SHUNT CAPACITOR
003130 C---      AND LOAD DATA
003140 C---      CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
003150 C---      HARMONIC ORDER TO BE ANALYZED
003160      IMPLICIT INTEGER*4(1-N)
003170      INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,IDSN,IW
003180      COMPLEX*8 D1,D2,DD1,DD,DZ1,DZ,DE,DSH,DCH,DYS,DZS,CMLPX,CSQRT,CEXP
003190      COMPLEX*8 DT1,DT2,DT3,DVZ,Z0,GAML
003200      COMMON /K1/IRD,IWT,IW,IDSN,M2
003210      COMMON /KL/NEX,NEL
003220      COMMON /KB/NBH,NBS,NBX,MS,NLR
003230      COMMON /BASE/LLL,JJJJ
003240      DIMENSION IP(NEX),IQ(NEX),ICT(NEX),R(NEX),X(NEX),ILIN(NEX)
003250      DIMENSION NB(NBH),NLB(NBX),NBE(NBX),Z0(NEX),GAML(NEX)
003260      DIMENSION RDN(4000,7),IRDN(4000,5)
003270      DIMENSION RDC(4000),A6(4000),BER(2),BE1(2),BE1D(2)
003280 C---      NEX=MAXIMUM NUMBER OF ELEMENTS
003290 C---      NEL=NUMBER OF ELEMENTS

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003300 C--- NBH=LARGEST BUS NUMBER ALLOWED
003310 C--- NBS=NUMBER OF BUSES
003320 C--- NBX=MAXIMUM NUMBER OF BUSES
003330 C--- IP=ARRAY CONTAINING INTERNAL 'FROM' BUS #'S
003340 C--- IQ=ARRAY CONTAINING INTERNAL 'TO' BUS #'S
003350 C--- ICT=ARRAY CONTAINING ELEMENT CIRCUIT #'S
003360 C--- P, X=ARRAYS CONTAINING IMPEDANCE
003370 C--- NB=ARRAY CONTAINING CONVERSION OF EXTERNAL TO INTERNAL BUS #
003380 C--- NBE=ARRAY CONTAINING CONVERSION OF INTERNAL TO EXTERNAL BUS #
003390 C--- NLB=ARRAY CONTAINING THE NUMBER OF LINES TO A BUS
003400 NBS=0
003410 NE1=0
003420 NEL=0
003430 C--- IERROR=NUMBER OF BUS # ERRORS
003440 IERROR=0
003450 C--- NLR=NUMBER OF ELEMENTS CONNECTED TO REFERENCE
003460 NLR=0
003470 DO 1 I=1,NBH
003480 1 NB(I)=0
003490 DO 2 I=1,NBX
003500 2 NLB(I)=0
003510 IF (LLL.GT.1)GO TO 11
003520 WRITE(IWT,1100)
003530 C--- NE1=NUMBER OF ELEMENTS + 1
003540 11 NE1=NE1+1
003550 C--- LLL=FIRST TIME THROUGH LOOP FLAG
003560 C--- 1=FIRST TIME
003570 IF(LLL.GT.1)GO TO 300
003580 C--- INITIALIZE RDC ARRAY TO ZERO
003590 DO 3 I=1,NEX
003600 3 RDC(I)=0.
003610 C--- READ ELEMENT DATA
003620 C--- KJ=ELEMENT CODE
003630 C--- 1=LINE
003640 C--- 2=TRANSFORMER
003650 C--- 3=GENERATOR OR SHUNT CAPACITOR
003660 C--- 4=LOAD
003670 C--- KJP='FROM' BUS (9999 FOR END OF ELEMENTS)
003680 C--- KJQ='TO' BUS
003690 C--- KCT=ELEMENT CIRCUIT # (OR) TRANSFORMER AUXILIARY BUS #
003700 C--- RP1=LINE POS/NEG SEQ RESISTANCE (OR) TRANSFORMER POS/NEG
003710 C--- SEQ SERIES REACTANCE BOTH IN % (OR) LOAD REAL POWER IN MW
003720 C--- XX1=LINE POS/NEG SEQ REACTANCE (OR) TRANSFORMER ZERO SEQ
003730 C--- SERIES REACTANCE (OR) GEN/CAP REACTANCE ALL IN % (OR)
003740 C--- LOAD REACTIVE POWER IN MVAR
003750 C--- XC1=LINE POS/NEG SEQ SUSCEPTANCE (OR) TRANSFORMER POS/NEG
003760 C--- SEQ SHUNT REACTANCE (OR) GEN ZERO SEQ REACTANCE ALL IN %
003770 C--- RRD=LINE ZERO SEQ RESISTANCE (OR) TRANSFORMER POS/NEG/ZERO
003780 C--- SEQ CORE LOSS RESISTANCE BOTH IN %
003790 C--- XX0=LINE ZERO SEQ REACTANCE IN % (OR) TRANSFORMER CONNECTION
003800 C--- CODE
003810 C--- XCD=LINE ZERO SEQ SUSCEPTANCE (OR) TRANSFORMER ZERO SEQ
003820 C--- SHUNT REACTANCE BOTH IN %
003830 C--- KK=LINE VOLTAGE AND BUNDLE CODE
003840 C--- VOLTAGE(KV) CODE(FIRST DITIT) (SECOND DIGIT)
003850 C--- 13.80 9 NUMBER OF BUNDLES
003860 C--- 69 1 PER CONDUCTOR
003870 C--- 115 2
003880 C--- 132 3
003890 C--- 138 4
003900 C--- 161 5
003910 C--- 230 6
003920 C--- 345 7
003930 C--- 500 8
003940 C--- (OR) KK=TRANSFORMER CONNECTION CODE
003950 C--- 0,XY0.GT.1.:NO ZERO SEQ IMPEDANCE

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003960 C---      0.0.9.LT.XX0.LT.1.;ONE IMPEDANCE (XX1) 'TO' BUS TO
003970 C---      REFERENCE
003980 C---      0.0.7.LT.XX0.LT.0.9;ONEIMPEDANCE (XX1) 'FROM' BUS
003990 C---      TO REFERENCE
004000 C---      0.XX0.LT.0.7:T-TYPE CKT WITH POS/NEG SEQ MAG BRANCH
004010 C---      1:SHORTED T-TYPE (XX1,XC0) 'FROM' BUS TO REFERENCE
004020 C---      2:SHORTED T-TYPE (XX1,XC0) 'TO' BUS TO REFERENCE
004030 C---      3:OPEN T-TYPE (XX1,XC0) 'TO' BUS TO REFERENCE
004040 C---      4:OPEN T-TYPE (XX1,XC0) 'FROM' BUS TO REFERENCE
004050 C---      .GT.4:T-TYPE (XX1,XC0) CORE LOSS NEGLECTED
004060 C---      (OR) KK=GEN/CAP CODE
004070 C---      1=CAPACITOR
004080 C---      (OP) KK=LOAD CODE
004090 C---      1=RESIDENTIAL
004100 C---      2=COMMERCIAL
004110 C---      3=INDUSTRIAL
004120 C---      XLM=LINE LENGTH IN MILES
004130      READ(IPD,1000,END=50)KJ,KJP,KJQ,KCT,RR1,XX1,XC1,RR0,XX0,XC0,KK,XLM
004131      IF(KJP.EQ.9999) GO TO 200
004140      WRITE (IWT,1200)KJ,KJP,KJQ,KCT,RR1,XX1,XC1,RR0,XX0,XC0,KK,XLM
004141      200 CONTINUE
004150 C---      CONVERT FROM PER CENT TO PER UNIT
004160      RR1=RR1/100.0
004170      XX1=XX1/100.0
004180      XC1=XC1/100.0
004190      RR0=RR0/100.0
004200 C---      XX0 IS CONVERTED LATER
004210      XC0=XC0/100.0
004220 C---      STOPE INPUT DATA
004230 C---      IRDN=INTEGER ARRAY STORING INPUT DATA
004240      IRDN(NE1,1)=KJ
004250      IRDN(NE1,2)=KJP
004260      IRDN(NE1,3)=KJQ
004270      IRDN(NE1,4)=KCT
004280      IRDN(NE1,5)=KK
004290 C---      RDN=REAL ARRAY STORING INPUT DATA
004300      RDN(NE1,1)=RR1
004310      RDN(NE1,2)=XX1
004320      RDN(NE1,3)=XC1
004330      RDN(NE1,4)=RR0
004340      RDN(NE1,5)=XX0
004350      RDN(NE1,6)=XC0
004360      RDN(NE1,7)=XLM
004370      GO TO 301
004380 C---      RECOVER INPUT DATA
004390      300 KJ=IRDN(NE1,1)
004400      KJP=IRDN(NE1,2)
004410      KJQ=IRDN(NE1,3)
004420      KCT=IRDN(NE1,4)
004430      KK=IRDN(NE1,5)
004440      RR1=RDN(NE1,1)
004450      XX1=RDN(NE1,2)
004460      XC1=RDN(NE1,3)
004470      RR0=RDN(NE1,4)
004480      XX0=RDN(NE1,5)
004490      XC0=RDN(NE1,6)
004500      XLM=RDN(NE1,7)
004510      301 IF(KJP.EQ.9999) GO TO 45
004520 C---      IDSN=SEQUENCE CODE FOR HARMONIC
004530 C---      0=UNDETERMINED
004540 C---      1=ZERO SEQUENCE
004550 C---      2=NEG SEQUENCE
004560 C---      3=POS SEQUENCE
004570      150 IF(IDSN-1)101,106,141
004580      141 IF(IDSN-2)110,110,112
004590      101 B=1.0

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004600 C--- WT=HARMONIC ORDER
004610 WT=FLOAT(1W)
004611 IF(WT.EQ.1) GO TO 112
004620 C--- IS HARMONIC ZERO SEQ.
004630 107 A=3.0*B
004640 IF(WT/A-1.0)105,106,105
004650 105 B=B+1.0
004660 IF(B-22.0)107,108,108
004670 C--- IS HARMONIC NEG. SEQ.
004680 108 B=1.0
004690 111 A=(3.0*B)-1.0
004700 IF(WT/A-1.0)109,110,109
004710 109 B=B+1.0
004720 IF(B-22.0)111,112,112
004730 112 IDSN=3
004740 C--- HARMONIC IS POS. SEQ.
004750 C--- WHAT IS ELEMENT
004760 IF(KJ-2)113,114,115
004770 C--- POS. + NEG. SEQ. TRANSMISSION LINE
004780 C--- DETERMINE BASE IMPEDANCE
004790 113 IF(KK.GT.20)GO TO 210
004800 C--- BI=BASE IMPEDANCE
004810 BI=47.61
004820 GO TO 218
004830 210 IF(KK.GT.30)GO TO 211
004840 BI=132.25
004850 KK=KK-10
004860 GO TO 218
004870 211 IF(KK.GT.40)GO TO 212
004880 BI=174.24
004890 KK=KK-20
004900 GO TO 218
004910 212 IF(KK.GT.50)GO TO 213
004920 BI=190.44
004930 KK=KK-30
004940 GO TO 218
004950 213 IF(KK.GT.60)GO TO 214
004960 BI=259.21
004970 KK=KK-40
004980 GO TO 218
004990 214 IF(KK.GT.70)GO TO 215
005000 BI=529.00
005010 KK=KK-50
005020 GO TO 218
005030 215 IF(KK.GT.80)GO TO 216
005040 BI=1190.25
005050 KK=KK-60
005060 GO TO 218
005070 216 IF(KK.GT.90)GO TO 217
005080 BI=2500.00
005090 KK=KK-70
005100 GO TO 218
005110 217 BI=1.9044
005120 KK=KK-80
005130 C--- R60=60 HZ LINE RESISTANCE IN OHMS/MILE
005140 218 R60=RR1*BI*(KK-10)/XLM
005141 IF(WT.EQ.1) GO TO 160
005150 I=1
005160 IF(RDC(NE1).NE.0.) GO TO 206
005170 C--- RDC=DC LINE RESISTANCE IN OHMS/MILE
005180 RDC(NE1)=R60
005190 C--- F=FREQUENCY IN HZ
005200 F=60.0
005210 C--- SKIN EFFECT
005220 203 B=F/RDC(NE1)
005230 C--- A=MR

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005240      A=0.0636*SQRT(B)
005250      IF(H2.NE.0.) GO TO 400
005260      H2=4.
005270      H4=64.
005280      H6=2704.
005290      H8=147456.
005300      H10=1.47456E7
005310      H12=H10*144.
005320      H14=H12*196.
005330      H16=H14*256.
005340      H18=H16*324.
005350      H20=H18*400.
005360      H22=H20*484.
005370      H24=H22*576.
005380      H26=H24*676.
005390      H28=H26*784.
005400      H30=H28*900.
005410      H32=H30*1024.
005420      H34=H32*1156.
005430      H36=H34*1296.
005440 C---      BER(I)=REAL BESSEL FUNCTION OF MR
005450 C---      1=60 HZ
005460 C---      2=HARMONIC FREQ
005470      400 BER(I)=1.0-A**4/H4+A**8/H8-A**12/H12+A**16/H16-A**20/H20
005480      1 +A**24/H24-A**28/H28+A**32/H32-A**36/H36
005490 C---      BEI(I)=IMAGINARY BESSEL FUNCTION OF MR
005500      BEI(I)=A**2/H2-A**6/H6+A**10/H10-A**14/H14+A**18/H18
005510      1 -A**22/H22+A**26/H26-A**30/H30-A**34/H34
005520 C---      BERD(I)=DERIVATIVE OF BER(I)
005530      BEPD(I)=-4.0*A**3/H4+8.0*A**7/H8-12.0*A**11/H12+16.0*A**15/H16
005540      1 -20.0*A**19/H20+24.0*A**23/H24-28.0*A**27/H28+32.0*A**31/H32
005550      2 -36.0*A**35/H36
005560 C---      BEID(I)=DERIVATIVE OF BEI(I)
005570      BEID(I)=2.0*A/H2-6.0*A**5/H6+10.0*A**9/H10-14.0*A**13/H14
005580      1 -18.0*A**17/H18+22.0*A**21/H22+26.0*A**25/H26-30.0*A**29/H30
005590      2 -34.0*A**33/H34
005600 C---      RR7=AC TO DC RESISTANCE RATIO
005610      RR7=A*(BER(I)*BEID(I)-BEI(I)*BERD(I))/
005620      1 (2.0*(BEID(I)**2+BERD(I)**2))
005630      IF(F.NE.60.0)GO TO 204
005640 C---      TR60=ESTIMATE OF 60 HZ RESISTANCE
005650      TR60=RR7*RDC(NE1)
005660      ER=TR60-R60
005670 C---      ERA=ERROR DIFFERENCE OF ACTUAL AND ESTIMATE OF 60 HZ RESIS
005680      ERA=ABS(ER)
005690 C---      CHECK ACCURACY OF TR60
005700      IF(ERA.GT.0.00005)GO TO 205
005710 C---      A6=ALPHAL AT 60 HZ
005720      A6(NE1)=4.0*(BER(I)*BEPD(I)-BEI(I)*BEID(I))/
005730      1 (A*(BERD(I)**2+BEID(I)**2))
005740      GO TO 206
005750 C---      OBTAIN NEW ESTIMATE OF RDC
005760      205 RDC(NE1)=RDC(NE1)-ER
005770      GO TO 203
005780 C---      F=HARMONIC FREQUENCY
005790      206 F=60.0*W
005800      I=2
005810      GO TO 203
005820 C---      R1=LINE RESISTANCE AT HARMONIC FREQ IN PU
005821 C-----R1=RR1 IS USED FOR FUNDAMENTAL FREQ ONLY
005822      160 R1=RR1
005823      GO TO 170
005830      204 R1=RR7*RDC(NE1)*XLM/(B1*(K-10))
005840 C---      AL=ALPHAL AT HARMONIC FREQUENCY
005850      208 AL=4.0*(BER(I)*BEPD(I)-BEI(I)*BEID(I))/
005860      1 (A*(BERD(I)**2+BEID(I)**2))

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005870 C--- X60=TOTAL 60 HZ REACTANCE IN OHMS/MILE
005880 X60=XX1*BI/XLM
005890 C--- D=60 HZ EXTERNAL REACTANCE IN OHMS/MILE
005900 D=X60-A6(NE1)*0.030335/(KK-10)
005910 C--- XF=TOTAL REACTANCE AT HARMONIC FREQUENCY IN OHMS/MILE
005920 XF=(D+AL*0.030335/(KK-10))*WT
005930 C--- XL=LINE REACTANCE IN PU
005931 GO TO 175
005932 C----- XL=XX1 IS USED FOR FUNDAMENTAL FREQ ONLY
005933 170 XL=XX1
005934 GO TO 180
005940 175 XL=XF*XLM/BI
005950 C--- YC=LINE SHUNT SUSCEPTANCE AT HARMONIC FREQ IN PU
005960 180 YC=WT*XC1
005970 C--- GO=LINE SHUNT CONDUCTANCE
005980 116 GO=0.0
005990 C--- D1=LINE SERIES IMPEDANCE IN PU
006000 D1=CMPLX(R1,XL)
006010 C--- D2=LINE SHUNT ADMITTANCE IN PU
006020 D2=CMPLX(GO,YC)
006030 DD1=D1*D2
006040 C--- DD=GAMMA*L (GAMMA=PROPAGATION CONSTANT, L=LINE LENGTH)
006050 DD=CSQRT(DD1)
006060 DZ1=D1/D2
006070 C--- DZ=CHARACTERISTIC IMPEDANCE IN PU
006080 DZ=CSQRT(DZ1)
006090 DE=CEXP(DD)
006100 C--- DSH=SINH(GAMMA*L)
006110 DSH=0.500*(DE-1.000/DE)
006120 C--- DCH=COSH(GAMMA*L)
006130 DCH=0.500*(DE+1.000/DE)
006140 C--- DYS=PI LINE SHUNT ADMITTANCE IN PU
006150 DYS=(1.000/DZ1)*((DCH-1.000)/DSH)
006160 C--- DZS=PI LINE SERIES IMPEDANCE IN PU
006170 DZS=DZ*DSH
006180 C--- DYZ=PI LINE SHUNT IMPEDANCE IN PU
006190 DYZ=1.0/DYS
006200 C--- RS1=REAL PART OF SERIES IMPEDANCE IN PU
006210 RS1=REAL(DZS)
006220 C--- RS2=REAL PART OF SHUNT IMPEDANCE IN PU
006230 RS2=REAL(DYZ)
006240 C--- XS1=IMAGINARY PART OF SERIES IMPEDANCE IN PU
006250 XS1=AIMAG(DZS)
006260 C--- XS2=IMAGINARY PART OF SHUNT IMPEDANCE IN PU
006270 XS2=AIMAG(DYZ)
006280 GO TO 117
006290 110 IDSN=2
006300 C--- HARMONIC IS NEGATIVE SEQUENCE
006310 C--- WHAT IS ELEMENT
006320 IF(KJ-2)113,114,120
006330 106 IDSN=1
006340 C--- HARMONIC IS ZERO SEQUENCE
006350 C--- WHAT IS ELEMENT
006360 IF(KJ-2)118,121,122
006370 C--- ZERO SEQ. TRANSMISSION LINE
006380 C--- PROE=EARTH RESISTANCE COMPONENT AT 60 HZ IN PU
006390 118 PROE=RR0-RR1
006400 C--- RRWE=EARTH RESISTANCE COMPONENT AT 60 HZ IN PU
006410 RRWE=PROE*WT
006420 C--- R1=LINE RESISTANCE AT HARMONIC FREQ IN PU
006430 R1=RR1+RRWE
006440 C--- XL=LINE SERIES REACTANCE AT HARMONIC FREQ IN PU
006450 XL=XX0*WT/100.0
006460 C--- YC=LINE SHUNT SUSCEPTANCE AT HARMONIC FREQ IN PU
006470 YC=WT*XC0
006480 GO TO 116

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006490 C--- POS. + NEG. SEQ. TRANSFORMER
006500 C--- XS3=HALF OF TX SERIES REACTANCE AT HARMONIC FREQ IN PU
006510 114 XS3=RR1*WT/2.0
006520 C--- XS4=TX SHUNT REACTANCE AT HARMONIC FREQ IN PU
006530 127 XS4=XC1*WT
006540 C--- ASSUME SILICON STEEL W/ 3/1 MYS/EDDY LOSSES
006550 C--- RR4=TX SHUNT RESISTANCE AT HARMONIC FREQ IN PU
006560 RR4=(3.0*RR0/(WT*4.0))*(RR0/(4.0*WT**2))
006570 XS5=0.0
006580 PR3=0.0
006590 DT1=CMPLX(RR4,XS5)
006600 DT2=CMPLX(RR3,XS4)
006610 C--- DT3=TX SHUNT IMPEDANCE AT HARMONIC FREQ IN PU
006620 DT3=(DT1*DT2)/(DT1+DT2)
006630 C--- RT1=REAL PART OF TX SHUNT IMPEDANCE
006640 RT1=REAL(DT3)
006650 C--- XT1=IMAGINARY PART OF TX SHUNT IMPEDANCE
006660 XT1=AIMAG(DT3)
006670 GO TO 119
006680 C--- ZERO SEQ. TRANSFORMER
006690 121 IF(KK)143,142,143
006700 142 IF(XK0-1.0)123,124,124
006710 124 GO TO 119
006720 123 IF(XK0-.70)125,125,126
006730 125 XS3=XX1*WT/2.0
006740 GO TO 127
006750 126 XT2=XX1*WT
006760 IF(XK0-.90)128,129,129
006770 143 XZ=XX1*WT/2.0
006780 XT2=XZ+(XZ*XCO*WT)/(XZ+XCO*WT)
006790 IF(KK-2)144,145,146
006800 146 IF(KK-4)147,148,149
006810 144 GO TO 128
006820 145 GO TO 129
006830 147 XT2=XZ+XCO*WT
006840 GO TO 129
006850 148 XT2=XZ+XCO*WT
006860 GO TO 128
006870 149 XS3=XZ
006880 RT1=0.0
006890 XT1=XCO*WT
006900 GO TO 119
006910 C--- POS SEQUENCE GENERATORS
006920 C--- GENERATOR OR LOAD?
006930 115 IF(KJ GE.4)GO TO 444
006940 C--- GENERATOR OR CAPACITOR?
006950 IF(KK.EQ.1)GO TO 500
006960 C--- XG1=GEN REACTANCE AT HARMONIC FREQ IN PU
006970 XG1=XX1*WT
006980 GO TO 130
006990 C--- ZERO SEQUENCE GENERATORS
007000 122 IF(KJ.EQ.4)GO TO 444
007010 IF(KK.EQ.1)GO TO 500
007020 XG1=YC1*WT
007030 GO TO 130
007040 C--- NEG SEQUENCE GENERATORS
007050 120 IF(KJ.EQ.4)GO TO 444
007060 IF(KK.EQ.1)GO TO 500
007070 XG1=XX1*WT
007080 GO TO 130
007090 C--- SHUNT CAPACITORS
007100 C--- XG1=CAP REACTANCE AT HARMONIC FREQ IN PU
007110 500 XG1=XX1*WT
007120 GO TO 130
007130 C--- LOADS
007140 C--- RESIDENTIAL, COMMERCIAL, OR INDUSTRIAL?

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007141 444 IF (IW.EQ.1) GO TO 510
007150 IF(KK-2)445,446,447
007160 C--- RESIDENTIAL LOADS
007170 C--- PMOT=MOTOR COMPONENT OF REAL POWER
007180 445 PMOT=0.5*RR1
007190 C--- PRES=RESISTIVE COMPONENT OF REAL POWER
007200 PRES=0.5*RR1
007210 GO TO 448
007220 C--- COMMERCIAL LOADS
007230 446 PMOT=0.6*RR1
007240 PRES=0.4*RR1
007250 GO TO 448
007260 C--- INDUSTRIAL LOADS
007270 447 PMOT=0.7*RR1
007280 PRES=0.3*RR1
007290 C--- XONE=MOTOR STATOR REACTANCE AT HARMONIC FREQ IN PU
007300 448 XONE=XX1/(4.64*(PMOT**2+XX1**2))
007310 XONE=XONE*WT
007320 RHE=1.03/(0.03*PMOT)
007330 C--- ASSUME SILICON STEEL W/ 3/1 HYS/EDDY LOSSES
007340 C--- RHE=MOTOR CORE LOSS RESISTANCE AT HARMONIC FREQ IN PU
007350 RHE=(3.0*RHE/(WT*4.0))+(RHE/(4.0*WT**2))
007360 C--- REQ=MOTOR EQUIV SERIES RESISTANCE IN PU
007370 520 REQ=(XONE**2)*RHE/(RHE**2+XONE**2)
007380 C--- XEQ=MOTOR EQUIV SERIES REACTANCE IN PU
007390 XEQ=((RHE**2)*XONE/(RHE**2+XONE**2))+XONE
007400 C--- RES=CONSTANT LOAD RESISTANCE
007410 RES=1.0/PRES
007420 DEQ=(REQ+RES)**2+XEQ**2
007430 REQN=(RES**2*REQ)+(REQ**2*RES)+(XEQ**2*RES)
007440 XEQN=XEQ*RES**2
007450 C--- REQ=LOAD RESISTANCE AT HARMONIC FREQ IN PU
007460 REQ=REQN/DEQ
007470 C--- XEQ=LOAD REACTANCE AT HARMONIC FREQ IN PU
007480 XEQ=XEQN/DEQ
007481 GO TO 449
007482 C----- LOAD SERIES RESISTANCE AND REACTANCE FOR FUNDAMENTAL FREQ
007483 510 REQ=RR1/(RR1**2+XX1**2)
007484 XEQ=XX1/(RR1**2+XX1**2)
007490 GO TO 449
007500 C--- ASSIGN TRANSMISSION LINE ELEMENTS
007510 C--- M=ELEMENT FLAG
007520 C--- 0=SERIES ELEMENT
007530 C--- 1='FROM' BUS SHUNT ELEMENT
007540 C--- 2='TO' BUS SHUNT ELEMENT
007550 117 M=0
007560 139 IF(M-1)131,132,133
007570 C--- JP='FROM' BUS EXTERNAL NUMBER
007580 131 JP=KJP
007590 C--- JQ='TO' BUS EXTERNAL NUMBER
007600 JO=KJO
007610 C--- JCT=CIRCUIT NUMBER
007620 JCT=KCT
007630 C--- RR=ELEMENT RESISTANCE IN PU
007640 RR=RS1
007650 C--- XX=ELEMENT REACTANCE IN PU
007660 XX=XS1
007670 C--- ILINE=LINE FLAG
007680 ILINE=1
007690 GO TO 134
007700 132 JP=KJP
007710 JQ=0
007720 JCT=KCT
007730 RR=RS2
007740 XX=XS2
007750 ILINE=0

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007760      GO TO 134
007770      133 JP=0
007780      JQ=KJQ
007790      JCT=KCT
007800      RR=RS2
007810      XX=XS2
007820      ILINE=0
007830      GO TO 134
007840 C---      ASSIGN GENERATOR ELEMENTS
007850      130 M=2
007860      JP=KJP
007870      JQ=KJQ
007880      JCT=KCT
007890      RR=RR1
007900      XX=XG1
007910      ILINE=0
007920      GO TO 134
007930 C---      ASSIGN LOAD ELEMENTS
007940      449 M=2
007950      JP=KJP
007960      JQ=0
007970      JCT=KCT
007980      RR=REQ
007990      XX=XEQ
008000      ILINE=0
008010      GO TO 134
008020 C---      ASSIGN TRANSFORMER ELEMENTS
008030      119 M=0
008040      140 IF(M-1)135,136,137
008050      135 JP=KJP
008060 C---      ASSIGN ADDITIONAL NODE = KCT
008070      JQ=KCT
008080      RR=0.0
008090      JCT=1
008100      XX=XS3
008110      ILINE=0
008120      GO TO 134
008130      136 JP=KCT
008140      JQ=KJQ
008150      RR=0.0
008160      JCT=1
008170      XX=XS3
008180      ILINE=0
008190      GO TO 134
008200      137 JP=KCT
008210      JQ=0
008220      RR=RT1
008230      XX=XT1
008240      JCT=1
008250      ILINE=0
008260      GO TO 134
008270      128 M=2
008280      JP=KJP
008290      JQ=0
008300      RR=0.0
008310      JCT=1
008320      XX=XT2
008330      ILINE=0
008340      GO TO 134
008350      129 M=2
008360      JP=0
008370      JQ=KJQ
008380      RR=0.0
008390      JCT=1
008400      XX=XT2
008410      ILINE=0

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008420      GO TO 134
008430 C---      CHANGE TO INTERNAL BUS NUMBERS
008440 C---      BUS NUMBER ERROR?
008450      134 IF(JP.EQ.JQ)GO TO 40
008460 C---      IS 'FROM' BUS REF NODE?
008470      IF(JP.GT.0)GO TO 12
008480 C---      KP=INTERNAL BUS NUMBER INDEX
008490      KP=0
008500 C---      INCREMENT NUMBER OF ELEMENTS CONNECTED TO REF
008510      NLR=NLR+1
008520      GO TO 14
008530 C---      IS 'FROM' BUS NUMBER TOO LARGE?
008540      12 IF(JP.GT.NBH)GO TO 40
008550      KP=NB(JP)
008560 C---      FIRST ELEMENT CONNECTED TO BUS?
008570      IF(KP.NE.0)GO TO 13
008580 C---      TOO MANY BUSES?
008590      IF(NBS.GE.NBX)GO TO 55
008600 C---      INCREMENT NUMBER OF BUSES
008610      NBS=NBS+1
008620 C---      STORE INTERNAL BUS NUMBER
008630      NB(JP)=NBS
008640      KP=NBS
008650 C---      STORE EXTERNAL 'FROM' BUS NUMBER
008660      NBE(KP)=JP
008670 C---      INCREMENT NUMBER OF SERIES ELEMENTS CONNECTED TO BUS
008680      13 NLB(KP)=NLB(KP)+1
008690 C---      IS 'TO' BUS REFERENCE NODE?
008700      14 IF(JQ.GT.0)GO TO 15
008710 C---      KQ=INTERNAL BUS NUMBER INDEX
008720      KQ=0
008730 C---      INCREMENT NUMBER OF ELEMENTS CONNECTED TO REF
008740      NLR=NLR+1
008750      GO TO 17
008760 C---      IS 'TO' BUS NUMBER TOO LARGE?
008770      15 IF(JQ.GT.NBH)GO TO 40
008780      KQ=NB(JQ)
008790 C---      FIRST ELEMENT CONNECTED TO BUS?
008800      IF(KQ.NE.0)GO TO 16
008810 C---      TOO MANY BUSES?
008820      IF(NBS.GE.NBX)GO TO 55
008830 C---      INCREMENT NUMBER OF BUSES
008840      NBS=NBS+1
008850 C---      STORE INTERNAL BUS NUMBER
008860      NB(JQ)=NBS
008870      KQ=NBS
008880 C---      STORE EXTERNAL 'TO' BUS NUMBER
008890      NBE(KQ)=JQ
008900 C---      INCREMENT NUMBER OF SERIES ELEMENTS CONNECTED TO BUS
008910      16 NLB(KQ)=NLB(KQ)+1
008920 C---      KP, KQ CONTAIN THE INTERNAL BUS NUMBER - NOW STORE THE DATA
008930 C---      TOO MANY ELEMENTS?
008940      17 IF(NEL.GE.NEX)GO TO 60
008950 C---      INCREMENT NUMBER OF ELEMENTS
008960      NEL=NEL+1
008970 C---      STORE INTERNAL 'FROM' BUS NUMBER
008980      IP(NEL)=KP
008990 C---      STORE INTERNAL 'TO' BUS NUMBER
009000      IQ(NEL)=KQ
009010 C---      STORE CIRCUIT NUMBER
009020      ICT(NEL)=JCT
009030 C---      STORE ELEMENT RESISTANCE
009040      R(NEL)=RR
009050 C---      STORE ELEMENT REACTANCE
009060      X(NEL)=XX
009070 C---      STORE LINE FLAG

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009080      ILINE(NEL)=ILINE
009090 C---      STORE CHARACTERISTIC IMPEDANCE FOR LINES
009100      ZO(NEL)=OZ
009110 C---      STORE PROPAGATION CONSTANT FOR LINES
009120      GAML(NEL)=DD
009130 C---      ALL ELEMENTS OF COMPONENT?
009140      IF(M-2)138,11,11
009150 C---      BUS NUMBER ERROR
009160      40 WRITE(IWT,1001)JP,JQ,JCT,RR,XX
009170 C---      COUNT BUS NUMBER ERRORS
009180      IERROR=IERROR+1
009190      IF(M-2)138,11,11
009200 C---      INCREMENT ELEMENT FLAG
009210      138 M=M+1
009220 C---      LINE OR TRANSFORMER?
009230      IF(K,-2)139,140,140
009240 C---      NORMAL RETURN
009250      45 IF(IERROR.EQ.0)RETURN 1
009260 C---      PRINT NUMBER OF BUS NUMBER ERRORS
009270      WRITE(IWT,1002)IERROR
009280 C---      ABNORMAL RETURN
009290      RETURN 2
009300 C---      LAST CARD (9999) NOT READ
009310      50 WRITE(IWT,1003)
009320      RETURN 2
009330 C---      TOO MANY BUSES
009340      55 WRITE(IWT,1004)NBX
009350      RETURN 2
009360 C---      TOO MANY ELEMENTS
009370      60 WRITE(IWT,1005)NEX
009380      RETURN 2
009390      1000 FORMAT(11,2I4,13,F10.4,F12.4,F10.8,2F9.4,F10.8,I2,F6.2)
009400      1001 FORMAT('0*** BUS NUMBER ERROR = ',2(I4,2X),12.2(4X,F6.2))
009410      1002 FORMAT('0*** TOTAL NUMBER OF ERRORS = ',15)
009420      1003 FORMAT('0*** UNEXPECTED END OF LINE DATA')
009430      1004 FORMAT('0*** TOO MANY BUSES - MORE THAN ',I4)
009440      1005 FORMAT('0*** TOO MANY ELEMENTS - MORE THAN ',15)
009450      1100 FORMAT('1',2X,'KJ',2X,'KJP',2X,'KJQ',2X,'KCT',6X,'RR1',11X,'XX1',
009460      1,12X,'XC1',12X,'RR0',11X,'XX0',9X,'XC0',10X,'KK',4X,'XLM'/)
009470      1200 FORMAT(4X,11,1X,I4,1X,I4,2X,13,1X,F10.4,2X,F12.4,
009480      12X,F15.8,2(2X,F12.4),2X,F15.8,2X,I2,2X,F6.2)
009490      END
009500      SUBROUTINE ORDER(IP,IQ,NLB,JP1,JP2,KP1,KP2,ISC,ILO,IBO,*,*)
009510 C---      CREATE ORDERED LISTS FOR BUSES AND ELEMENTS
009520 C---      CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
009530 C---      HARMONIC ORDER TO BE ANALYZED
009540      IMPLICIT INTEGER*4(I-N)
009550      INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,IW,IOSN
009560      COMMON /K1/IRD,IWT,IW,IOSN
009570      COMMON /KL/NEX,NEL
009580      COMMON /KB/NBH,NBS,NBX,MS,NLR
009590      DIMENSION IP(NEL),IQ(NEL),KP1(NEL),KP2(NEL),ILO(NEL)
009600      DIMENSION NLB(NBS),JP1(NBS),JP2(NBS),ISC(NBS),IBO(NBS)
009610 C---      JP1=POINTER FROM BUS TO THE LINE 'FROM' BUS
009620 C---      JP2=POINTER FROM BUS TO THE LINE 'TO' BUS
009630 C---      KP1=POINTER FROM LINE TO THE NEXT LINE 'FROM' BUS
009640 C---      KP2=POINTER FROM LINE TO THE NEXT LINE 'TO' BUS
009650 C---      JP1R, JP2R= POINTERS FROM THE REFERENCE BUS
009660 C---      ISC=THE ORDERING SCORE OF THE BUS
009670 C---      IBO=THE BUS ORDER
009680 C---      ILO=THE LINE ORDER
009690      DO 1 I=1,NBS
009700      JP1(I)=0
009710      JP2(I)=0
009720      1 ISC(I)=0
009730      JP1R=0

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009740      JP2R=0
009750 C---      CHAIN LINES BY BUS NUMBER
009760      DO 29 I=1,NEL
009770 C---      KP=INTERNAL 'FROM' BUS NUMBER
009780      KP=IP(I)
009790 C---      KQ=INTERNAL 'TO' BUS NUMBER
009800      KQ=IQ(I)
009810      KP1(I)=0
009820      KP2(I)=0
009830 C---      IS 'FROM' BUS REF NODE?
009840      IF(KP.NE.0)GO TO 13
009850 C---      INCREMENT ORDERING SCORE OF 'TO' BUS
009860      ISC(KQ)=ISC(KQ)+1
009870      IF(JP1R.NE.0)GO TO 10
009880      JP1R=I
009890      GO TO 19
009900      10 JP=JP1R
009910      11 JQ=KP1(JP)
009920      IF(JQ.EQ.0)GO TO 12
009930      JP=JQ
009940      GO TO 11
009950      12 KP1(JP)=I
009960      GO TO 19
009970      13 JP=JP1(KP)
009980      IF(JP.NE.0)GO TO 11
009990      JP1(KP)=I
010000      19 IF(KQ.NE.0)GO TO 23
010010      ISC(KP)=ISC(KP)+1
010020      IF(JP2R.NE.0)GO TO 20
010030      JP2R=I
010040      GO TO 29
010050      20 JP=JP2R
010060      21 JQ=KP2(JP)
010070      IF(JQ.EQ.0)GO TO 22
010080      JP=JQ
010090      GO TO 21
010100      22 KP2(JP)=I
010110      GO TO 29
010120      23 JP=JP2(KQ)
010130      IF(JP.NE.0)GO TO 21
010140      JP2(KQ)=I
010150      29 CONTINUE
010160 C---      CREATE THE ORDERED LISTS
010170      ML=0
010180      MB=0
010190      MS=0
010200      30 ISCH=0
010210      DO 33 I=1,NBS
010220      IF(ISC(I)-ISCH)33,31,32
010230      31 IF(ISCH.EQ.0)GO TO 33
010240      IF(NLB(N).GE.NLB(I))GO TO 33
010250      32 N=I
010260      ISCH=ISC(I)
010270      33 CONTINUE
010280 C---      ADD BUS N TO ORDERED BUS LIST
010290      IF(ISCH.EQ.0)GO TO 70
010300      ISCH=ISCH-1
010310      MB=MB+1
010320      MS=MS+ISCH*((MB*(MB+3))/2)
010330      IB(MB)=N
010340      ISC(N)=-9999
010350 C---      CHECK FOR LINES CONNECTED TO BUS N
010360      JP=JP1(N)
010370      51 IF(JP.EQ.0)GO TO 55
010380      KQ=IQ(JP)
010390      IF(KQ.EQ.0)GO TO 52

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010470      IF(ISC(KQ).LT.0)GO TO 52
010480      ISC(KQ)=ISC(KQ)+1
010490      GO TO 53
010430      52 ML=ML+1
010440      ILO(ML)=JP
010450      53 JP=KPI(JP)
010460      GO TO 51
010470      55 JP=JP2(N)
010480      56 IF(JP.EQ.0)GO TO 60
010490      KP=IP(JP)
010500      IF(KP.EQ.0)GO TO 57
010510      IF(ISC(KP).LT.0)GO TO 57
010520      ISC(KP)=ISC(KP)+1
010530      GO TO 58
010540      57 ML=ML+1
010550      ILO(ML)=JP
010560      58 JP=KP2(JP)
010570      GO TO 56
010580      60 IF(ML.LT.NEL)GO TO 30
010590      RETURN 1
010600      C--- ORDERED LISTS ARE COMPLETE IOB, IOL
010610      70 WRITE(IWT,1000)
010620      RETURN 2
010630      1000 FORMAT('0*** SYSTEM IS NOT CONNECTED TOGETHER')
010640      END
010650      SUBROUTINE ZBUS(IP,IQ,R,X,ILO,IBO,IBOR,RBUS,XBUS,RL,XL,NBE,*,*)
010660      IMPLICIT INTEGER*4(I-N)
010670      INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,MBUS,IW,IDSN
010680      COMMON /K1/IRD,IWT,IW,IDSN
010690      COMMON /KL/NEX,NEL
010700      COMMON /KB/NBH,NBS,NBX,MS,NLR
010710      COMMON /K2/MBUS
010720      DIMENSION IP(NEL),IQ(NEL),R(NEL),X(NEL),ILO(NEL)
010730      DIMENSION IBO(NBS),IBOR(NBS),NBE(NBS),RL(NBS),XL(NBS)
010740      DIMENSION RBUS(MBUS),XBUS(MBUS)
010750      C--- RBUS=REAL PART OF ZBUS
010760      C--- XBUS=IMAGINARY PART OF ZBUS
010770      C--- IBOR=BUS ORDER LIST WITH INDEX AS INTERNAL BUS NUMBER
010780      C--- RL, XL=LINK IMPEDANCES
010790      MB=0
010800      DO 1 I=1,NBS
010810      J=IBO(I)
010820      1 IBOR(J)=I
010830      C--- READY TO START THE ALGORITHM
010840      DO 40 I=1,NEL
010850      II=ILO(I)
010860      IPP=IP(II)
010870      IF(IPP.EQ.0)GO TO 2
010880      IPP=IBOR(IPP)
010890      2 IQQ=IQ(II)
010900      IF(IQQ.EQ.0)GO TO 3
010910      IQQ=IBOR(IQQ)
010920      3 IF(IPP.LT.IQQ)GO TO 6
010930      IT=IQQ
010940      IQQ=IPP
010950      IPP=IT
010960      C--- TEST FOR BRANCH OR A LINK
010970      6 IF(IQQ.LE.MB)GO TO 15
010980      JJ=(MB*(MB+1))/2
010990      C--- FOUND A BRANCH. TEST FOR REFERENCE
011000      IF(IPP.NE.0)GO TO 9
011010      C--- BRANCH TO REFERENCE
011020      IF(MB.GT.0)GO TO 7
011030      RBUS(1)=R(II)
011040      XBUS(1)=X(II)
011050      MB=1

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```

011060      GO TO 40
011070      7 DO 8 J=1,MB
011080          JJJ=JJ+J
011090          RBUS(JJJ)=0.0
011100      8 XBUS(JJJ)=0.0
011110          JJJ=JJJ+1
011120          RBUS(JJJ)=R(II)
011130          XBUS(JJJ)=X(II)
011140          MB=MB+1
011150          GO TO 40
011160 C---      BRANCH TO AN OLD BUS
011170      9 DO 12 J=1,MB
011180          JJJ=JJ+J
011190          IF(IPP.LT.J)GO TO 10
011200          KK=J-(IPP*(IPP-1))/2
011210          GO TO 11
011220      10 KK=IPP+(J*(J-1))/2
011230          11 RBUS(JJJ)=RBUS(KK)
011240          12 XBUS(JJJ)=XBUS(KK)
011250          JJJ=JJJ+1
011260          KK=JJ+IPP
011270          RBUS(JJJ)=RBUS(KK)+R(II)
011280          XBUS(JJJ)=XBUS(KK)+X(II)
011290          MB=MB+1
011300          GO TO 40
011310 C---      FOUND A LINK,TEST FOR REFERENCE
011320      15 IF(IPP.NE.0)GO TO 20
011330 C---      LINK TO REFERENCE
011340          DO 18 J=1,MB
011350          IF(IQQ.LT.J)GO TO 16
011360          KK=J-(IQQ*(IQQ-1))/2
011370          GO TO 17
011380          16 KK=IQQ+(J*(J-1))/2
011390          17 PL(J)=-RBUS(KK)
011400          18 XL(J)=-XBUS(KK)
011410          RLL=-RL(IQQ)+R(II)
011420          XLL=-XL(IQQ)+X(II)
011430          GO TO 30
011440 C---      LINK BETWEEN OLD BUSES
011450      20 DO 25 J=1,MB
011460          IF(IPP.LT.J)GO TO 21
011470          JJ=J-(IPP*(IPP-1))/2
011480          GO TO 22
011490          21 JJ=IPP+(J*(J-1))/2
011500          22 IF(IQQ.LT.J)GO TO 23
011510          KK=J-(IQQ*(IQQ-1))/2
011520          GO TO 24
011530          23 KK=IQQ+(J*(J-1))/2
011540          24 RL(J)=RBUS(JJ)-RBUS(KK)
011550          25 XL(J)=XBUS(JJ)-XBUS(KK)
011560          RLL=RL(IPP)-RL(IQQ)+R(II)
011570          XLL=XL(IPP)-XL(IQQ)+X(II)
011580 C---      KRON REDUCTION
011590      30 ZLL=RLL*RLL+XLL*XLL
011600          IF(ZLL.LT.1.E-50)GO TO 50
011610          DO 32 J=1,MB
011620          JJ=(J*(J-1))/2
011630          RLJ=(RLL*RL(J)+XLL*XL(J))/ZLL
011640          XLJ=(RLL*XL(J)-XLL*RL(J))/ZLL
011650          DO 31 K=1,J
011660          KJ=JJ+K
011670          RBUS(KJ)=RBUS(KJ)-RLJ*RL(K)+XLJ*XL(K)
011680          31 XBUS(KJ)=XBUS(KJ)-RLJ*XL(K)-XLJ*RL(K)
011690          32 CONTINUE
011700          40 CONTINUE
011710          RETURN 1

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011720 50 IPP=IP(II)
011730 I=NBE(IPP)
011740 IQQ=IQ(II)
011750 J=NBE(IQQ)
011760 WRITE(IWT,1000)II,I,J
011770 RETURN 2
011780 1000 FORMAT('D*** LINE NUMBER ',I4,' BETWEEN BUSES ',I4,' AND ',I4,' CA
011790 1USED A ZLL**2 DIVISOR IN THE KRON REDUCTION OF ',E12.5)
011800 END
011810 SUBROUTINE HARM1(IP,IO,ICT,R,X,KP1,KP2,NB,NBE,JP1,JP2,IBOR,RBUS,
011820 1XBUS,VR,VI,ILIN,ZO,VMSQ,VVM1,GAML,*,*)
011830 C--- READ HARMONIC SOURCE LOCATION AND OPTIONS, PERFORM HARMONIC
011840 C--- LOADFLOW, PRINT RESULTS
011850 C--- CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
011860 C--- HARMONIC ORDER TO BE ANALYZED
011870 IMPLICIT INTEGER*4(I-N)
011880 INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,MBUS,IW,IDSN,FLAG
011890 REAL*8 NAME,EE2,EE5,EEB,EE11,EE15,EE18,R5H,X5H,R5E,X5E
011900 COMPLEX*8 CMPLX,SOURCE,FUND,ZO,GAML,DZ,DO,ZR,KR,IR
011910 COMPLEX*8 IRPLUS,IRMIN,IMAX,VCK,VCL
011920 COMMON /K1/IRD,IWT,IW,IDSN
011930 COMMON /K2/NEX,NEL
011940 COMMON /K3/NBH,NBS,NBX,MS,NLR
011950 COMMON /K4/MBUS
011960 COMMON /K5/CDC/SOURCE,VCK,LHARM,JJJ,IVC
011970 COMMON /K6/BASE/LLL,JJJ,IOPT
011980 DIMENSION IP(NEL),IQ(NEL),ICT(NEL),R(NEL),X(NEL),KP1(NEL),KP2(NEL)
011990 DIMENSION RBUS(MBUS),XBUS(MBUS),SOURCE(128,4),ILIN(NEL)
012000 DIMENSION IBOR(NBS),NBE(NBS),NB(NBH),JP1(NBS),JP2(NBS)
012010 DIMENSION VR(NBS),VI(NBS),ZO(NEL),GAML(NEL)
012020 DIMENSION SVR(9998),SVI(9998),VMSQ(9998),VVM1(9998)
012030 C--- JJJ=COUNTER FOR NUMBER OF OPTIONS
012040 JJJ=0
012050 C--- FIRST TIME CALLED?
012060 1 IF(LLL.GT.1)GO TO 700
012070 IF(JJJ.GT.0)GO TO 3
012080 DO 2 I=1,NBH
012090 VMSQ(I)=0.
012091 VVM1(I)=0.
012100 2 CONTINUE
012110 3 READ(IRD,1000,END=99)JF,NAME,IOPT,PHA,FUND
012120 C--- JF=HARMONIC SOURCE BUS # LOCATION (SET TO 9999 FOR END)
012130 C--- NAME=BUS NAME
012140 C--- IOPT=OPTION
012150 C--- 0=ADJACENT BUSES ONLY
012160 C--- 1=ALL BUSES
012170 C--- 2=FIRST ENTRY FOR COMBINED ANALYSIS OF TWO HARMONIC SOURCES
012180 C--- 3=SEC ENTRY FOR COMBINED ANALYSIS OF TWO HARMONIC SOURCES
012190 C--- PHA=PHASE ANGLE BETWEEN VOLTAGES FOR HARM SOURCES 2 & 3
012200 C--- FUND=FUNDAMENTAL COMPONENT OF HARMONIC SOURCE CURRENT (COMPLEX)
012210 C--- OPTION 2 OR 3?
012220 IF(IOPT.GT.1)GO TO 800
012230 IF(JJJ.NE.0)GO TO 701
012240 C--- EE1-EE13=TEMPORARY STORAGE LOCATIONS FOR INPUT DATA
012250 EE1=JF
012260 EE2=NAME
012270 EE3=IOPT
012280 SOURCE(2,1)=FUND
012290 GO TO 705
012300 701 IF(JJJ.NE.1)GO TO 702
012310 EE4=JF
012320 EE5=NAME
012330 EE6=IOPT
012340 SOURCE(2,2)=FUND
012350 GO TO 705
012360 702 IF(JJJ.NE.2)GO TO 703

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012370      EE7=JF
012380      EER=NAME
012390      EE9=IOPT
012400      SOURCE(2,3)=FUND
012410      GO TO 705
012420 703 IF(JJJ.NE.3)GO TO 704
012430      EE10=JF
012440      EE11=NAME
012450      EE12=IOPT
012460      SOURCE(2,4)=FUND
012470      GO TO 705
012480 704 EE13=JF
012490      GO TO 705
012500 C---      JJJJ=COMBINED ANALYSIS CODE
012510 C---      1=COMBINED ANALYSIS (OPTION 2.3)
012520 700 IF(JJJJ.EQ.1)GO TO 802
012530      IF(JJJ.NE.0)GO TO 708
012540 C---      RECOVER INPUT DATA
012550      JF=EE1
012560      NAME=EE2
012570      IOPT=EE3
012580      GO TO 705
012590 708 IF(JJJ.NE.1)GO TO 709
012600      JF=EE4
012610      NAME=EE5
012620      IOPT=EE6
012630      GO TO 705
012640 709 IF(JJJ.NE.2)GO TO 710
012650      JF=EE7
012660      NAME=EE8
012670      IOPT=EE9
012680      GO TO 705
012690 710 IF(JJJ.NE.3)GO TO 711
012700      JF=EE10
012710      NAME=EE11
012720      IOPT=EE12
012730      GO TO 705
012740 711 JF=EE13
012750 C---      END OF ANALYSIS?
012760 705 IF(JF.EQ.9999)RETURN 1
012770      JJJ=JJJ-1
012780 C---      TOO MANY OPTIONS?
012790      IF(JJJ.GT.4)GO TO 706
012800      GO TO 707
012810 706 WRITE(IWT,1009)
012820      EE13=9999
012830      RETURN 1
012840 C---      HARMONIC SOURCE BUS EXISTS?
012850 707 IF(JF.LE.0.OR.JF.GT.NBH)GO TO 90
012860 C---      KF=INTERNAL BUS # LOCATION OF HARMONIC SOURCE
012870      KF=NB(JF)
012880 C---      HARMONIC SOURCE BUS EXISTS?
012890      IF(KF.EQ.0)GO TO 90
012900 C---      LF=BUS ORDER NUMBER FOR HARMONIC SOURCE
012910      LF=IBOR(KF)
012920 C---      LL=INDEX TO HARMONIC SOURCE BUS IMPEDANCE (DIAGONAL ELEMENT
012930 C---      OF A LOWER TRIANGULARIZED MATRIX)
012940      LL=(LF*(LF+1))/2
012950 C---      RX,XX=HARMONIC SOURCE BUS RESISTANCE AND REACTANCE
012960      RX=RBUS(LL)
012970      XX=XBUS(LL)
012980 C---      Z*=SQUARE OF HARMONIC SOURCE BUS IMPEDANCE MAGNITUDE
012990      ZX=RX*RX+XX*XX
013000 C---      CONVERT PHASE FROM DEGREES TO RADIAN
013010      PHA=PHA/57.29577951
013020      VCL=VCK*CMPLX(COS(PHA),SIN(PHA))

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013030      IF(IVC.EQ.0) GO TO 620
013040      CR=REAL(VCL)
013050      CI=AIMAG(VCL)
013060      VRK=CR*RX-CI*XX
013070      VIK=CR*XX+CI*RX
013080      SOURCE(IW+1,JJJ)=CMPLX(VRK,VIK)
013090      GO TO 621
013100 C---      VRK=REAL COMPONENT OF HARMONIC SOURCE VOLTAGE
013110      620 VRK=REAL(VCL)
013120 C---      VIK=IMAGINARY COMPONENT OF HARMONIC SOURCE VOLTAGE
013130      VIK=AIMAG(VCL)
013140 C---      CR=REAL COMPONENT OF HARMONIC SOURCE CURRENT
013150      CR=(VRK*RX+VIK*XX)/ZX
013160 C---      CI=IMAGINARY COMPONENT OF HARMONIC SOURCE CURRENT
013170      CI=(VII*RX-VRK*XX)/ZX
013180      SOURCE(IW+1,JJJ)=CMPLX(CR,CI)
013190      621 CALL MAGANG(CR,CI,CM,CA)
013200 C---      CM=HARMONIC SOURCE CURRENT MAGNITUDE
013210 C---      CA=HARMONIC SOURCE CURRENT ANGLE
013220      CALL MAGANG(VRK,VIK,VKM,VKA)
013230 C---      VKM=HARMONIC SOURCE VOLTAGE MAGNITUDE
013240 C---      VKA=HARMONIC SOURCE VOLTAGE ANGLE
013250 C---      PRINT HARMONIC SOURCE SUMMARY
013260      WRITE(IWT,1001)JF,NAME,IOPT,PHA,FUND,CM,CA,VKM,VKA
013270      IF(IW.GT.LHARM) GO TO 1
013280      IF(IOPT.EQ.2)GO TO 804
013290      IF(IOPT.EQ.3)GO TO 805
013300      IF(IOPT.GT.0)GO TO 30
013310 C---      CALCULATIONS FOR ADJACENT BUSES ONLY
013320 C---      PRINT HEADING FOR ADJACENT BUS LOADFLOW SUMMARY
013330      WRITE(IWT,1002)
013340 C---      J='FROM' BUS OR 'TO' BUS FLAG
013350      J=1
013360 C---      JP=# OF FIRST ELEMENT CONNECTED 'FROM' HARMONIC SOURCE BUS
013370      JP=JP1(KP)
013380 C---      ELEMENT EXISTS?
013390      IF(JP.EQ.0)GO TO 16
013400 C---      KP=ADJACENT INTERNAL BUS #
013410      9 KP=IQ(JP)
013420 C---      SHUNT ELEMENT?
013430      10 IF(KP.NE.0)GO TO 11
013440      VRR=-VRK
013450      VII=-VIK
013460      N=0
013470      GO TO 15
013480      11 CALL VBUS(KP,KP,IBOP,LF,VR,VI,CR,CI,RBUS,XBUS)
013490 C---      VR(KP)=REAL COMPONENT OF 'TO' BUS VOLTAGE
013500 C---      VI(KP)=IMAGINARY COMPONENT OF 'TO' BUS VOLTAGE
013510      CALL MAGANG(VR(KP),VI(KP),VVM,VAA)
013520 C---      VVM='TO' BUS VOLTAGE MAGNITUDE
013530 C---      VAA='TO' BUS VOLTAGE ANGLE
013540 C---      VRR=REAL COMPONENT OF VOLTAGE DROP
013550      VRR=VR(KP)-VRK
013560 C---      VII=IMAGINARY COMPONENT OF VOLTAGE DROP
013570      VII=VI(KP)-VIK
013580 C---      N=ADJACENT EXTERNAL BUS #
013590      N=NBE(KP)
013600 C---      RX,XX=ELEMENT RESISTANCE AND REACTANCE
013610      15 RX=R(JP)
013620      XX=X(JP)
013630 C---      ZX=SQUARE OF ELEMENT IMPEDANCE MAGNITUDE
013640      ZX=RX*RX+XX*XX
013650 C---      CRL=REAL COMPONENT OF ELEMENT CURRENT
013660      CRL=(VII*XX+VRR*RX)/ZX
013670 C---      CIL=IMAGINARY COMPONENT OF ELEMENT CURRENT
013680      CIL=(VII*RX-VRR*XX)/ZX

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013690      IF(ILIN(JP).EQ.0) GO TO 14
013700      DZ=Z0(JP)
013710      DD=GAML(JP)
013720      IF(J.EQ.2) GO TO 12
013730      JP=KP1(JP)
013740      GO TO 13
013750      12 JP=KP2(JP)
013760      13 RX=R(JP)
013770      XX=X(JP)
013780      ZX=RK*PK+XX*XX
013790      CRL=CRL-(VIK*XX+VRK*RX)/ZX
013800      CIL=CIL-(VIK*RX-VRK*XX)/ZX
013810      CM1=CRL*CRL+CIL*CIL
013820      IF(CM1.LT.1.E-8) GO TO 631
013830      RX=(VRV*CRL+VIK*CIL)/CM1
013840      XX=(VIK*CRL-VRK*CIL)/CM1
013850      ZR=CMPLX(RX,XX)
013860      631 RX=REAL(DZ)
013870      XX=AIMAG(DZ)
013880      CALL MAGANG(CRL,CIL,CMM,CAA)
013890      WRITE(IWT,1003) N,VMM,VAA,ICT(JP),CMM,CAA,RX,XX
013900      IF(CM1.LT.1.E-8) GO TO 604
013910      KR=(ZR-DZ)/(ZR+DZ)
013920      IR=-CMPLX(CRL,CIL)
013930      IRPLUS=IR/(1.-KR)
013940      IRMIN=KR*IR/(KR-1.)
013950      BL=ABS(AIMAG(DD))
013960      WAVE=6.2831853/BL
013961      IF (BL.EQ. 0.) CALL SDUMP
013970      NLAM=0
013980      603 XOL=(ANGLE(IRMIN)-ANGLE(IRPLUS))/(2.*BL)+NLAM*WAVE/2.
013990      IF(XOL.GE.1.) GO TO 604
014000      IF(XOL.LE.0.) GO TO 605
014010      C  IMAX=(IR/(2.*DZ))*((ZR+DZ)*CEXP(DD*XOL)+(DZ-ZR)*CEXP(-DD*XOL))
014020      C  CMAXM=CABS(IMAX)
014030      C  CMAXA=ANGLE(IMAX)*57.29577951
014040      C  WRITE(IWT,1011) CMAXM,CMAXA,XOL,WAVE
014050      605 NLAM=NLAM+1
014060      GO TO 603
014070      14 CALL MAGANG(CRL,CIL,CMM,CAA)
014080      C--- CMM=ELEMENT CURRENT MAGNITUDE
014090      C--- CAA=ELEMENT CURRENT ANGLE
014100      C--- SERIES OR SHUNT ELEMENT?
014110      IF(N.NE.0)GO TO 900
014120      VMM=0.0
014130      VAA=0.0
014140      C--- PRINT SUMMARY FOR ELEMENT
014150      900 WRITE(IWT,1003)N,VMM,VAA,ICT(JP),CMM,CAA,RX,XX
014160      C--- 'FROM' BUS OR 'TO' BUS?
014170      604 IF(J.EQ.2)GO TO 18
014180      C--- JP=# OF NEXT ELEMENT CONNECTED 'FROM' HARMONIC SOURCE BUS
014190      JP=KP1(JP)
014200      C--- ELEMENT EXISTS?
014210      IF(JP.NE.0)GO TO 9
014220      C--- COMPLETED SUMMARY OF ALL ELEMENTS CONNECTED 'FROM' HARMONIC
014230      C--- SOURCE BUS
014240      16 J=2
014250      C--- JP=# OF FIRST ELEMENT CONNECTED 'TO' HARMONIC SOURCE BUS
014260      JP=JP2(KF)
014270      C--- ELEMENT EXISTS?
014280      IF(JP.EQ.0)GO TO 1
014290      C--- KP=ADJACENT INTERNAL BUS #
014300      17 KP=IP(JP)
014310      GO TO 10
014320      C--- JP=# OF NEXT ELEMENT CONNECTED 'TO' HARMONIC SOURCE BUS
014330      18 JP=KP2(JP)

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014340 C--- ELEMENT EXISTS?
014350 IF(JP.NE.0)GO TO 17
014360 GO TO 1
014370 C--- CALCULATIONS FOR ALL BUSES
014380 C--- CALCULATIONS FOR BUS VOLTAGES
014390 30 NBDUM=NBS
014400 JDUM=1
014410 CALL VBUS(JDUM,NBDUM,IBOR,LF,VR,VI,CR,CI,RBUS,XBUS)
014420 C--- VR=REAL COMPONENT OF BUS VOLTAGE
014430 C--- VI=IMAGINARY COMPONENT OF BUS VOLTAGE
014440 C--- PRINT HEADING FOR ALL BUS LOADFLOW SUMMARY
014450 WRITE(IWT,1004)
014460 DO 50 J=1,NBH
014470 C--- J=EXTERNAL BUS #
014480 C--- KP=INTERNAL BUS #
014490 KP=NB(J)
014500 C--- BUS EXISTS?
014510 IF(KP.EQ.0)GO TO 50
014520 CALL MAGANG(VR(KP),VI(KP),VVM,VVA)
014530 C--- VVM=BUS VOLTAGE MAGNITUDE
014540 C--- VVA=BUS VOLTAGE ANGLE
014550 C--- PRINT BUS VOLTAGE SUMMARY
014560 WRITE(IWT,1005)J,VVM,VVA
014561 IF(IW.EQ.1) GO TO 20
014570 VMSQ(J)=VMSQ(J)+VVM*VVM
014571 GO TO 25
014572 20 VVM1(J)=VVM1(J)+VVM
014573 25 CONTINUE
014580 C WRITE(IWT,1012)J,VMSQ(J),VVM1(J)
014590 C--- K='FROM' BUS OR 'TO' BUS FLAG
014600 K=1
014610 C--- JP=# OF FIRST ELEMENT CONNECTED 'FROM' THE BUS
014620 JP=JP1(KP)
014630 C--- ELEMENT EXISTS?
014640 IF(JP.EQ.0)GO TO 39
014650 C--- KQ=INTERNAL 'TO' BUS #
014660 35 KQ=IQ(JP)
014661 36 RSH=0.0
014662 XSH=0.0
014663 RSE=0.0
014664 XSE=0.0
014670 C--- SHUNT ELEMENT?
014680 IF(KQ.NE.0)GO TO 37
014690 VRR=0.0
014700 VII=0.0
014710 N=0
014711 FLAG=0
014720 GO TO 38
014730 C--- VRR=REAL COMPONENT OF ADJACENT BUS VOLTAGE
014731 37 FLAG=1
014740 VRR=VR(KQ)
014750 C--- VII=IMAGINARY COMPONENT OF ADJACENT BUS VOLTAGE
014760 VII=VI(KQ)
014770 C--- N=ADJACENT EXTERNAL BUS #
014780 N=NBE(KQ)
014790 C--- VRR=REAL COMPONENT OF VOLTAGE DROP
014800 38 VRR=VR(KP)-VRR
014810 C--- VII=IMAGINARY COMPONENT OF VOLTAGE DROP
014820 VII=VI(KP)-VII
014821 C-----
014822 IF (FLAG.GT.0) GO TO 26
014823 C-----RSH,XSH ARE SHUNT ELEMENT RESISTANCE AND REACTANCE
014824 RSH=R(JP)
014825 XSH=X(JP)
014826 GO TO 27
014827 C-----RSE,XSE ARE SERIES ELEMENT RESISTANCE AND REACTANCE

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014828 26 RSE=R(JP)
014829 XSE=X(JP)
014830 C-----
014831 C--- RX,XX=ELEMENT RESISTANCE AND REACTANCE
014840 27 RX=P(JP)
014850 XX=X(JP)
014860 C--- ZX=SQUARE OF ELEMENT IMPEDANCE MAGNITUDE
014870 ZX=RX*RX+XX*XX
014880 C--- CRL=REAL COMPONENT OF ELEMENT CURRENT
014890 CRL=(V*I*XX-VRR*RX)/ZX
014900 C--- CIL=IMAGINARY COMPONENT OF ELEMENT CURRENT
014910 CIL=(V*I*RX-VRR*XX)/ZX
014920 IF(LIN(JP).EQ.0) GO TO 42
014930 DZ=ZO(JP)
014940 DD=GAML(JP)
014950 IF(K.EQ.2) GO TO 31
014960 JP=KP1(JP)
014970 GO TO 32
014980 31 JP=KP2(JP)
014990 32 RX=R(JP)
015000 XX=X(JP)
015010 ZX=RX*RX+XX*XX
015011 RSH=R(JP)
015012 XSH=X(JP)
015020 CRL=CRL+(V*(KP)*XX+VRR*(KP)*RX)/ZX
015030 CIL=CIL+(V*(KP)*RX-VRR*(KP)*XX)/ZX
015040 CM2=CRL*CRL+CIL*CIL
015050 IF(CM2.LT.1.E-8)GO TO 630
015060 RX=(VRR*(KP)*CPL+V*(KP)*CIL)/CM2
015070 XX=(V*(KP)*CRL-VRR*(KP)*CIL)/CM2
015080 ZR=-CMPLX(RX,XX)
015090 630 RX=REAL(DZ)
015100 XX=AIMAG(DZ)
015110 CALL MAGANG(CRL,CIL,CCM,CCA)
015120 WRITE(IWT,1006) N,ICT(JP),CCM,CCA,RSH,XSH,RSE,XSE
015130 IF(CM2.LT.1.E-8)GO TO 601
015140 KR=(ZR-DZ)/(ZR+DZ)
015150 IR=-CMPLX(CRL,CIL)
015160 IRPLUS=IR/(1.-KR)
015170 IRMIN=KR*IR/(KR-1.)
015180 BL=ABS(AIMAG(DD))
015190 WAVE=6.2831853/BL
015200 NLAM=0
015210 600 XOL=(ANGLE(IRMIN)-ANGLE(IRPLUS))/(2.*BL)+NLAM*WAVE/2.
015220 IF(XOL.GE.1.) GO TO 601
015230 IF(XOL.LE.0.) GO TO 602
015240 C IMAX=(IR/(2.*DZ))*((ZR-DZ)*CEXP(DD*XOL)+(DZ-ZR)*CEXP(-DD*XOL))
015250 C CMAXM=CABS(IMAX)
015260 C CMAXA=ANGLE(IMAX)*57.29577951
015270 C WRITE(IWT,1010) CMAXM,CMAXA,XOL,WAVE
015280 602 NLAM=NLAM+1
015290 GO TO 600
015300 42 CALL MAGANG(CRL,CIL,CCM,CCA)
015310 C--- CCM=ELEMENT CURRENT MAGNITUDE
015320 C--- CCA=ELEMENT CURRENT ANGLE
015330 C--- PRINT SUMMARY FOR ELEMENT
015340 WRITE(IWT,1006)N,ICT(JP),CCM,CCA,RSH,XSH,RSE,XSE
015350 C--- 'FROM' BUS OR 'TO' BUS?
015360 601 IF(K.EQ.2)GO TO 41
015370 C--- JP=# OF NEXT ELEMENT CONNECTED 'FROM' THE BUS
015380 JP=KP1(JP)
015390 C--- ELEMENT EXISTS?
015400 IF(JP.NE.0)GO TO 35
015410 C--- COMPLETED SUMMARY OF ALL ELEMENTS CONNECTED 'FROM' THE BUS
015420 39 K=2
015430 C--- JP=# OF FIRST ELEMENT CONNECTED 'TO' THE BUS

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015440      JP=JP2(KP)
015450 C---      ELEMENT EXISTS?
015460      IF(JP.EQ.0)GO TO 50
015470 C---      KQ=ADJACENT INTERNAL 'FROM' BUS #
015480      40 KQ=IP(JP)
015490      GO TO 36
015500 C---      JP=# OF NEXT ELEMENT CONNECTED 'TO' THE BUS
015510      41 JP=KP2(JP)
015520 C---      ELEMENT EXISTS?
015530      IF(JP.NE.0)GO TO 40
015540      50 CONTINUE
015550      GO TO 1
015560 C---      CALCULATIONS FOR COMBINED CONVERTER ACTION
015570 C---      CONVERTER VOLTAGES AND CURRENTS
015580      800 JJJ=1
015590 C---      FIRST OPTION?
015600      IF(JJJ.NE.0)GO TO 801
015610 C---      EE14-EE20=TEMPORARY STORAGE LOCATIONS FOR INPUT DATA
015620      EE14=JF
015630      EE15=NAME
015640      EE16=IOPT
015650      SOURCE(2,1)=FUND
015660      JJJ=JJJ+1
015670      GO TO 1
015680      801 EE17=JF
015690      EE18=NAME
015700      EE19=IOPT
015710      EE20=PHA
015720      SOURCE(2,2)=FUND
015730      JJJ=0
015740      802 JF=EE14
015750      NAME=EE15
015760      IOPT=EE16
015770      PHA=0.0
015780      GO TO 705
015790      804 LF1=LF
015800      CR1=CR
015810      CI1=CI
015820      JF=EE17
015830      NAME=EE18
015840      IOPT=EE19
015850      PHA=EE20
015860      GO TO 705
015870 C---      BUS VOLTAGES AND CURRENTS
015880      805 NBDUM=NBS
015890      JDUM=1
015900      CALL VBUS(JDUM,NBDUM,IBOR,LF1,SVR,SVI,CR1,CI1,RBUS,XBUS)
015910      CALL VBUS(JDUM,NBDUM,IBOR,LF,VR,VI,CR,CI,RBUS,XBUS)
015920      821 WRITE(IWT,1004)
015930 C---      COMBINED HARMONIC SOURCE ANALYSIS USES SIMILAR PROCEDURE
015940 C---      TO SINGLE HARMONIC SOURCE
015950      DO 850 J=1,NBH
015960      KP=NB(J)
015970      IF(KP.EQ.0)GO TO 850
015980      TVR=VR(KP)+SVR(KP)
015990      TVI=VI(KP)+SVI(KP)
016000      CALL MAGANG(TVR,TVI,VVM,VVA)
016010      WRITE(IWT,1005)J,VVM,VVA
016020      K=1
016030      JP=JP1(KP)
016040      IF(JP.EQ.0)GO TO 839
016050      835 KQ=IQ(JP)
016060      836 IF(KQ.NE.0)GO TO 837
016070      VRR=0.0
016080      VII=0.0
016090      N=0

```

```

016100      GO TO B38
016110      B37 VRR=VR(KQ)+SVR(KQ)
016120      VII=VI(KQ)+SVI(KQ)
016130      N=NBE(KQ)
016140      B38 VPP=TVR-VRR
016150      VII=TVI-VII
016160      RX=R(JP)
016170      XX=X(JP)
016180      ZX=RX*RX-XX*XX
016190      CRL=(VII*XX+VRR*RX)/ZX
016200      CIL=(VII*RX-VRR*XX)/ZX
016210      IF(ILIN(JP).EQ.0) GO TO B31
016220      DZ=Z0(JP)
016230      DD=GAML(JP)
016240      IF(K.EQ.2) GO TO B32
016250      JP=KP1(JP)
016260      GO TO B33
016270      B32 JP=KP2(JP)
016280      B33 RX=R(JP)
016290      XX=X(JP)
016300      ZX=RX*RX-XX*XX
016310      CRL=CRL+(TVI*XX+TVR*RX)/ZX
016320      CIL=CIL+(TVI*RX-TV*XX)/ZX
016330      CM2=CRL*CRL+CIL*CIL
016340      IF(CM2.LT.1.E-8) GO TO 632
016350      RX=(TVI*XX+TVR*RX)/CM2
016360      XX=(TVI*RX-TV*XX)/CM2
016370      ZR=-CMPLX(RX,XX)
016380      B32 RX=REAL(DZ)
016390      XX=AIMAG(DZ)
016400      CALL MAGANG(CRL,CIL,CCM,CCA)
016410      WRITE(IWT,1006) N,ICT(JP),CCM,CCA,RX,XX
016420      IF(CM2.LT.1.E-8) GO TO 607
016430      KP=(ZR-DZ)/(ZR+DZ)
016440      IR=-CMPLX(CRL,CIL)
016450      IRPLUS=IR/(1.-KP)
016460      IPMIN=KP*IR/(KP-1.)
016470      BL=ABS/AIMAG(DD)
016480      WAVE=6.2831853/BL
016490      NLAM=0
016500      B06 XOL=(ANGLE(IRMIN)-ANGLE(IRPLUS))/(2.*BL)+NLAM*WAVE/2.
016510      IF(XOL.GE.1.) GO TO 607
016520      IF(XOL.LE.0.) GO TO 608
016530      C IMAX=(IR/(2.*DZ))*((ZR+DZ)*CEXP(DD*XOL)+(DZ-ZR)*CEXP(-DD*XOL))
016540      C CMAXM=CABS(IMAX)
016550      C CMAXA=ANGLE(IMAX)*57.29577951
016560      C WRITE(IWT,1010) CMAXM,CMAXA,XOL,WAVE
016570      B08 NLAM=NLAM+1
016580      GO TO 60E
016590      B31 CALL MAGANG(CRL,CIL,CCM,CCA)
016600      WRITE(IWT,1006)N,ICT(JP),CCM,CCA,RX,XX
016610      B07 IF(K.EQ.2)GO TO B41
016620      JP=KP1(JP)
016630      IF(JP.NE.0)GO TO B35
016640      B39 K=2
016650      JP=JP2(KP)
016660      IF(JP.EQ.0)GO TO B50
016670      B40 KQ=IP(JP)
016680      GO TO B36
016690      B41 JP=KP2(JP)
016700      IF(JP.NE.0)GO TO B40
016710      B50 CONTINUE
016720      RETURN 1
016730      90 WRITE(IWT,1007)JF
016740      GO TO 1
016750      99 WRITE(IWT,1008)

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016760      RETURN 2
016770 1000 FORMAT(14,A7,11,3F10.2)
016780 1001 FORMAT('0*** CONVERTER AT BUS ',I4,3X,A7,3X,'***',5X,'IOPT = ',
016790 1 12,5X,'PHA = ',F10.2,'FUND = ',2F10.2/'0HARMONIC CURRENT = ',
016800 2 F10.4,' MAG ',F10.2,' ANG ',10X,' HARMONIC VOLTAGE = ',
016810 3 F10.4,' MAG ',F10.2,' ANG ')
016820 1002 FORMAT('0',11X,'ADJACENT ADJACENT BUS VOLTAGE CIRCUIT CUR
016830 1RENT TOWARD CONVERTER',6X,'LINE IMPEDANCE'/14X,'BUS',9X,'MAG ',8X,
016840 2'ANG ',7X,'NUMBER',7X,'MAG ',8X,'ANG ',12X,'R',12X,'X')
016850 C 3'-----'/63X,
016860 C 4'MAX CURRENT FLOW',6X,'LOCATION WAVELENGTH')
016870 1003 FORMAT(12X,I4,5X,F10.4,1X,F10.2,7X,I2,6X,F10.4,1X,F10.2,5X,F10.4,3
016880 1X,F10.4)
016890 1004 FORMAT('0',8X,'FROM',9X,'BUS VOLTAGE',11X,'TO',5X,'CIRCUIT',5X,
016900 1' TERM CURRENT FLOW',12X,'SHUNT ELEMENT',3X,'SERIES ELEMENT'/8X,
016910 2'BUS',7X,'MAG',8X,'ANG ',9X,'BUS NUMBER',7X,'MAG ',8X,
016920 3'ANG ',12X,'R',12X,'X',12X,'R',12X,'X')
016930 C 4'MAX CURRENT FLOW',8X,'LOCATION WAVELENGTH')
016940 1005 FORMAT('0',9X,I4,3X,F10.4,1X,F10.2)
016950 1006 FORMAT(42X,I4,5X,I2,6X,F10.4,1X,F10.2,2(2X,F11.2),2(2X,F11.6))
016960 1007 FORMAT('0*** CONVERTER BUS ',I5,' IS NOT IN THE SYSTEM')
016970 1008 FORMAT('0*** UNEXPECTED END OF CONVERTER BUS DATA')
016980 1009 FORMAT('0***ONLY FOUR CONVERTER OPTIONS CAN BE USED FOR ONE ZBUS')
016990 C1010 FORMAT(62X,F10.4,1X,F10.2,5X,F10.4,3X,F10.2)
017000 C1011 FORMAT(57X,F10.4,1X,F10.2,5X,F10.4,3X,F10.2)
017010 C1012 FORMAT(1X,'VBUS J,VMSQ(J),VVM1(J)',I4,5X,E17.4,5X,E17.4)
017020 END
017030 SUBROUTINE VBUS(J1,J2,IBOR,LF,VR,VI,CR,CI,RBUS,XBUS)
017040 C--- CALCULATE HARMONIC BUS VOLTAGES
017050 C--- CALLED FROM HARM1
017060 IMPLICIT INTEGER*4(I-N)
017070 INTEGER*4 NBH,NBS,NBX,MS,MBUS
017080 COMMON /KB/NBH,NBS,NBX,MS,NLR
017090 COMMON /KZ/MBUS
017100 DIMENSION IBOR(NBS),VR(NBS),VI(NBS),RBUS(MBUS),XBUS(MBUS)
017110 DO 30 J=J1,J2
017120 C--- J=INTERNAL BUS #'S
017130 C--- I=BUS ORDER NUMBER
017140 I=IBOR(J)
017150 IF(I.LT.LF) GO TO 10
017160 C--- LL=INDEX TO IMPEDANCE BETWEEN BUSES
017170 LL=LF+(I*(I-1))/2
017180 GO TO 20
017190 10 LL=I+(LF*(LF-1))/2
017200 C--- VR=REAL COMPONENT OF BUS VOLTAGE
017210 20 VR(J)=CR*RBUS(LL)-CI*XBUS(LL)
017220 C--- VI=IMAGINARY COMPONENT OF BUS VOLTAGE
017230 VI(J)=CR*XBUS(LL)+CI*RBUS(LL)
017240 30 CONTINUE
017250 RETURN
017260 END
017270 SUBROUTINE MAGANG(REAL,AIMAG,AMAG,ANG)
017280 C--- CALCULATE MAGNITUDE & ANGLE FROM REAL & IMAG COMPONENTS
017290 C--- CALLED FROM HARM1
017300 AMAG2=REAL*REAL+AIMAG*AIMAG
017310 AMAG=SQRT(AMAG2)
017320 ANG=0.
017330 IF(REAL.EQ.0. AND AIMAG.EQ.0.) GO TO 10
017340 ANG=ATAN2(AIMAG,REAL)
017350 10 ANG=ANG*57.29577951
017360 RETURN
017370 END
017380 FUNCTION ANGLE(COMPLX)
017390 COMPLEX*8 COMPLX
017400 A=REAL(COMPLX)

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017410      B=AIMAG(COMPLX)
017420      ANGLE=0.
017430      IF(A.EQ.0. .AND. B.EQ.0.) GO TO 10
017440      ANGLE=ATAN2(B,A)
017450      10 RETURN
017460      END
017500      SUBROUTINE FFTCC
017600      WRITE(6,1000)
017700      1000 FORMAT(1H-,132(1H*)/62H0THIS IS A DUMMY FFTCC ROUTINE TO SATISFY E
017800      INTERNAL REFERENCES./1H0,132(1H*)/1H0)
017900      RETURN
018000      END
018100      SUBROUTINE GRAPH
018200      WRITE(6,1000)
018300      1000 FORMAT(1H-,132(1H*)/62H0THIS IS A DUMMY GRAPH ROUTINE TO SATISFY E
018500      INTERNAL REFERENCES./1H0,132(1H*)/1H0)
018600      RETURN
018700      END
```

X1. APPENDIX

D. MODIFICATION MATRIX FOR PROGRAM

HARMONIC LOADFLOW ANALYSIS PROGRAM MODIFICATIONS

LETTER CODE	DESIRED CHANGE TO THE PROGRAM
A	-- VOLTAGE BASE
B	-- VOLTAMPERE BASE
C	-- ARRAY FOR THE NUMBER OF ELEMENTS
D	-- ARRAY FOR THE NUMBER BUSES OR NODES
E	-- ARRAY FOR THE LARGEST BUS NUMBER
F	-- FOUR DIGIT BUS NUMBERS

NOTE - \* REPRESENTS ARRAY DIMENSION IS DETERMINED BY  
 THE FORMULA  $\left[ \frac{(\# \text{ OF BUSES})^2}{2} + \frac{\# \text{ OF BUSES}}{2} \right]$



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C---- D=NO PLOTS
C---- IVC=VOLTAGE OR CURRENT OR CONVERTER CODE
C---- LESS THAN -1 = CURRENT HARMONIC MAGNITUDES GIVEN
C---- -1=VOLTAGE HARMONIC MAGNITUDE GIVEN
C---- D=VOLTAGE WAVEFORM
C---- 1=CONVERTER
C---- ANYTHING ELSE=CURRENT WAVEFORM
C---- IUNIT=OUTPUT UNITS
C---- D=VOLTS
C---- ANYTHING ELSE=PER UNIT
1000 READ(IRD,1000)N,VCBASE,LHARM,JPLOT,IVC,IUNIT
    FORMAT(13,F10.2,4I3)
    WRITE(IWT,109)N,VCBASE,LHARM,JPLOT,IVC,IUNIT
109  FORMAT(1X,N=,13.5X,VCBASE=,F7.2,5X,LHARM=,13.
15X,JPLOT=,13.5X,IVC=,13.5X,IUNIT=,13)
    IF(IVC.GE.0)GO TO 40
    READ MEASURED HARMONIC VOLTAGES OR CURRENTS
C---- IY=HARMONIC ORDER
C---- VCM=HARMONIC VOLTAGE (CURRENT) MAGNITUDE
C---- VCA=HARMONIC VOLTAGE (CURRENT) ANGLE
    IF (IVC.NE.-1) GO TO 28
    IVC=0
    GO TO 29
28  IVC=2
29  CONTINUE
    WRITE(IWT,1051)
    DO 31 IM=1,65
31  VC(IM)=(0.,0.)
30  READ(IRD,600)IV,VCM,VCA
    IF(IV.EQ.999)GO TO 34
    WRITE(IWT,600)IV,VCM,VCA
600  FORMAT(3X,13.2X,F12.8,2X,F12.8)
    IF(IVCA.EQ.0.0)GO TO 32
    IM=1Y+1
    VC(IM)=CMPLX(-VCM,0.)
    GO TO 33
32  IM=1Y-1
33  GO TO 30
34  IF=65
    GO TO 30B
40  IF(IVC.NE.1)GO TO 301
    READ CONVERTER DATA
C---- POW=MW RATING OF CONVERTER
C---- ALFA=DELAY ANGLE IN DEGREES (0-60)
C---- OVLAP=OVERLAP ANGLE IN DEGREES
    READ(IRD,302) POW,ALFA,OVLAP
302  FORMAT(3F10.2)
303  WRITE(IWT,303) POW,ALFA,OVLAP
    FORMAT('050W =',F10.2,5X,'ALFA =',F10.2,5X,'OVLAP =',F10.2)
    ALFA=ALFA/RTD
    OVLAP=OVLAP/RTD
    GAM=ALFA+OVLAP
304  VC(IM)=(0.,0.)
    WRITE(IWT,1051)
    DHECOS(ALFA)-COS(GAM)
    DO 305 IM=N,65,N
    IF(OVLAP.NE.0.)GO TO 306
    SHAR1=0.779697*SORT(6)/PI
    SHAR2=0.779697/(IM+1.)
    GO TO 307
306  SHM=SIN((IM-2.)*OVLAP/2.)
    SHP=SIN((IM+OVLAP/2.)
    F2=SQRT((SHP/(IM-2.))*2+(SHP/IM)**2-2.*SHM*SHP*

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1 COS(2.*ALFA+OVLPL)/((IM-2.)*IM)
SHR1=0.779697*F2/((IM-1.)*DH)
SHM=SIN(IM*OVLPL/2.)
SHD=SIN((IM+2.)*OVLPL/2.)
F2=SQRT((SHM/IM)**2+(SHD/(IM+2.))**2-.5*SHM*SHD*
1 COS(2.*ALFA+OVLPL)/(IM*(IM-2.)))
SHR2=0.779697*F2/((IM+1.)*DH)
2.5651=2*PI/SQRT(6)
307 CR=2.5651*PDW/((COS(ALFA)+COS(GAM))*100.)
VCA=180.
VCM=CR*SHR1
IV=IM-1
VC(IM)=CMPLX(-VCM,0.)
WRITE(1MT,106) IV,VCM,VCA
VCA=0.
VCM=CR*SHR2
IV=IM+1
VC(IM+2)=CMPLX(VCM,0.)
WRITE(1MT,106) IV,VCM,VCA
305 CONTINUE
IF=65
GO TO 308
C--- READ IN SAMPLED DATA WAVEFORM
301 J=(N-1)/B+1
DO 9 IB=1,1
KJ=B*(IB-1)+1
KJ=B*(IB-1)+1
C--- A=ARRAY OF N VALUES OF THE SAMPLED DATA WAVEFORM IN COSINE
FORM IN KV
READ(1RD,1050) (A(K),K=K1,KJ)
1050 FORMAT(1F10.2)
9 CONTINUE
WRITE(1MT,200)
200 FORMAT(1H0.5X,'SAMPLED DATA POINTS',/1H0,'NUMBER',.35X,'VALUES')
DO 110 IB=1,J
KJ=B*(IB-1)+1
KJ=B*(IB-1)+1
WRITE(1MT,111) K1,(A(K),K=K1,KJ)
111 FORMAT(1H0.14,'B',10.2)
110 CONTINUE
DO 300 IB=1,N
300 VC(IB)=CMPLX(A(IB),0.)
C--- FFTCC IS A SPECIAL PROGRAM FROM A LIBRARY NOT INCLUDED
C--- THERE IS A DUMMY PROGRAM INCLUDED TO SATISFY EXTERNAL
REFERENCES
C--- PERFORM FAST FOURIER TRANSFORM
C--- IMK=INTEGER WORK ARRAY OF LENGTH 6N+150
C--- WK=REAL WORK ARRAY OF LENGTH 6N+150
CALL FFTCC(VC,N,IM,WK)
C--- RN=N/2
RN=N/2
WRITE(1MT,1051)
1051 FORMAT(1H-,'HARMONIC VALUES',/1HORDER',BX,'MAG',BX,'ANG')
1Z=N/2
C--- RESCALE TRANSFORM COEFFICIENTS
DO 26 IM=1,1Z
VC(IM)=CONJG(VC(IM))/(RN*VCBASE)
VCM=CABS(VC(IM))
VCA=ANGLE(VC(IM))*RTD
IV=IM-1
C--- PRINT HARMONIC VALUES
C--- WRITE(1MT,106) IV,VCM,VCA
106 FORMAT(3X,12.2X,F12.4,F12.2)
26 CONTINUE
C--- LLLFIRST TIME THROUGH LOOP FLAG

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C--- I=FIRST TIME
      IF(N/2)1
      LLL=1
308 IF(IPLT.EQ.0) IF=LHARM+1
C--- INITIALIZE DC HARMONIC TO ZERO
      DO 167 IE=1,4
167 SOURCE(I,IE)=(0.,0.)
C--- BEGIN LOOP FOR HARMONIC ANALYSIS
      JJ=HARMONIC ORDER + 1
      DO 27 JJ=3,1F
C--- IW=HARMONIC ORDER
      IW=JJ-1
C--- VCK=HARMONIC SOURCE VALUE IN PU
      VCK=VC(JJ)
C--- IDSN=SEQUENCE CODE FOR HARMONIC (SEE LINEIN)
      IDSN=0
C--- IF HARMONIC INJEC NEGLBLE, DO NOT PERFORM HARMONIC ANAL
      IF((CABS(VCK).GT.0.0001)GO TO 17
      DO 984 IE=1,4
984 SOURCE(JJ,IE)=(0.,0.)
      GO TO 27
17 IF(IW.GT.LHARM) GO TO 18
      GO TO 19
18 WRITE(IWT,10R) IW
19 FORMAT('0XXX HARMONICS OF ORDER',3X,13/)
      CONTINUE
C--- LINE=SUBROUTINE FOR READING AND STORING LINE, TRANSFORMER,
C--- GENERATOR, SHUNT CAPACITOR, AND LOAD DATA
      IP=ARRAY CONTAINING EXTERNAL 'FROM' BUS #'S
      IO=ARRAY CONTAINING EXTERNAL 'TO' BUS #'S
      IC=ARRAY CONTAINING ELEMENT CIRCUIT #'S
      PX=ARRAYS CONTAINING ELEMENT RESISTANCE AND REACTANCE
      NB=ARRAY CONTAINING CONVERSION OF EXTERNAL TO INTERNAL
      BUS #'S
      NLB=ARRAY CONTAINING THE # OF ELEMENTS TO A BUS
      NBE=ARRAY CONTAINING CONVERSION OF INTERNAL TO EXTERNAL
      BUS #'S
C--- CALL LINEIN(IP,IO,ICT,R,X,NB,NLB,NBE,ILIN,ZO,GAML,&2,&500)
      ORDER=SUBROUTINE FOR ORDERING AND INDEXING SYSTEM TOPOLOGY
      JP1=POINTER ARRAY FOR 'FROM' BUS TO ELEMENT #
      JP2=POINTER ARRAY FOR 'TO' BUS TO ELEMENT #
      KP1=POINTER ARRAY FOR 'FROM' BUS (ONE ELEMENT # TO NEXT)
      KP2=POINTER ARRAY FOR 'TO' BUS (ONE ELEMENT # TO NEXT)
      ISC=ARRAY CONTAINING THE ORDERING SCORE OF THE BUS
      ILO=ARRAY CONTAINING THE ELEMENT ORDER
      IBO=ARRAY CONTAINING THE BUS ORDER
2   CALL ORDER(IP,IO,NLB,JP1,JP2,KP1,KP2,ISC,ILO,IBO,&4,&500)
C--- ZBUS=SUBROUTINE FOR CALCULATION OF IMPEDANCE MATRIX
      RBUS=ARRAY CONTAINING REAL PART OF BUS IMPEDANCE MATRIX
C--- XBUS= ARRAY CONTAINING IMAGINARY PART OF BUS IMPEDANCE MATRI
      RL=ARRAY CONTAINING ELEMENT RESISTANCE
      XL=ARRAY CONTAINING ELEMENT REACTANCE
4   CALL ZBUS(IP,IO,R,X,ILO,IBO,ISC,RBUS,XBUS,RL,XL,NBE,&6,&500)
C--- HARMI=SUBROUTINE FOR HARMONIC ANALYSIS
6   WRITE(IWT,107)IW
107 FORMAT('1XXX HARMONICS OF ORDER',3X,13/)
      CALL HARMI(IP,IO,ICT,R,X,KP1,KP2,NB,NBE,JP1,JP2,ISC,RBUS,XBUS,RL,
      XL,ILIN,ZO,VMSQ,VVM1,GAML,&7,&500)
7   CONTINUE
      LLL=2
27   CONTINUE
C--- COMPUTE HARMONIC (VOLTAGE) DISTORTION FACTOR
C   IF(IOPT.EQ.0) GO TO 470
      WRITE (IWT,450)
      DO 400 J=1,NBH
      J=EXTERNAL BUS#

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C      KP=INTERNAL BUS #
C      KP=NB(J)
C      BUS EXISTS?
IF (KP.EQ.0) GO TO 400
IF (UNIT.EQ.0) GO TO 430
IF (VVM1(J).EQ.0.) VVM1(J)=1.0
HDF(J)=(VMSD(J)*0.5)*100./VVM1(J)
GO TO 440
430 IF (VVM1(J).EQ.0.) VVM1(J)=VCBASE*1000./SQRT(3.)
HDF(J)=(VMSD(J)*0.5)*100./VVM1(J)
440 WRITE(IWT,460) J,HDF(J)
400 CONTINUE
450 FORMAT('HARMONIC DISTORTION FACTOR '//6X,'BUS',12X,'HDF (%)')
460 FORMAT(6X,14.8X,F10.4)
IF (IPLOT.EQ.0) GO TO 500
IVCO=1
IF (IVC.EQ.0) IVCO=2
IF (IVC.EQ.1) N=128
J=(N-1)/4+1
IC=N/2+1
DO 37 IE=1, JJJ
WRITE(6,220) IE
FORMAT('H1.5X, WAVEFORM FOR HARMONIC SOURCE NUMBER', I5)
220 DO 47 IG=1, IC
IA=IG*N/2+1
IB=N/2+1-IG
47 SOURCE(IA,IE)=CONJG(SOURCE(IB,IE))
----- FFTCC IS A SPECIAL PROGRAM FROM A LIBRARY NOT INCLUDED
----- THERE IS A DUMMY PROGRAM INCLUDED TO SATISFY EXTERNAL
----- REFERENCES
CALL FFTCC(SOURCE(1,IE), N, IWK, WK)
DO 57 IA=1, N
SOURCE(IA,IE)=SOURCE(IA,IE)/2.
57 X(IA)=(IA-1)*1000./160.*N
DO 67 IB=1, J
KI=4*(IB-1)+1
KI=KI+3
67 WRITE(6,210) KI, SOURCE(1,IE), I=KI, KJ)
210 FORMAT('H0.14, F10.5)
----- THIS CALLS IOWA STATE UNIVERSITY'S VERSION OF CALCOM
----- THIS MAY NOT WORK WITH STANDARD CALCOM
CALL GRAPH(N, X, A, 4.103, 12., 9., 1.5, 0., 0., 0., 'TIME (MS)')
1 YLAB(1, IVCO), GLAB(1, IVCO), DATLAB(1, IE))
37 CONTINUE
500 STOP
END
SUBROUTINE LINEIN(IP, IO, ICT, R, X, NB, NLB, NBE, ILIN, ZO, GAML, * *)
READ AND STORE LINE, TRANSFORMER, GENERATOR, SHUNT CAPACITOR
AND LOAD DATA
CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
HARMONIC ORDER TO BE ANALYZED
IMPLICIT INTEGER*(I-N)
INTEGER*4 IRD, IWT, NEX, NEL, NBH, NBS, NBX, MS, IDSN, IW
COMPLEX*8 D1, D2, DD1, DD, DZ, DZ1, DZ, DSH, DCH, DYS, DZS, CMLPX, CSORT, CEXP
COMPLEX*8 DT1, DT2, DT3, DYZ, ZO, GAML
COMMON /K1/IRD, IWT, IW, IDSN, HZ
COMMON /K2/NEX, NEL
COMMON /K3/NBH, NBS, NBX, MS, NLR
COMMON /BASE/LLL, JJJJ
DIMENSION IP(NEX), IO(NEX), ICT(NEX), P(NEX), X(NEX), ILIN(NEX)
DIMENSION NB(NBH), NLB(NBX), NBE(NBX), ZO(NEX), GAML(NEX)
DIMENSION RON(4000, 7), IRON(4000, 5)
DIMENSION RDC(4000), AB(4000), BER(2), BEI(2), BERD(2)
NEX=MAXIMUM NUMBER OF ELEMENTS
NEL=NUMBER OF ELEMENTS
C-----
C-----
C-----
C-----

```



```

C--- 0.0.9.LT.XX0.LT.1:ONE IMPEDANCE (XX1) 'TO' BUS TO
C--- REFERENCE
C--- 0.0.7.LT.XX0.LT.0.9:ONEIMPEDANCE (XX1) 'FROM' BUS
C--- TO REFERENCE
C--- 0.XX0.LT.0.7:T-TYPE CKT WITH POS/NEG SEQ MAG BRANCH
C--- 1:SHORTED T-TYPE (XX1,XCO) 'FROM' BUS TO REFERENCE
C--- 2:SHORTED T-TYPE (XX1,XCO) 'TO' BUS TO REFERENCE
C--- 3:OPEN T-TYPE (XX1,XCO) 'TO' BUS TO REFERENCE
C--- 4:OPEN T-TYPE (XX1,XCO) 'FROM' BUS TO REFERENCE
C--- .GT.4:T-TYPE (XX1,XCO) CORE LOSS NEGLECTED
C--- (OR) KK=GEN/CAP CODE
C--- 1=CAPACITOR
C--- (OR) KK=LOAD CODE
C--- 1=RESIDENTIAL
C--- 2=COMMERCIAL
C--- 3=INDUSTRIAL
C--- XLM=LINE LENGTH IN MILES
C--- READ(IR,1000,END=50)KJ,KJP,KJO,KCT,RR1,XX1,XC1,PRO,XX0,XCO,KK,XLM
C--- IF(KJP.EQ.9999) GO TO 200
C--- WRITE (IWT,1200)KJ,KJP,KJO,KCT,RR1,XX1,XC1,RR0,XX0,XCO,KK,XLM
C--- CONTINUE
C--- Z00 CONVERT FROM PER CENT TO PER UNIT
C--- RR1=XX1/100.0
C--- XX1=XX1/100.0
C--- XC1=XC1/100.0
C--- PRO=RR0/100.0
C--- XX0 IS CONVERTED LATER
C--- XCO=XCO/100.0
C--- STORE INPUT DATA
C--- IPDN=INTEGER APRAY STORING INPUT DATA
C--- IRDN(NE1,1)=KJ
C--- IRDN(NE1,2)=KJP
C--- IRDN(NE1,3)=KJO
C--- IRDN(NE1,4)=KCT
C--- IRDN(NE1,5)=KK
C--- RDN=REAL ARRAY STORING INPUT DATA
C--- RDN(NE1,1)=RR1
C--- RDN(NE1,2)=XX1
C--- RDN(NE1,3)=XC1
C--- RDN(NE1,4)=PRO
C--- RDN(NE1,5)=XX0
C--- RDN(NE1,6)=XCO
C--- RDN(NE1,7)=XLM
C--- GO TO 301
C--- RECOVER INPUT DATA
C--- 300 KJ=IRDN(NE1,1)
C--- KJP=IRDN(NE1,2)
C--- KJO=IRDN(NE1,3)
C--- KCT=IRDN(NE1,4)
C--- KK=IRDN(NE1,5)
C--- RR1=IRDN(NE1,1)
C--- XX1=IRDN(NE1,2)
C--- XC1=IRDN(NE1,3)
C--- PRO=IRDN(NE1,4)
C--- XX0=IRDN(NE1,5)
C--- XCO=IRDN(NE1,6)
C--- XLM=IRDN(NE1,7)
C--- 301 IF(KJP.EQ.9999) GO TO 45
C--- IDSN=SEQUENCE CODE FOR HARMONIC
C--- 0=UNDETERMINED
C--- 1=ZERO SEQUENCE
C--- 2=NEG SEQUENCE
C--- 3=POS SEQUENCE
C--- 150 IF(IDSN=1)101,106,141
C--- 141 IF(IDSN=2)110,110,112
C--- 101 B=1.0

```

```

C---- WT=HARMONIC ORDER
      WT=FLOAT(IW)
      IF(WT.EQ.1) GO TO 112
      IS HARMONIC ZERO SEQ.
107 A=3.0*B
      IF(WT/A-1.0)105,106,105
105 B=B*1.0
      IF(B-22.0)107,108,108
      IS HARMONIC NEG. SEQ.
C----
108 B=1.0
111 A=(3.0*B)-1.0
      IF(WT/A-1.0)109,110,109
109 B=B*1.0
      IF(B-22.0)111,112,112
112 IDSN=3
C---- HARMONIC IS POS. SEQ.
      WHAT IS ELEMENT
C----
      IF(KJ-2)113,114,115
C---- POS. + NEG. SEQ. TRANSMISSION LINE
C---- DETERMINE BASE IMPEDANCE
113 IF(KK.GT.20)GO TO 210
C---- BI=BASE IMPEDANCE
      BI=47.61
      GO TO 218
210 IF(KK.GT.30)GO TO 211
      BI=132.25
      KK=KK-10
      GO TO 218
211 IF(KK.GT.40)GO TO 212
      BI=174.24
      KK=KK-20
      GO TO 218
212 IF(KK.GT.50)GO TO 213
      BI=190.44
      KK=KK-30
      GO TO 218
213 IF(KK.GT.60)GO TO 214
      BI=259.21
      KK=KK-40
      GO TO 218
214 IF(KK.GT.70)GO TO 215
      BI=529.00
      KK=KK-50
      GO TO 218
215 IF(KK.GT.80)GO TO 216
      BI=1190.25
      KK=KK-60
      GO TO 218
216 IF(KK.GT.90)GO TO 217
      BI=2500.00
      KK=KK-70
      GO TO 218
217 BI=1.9044
      KK=KK-80
C---- R60=60 HZ LINE RESISTANCE IN OHMS/MILE
218 R60=RR1*BI*(KK-10)/XLM
      IF(WT.EQ.1) GO TO 160
      I=1
C---- IF(RDC(NE1).NE.0.) GO TO 206
      RDC=DC LINE RESISTANCE IN OHMS/MILE
C---- RDC(NE1)=R60
C---- F=FREQUENCY IN HZ
      F=60.0
C---- SKIN EFFECT
203 B=F/RDC(NE1)
C---- A=MB

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A=0.0636*SORT(B)
IF(HZ.NE.0.) GO TO 400
M2=4.
M4=64.
M6=2304.
M8=147456.
M10=1.47456E7.
M12=H10*144.
M14=H12*196.
M16=H14*256.
M18=H16*324.
M20=H18*400.
M22=H20*484.
M24=H22*576.
M26=H24*676.
M28=H26*784.
M30=H28*900.
M32=H30*1024.
M34=H32*1156.
M36=H34*1296.
C---- BER(I)=REAL BESSEL FUNCTION OF MR
C---- Z=HARMONIC FREQ
C---- 1=60 HZ
400 BER(I)=1.0-A**4/H4+A**6/H6-A**8/H8-A**12/H12+A**16/H16-A**20/H20
1 -A**24/H24-A**28/H28+A**32/H32-A**36/H36
C---- BEI(I)=IMAGINARY BESSEL FUNCTION OF MR
BEI(I)=A**2/H2-A**6/H6+A**10/H10-A**14/H14+A**18/H18
1 -A**22/H22+A**26/H26-A**30/H30-A**34/H34
C---- BERD(I)=DERIVATIVE OF BER(I)
1 -20.0*A**19/H20-24.0*A**23/H24-28.0*A**27/H28+32.0*A**31/H32
2 -36.0*A**35/H36
C---- BEID(I)=DERIVATIVE OF BEI(I)
BEID(I)=2.0*A/H2-6.0*A**5/H6+10.0*A**9/H10-14.0*A**13/H14
1 +18.0*A**17/H18-22.0*A**21/H22+26.0*A**25/H26-30.0*A**29/H30
2 +34.0*A**33/H34
C---- PR7=AC TO DC RESISTANCE RATIO
PR7=A*(BER(I)*BEID(I)-BEI(I)*BERD(I))/
1 (2.0*(BEID(I)**2-BERD(I)**2))
IF(F.NE.60.0)GO TO 204
TR60=ESTIMATE OF 60 HZ RESISTANCE
ER=TR60-R60
C---- ERA=ERROR DIFFERENCE OF ACTUAL AND ESTIMATE OF 60 HZ RESIS
ERA=ABS(ER)
C---- CHECK ACCURACY OF TR60
IF(ERA.GT.0.00005)GO TO 205
A6=ALPHAL AT 60 HZ
A6(NE1)=4.0*(BER(I)*BERD(I)+BEI(I)*BEID(I))/
1 (A*(BERD(I)**2-BEID(I)**2))
GO TO 206
C---- OBTAIN NEW ESTIMATE OF RDC
205 RDC(NE1)=RDC(NE1)-ER
GO TO 203
C---- F=HARMONIC FREQUENCY
206 F=60.0*JW
J=2
GO TO 203
C---- RT=LINE RESISTANCE AT HARMONIC FREQ IN PU
C---- R1=RR1 IS USED FOR FUNDAMENTAL FREQ ONLY
160 R1=RR1
GO TO 170
204 R1=RR7+RDC(NE1)*XLW/(BI*(KK-10))
C---- ALPHAL AT HARMONIC FREQUENCY
208 AL=4.0*(BERD(I)*BERD(I)+BEI(I)*BEI(I))/
1 (A*(BERD(I)**2-BEID(I)**2))

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C---- X60=TOTAL 60 HZ REACTANCE IN OHMS/MILE
X60=XX1*BI/XLM
C---- D=60 HZ EXTERNAL REACTANCE IN OHMS/MILE
D=60-A6(NE1)*0.03035/(KK-10)
C---- XF=TOTAL REACTANCE AT HARMONIC FREQUENCY IN OHMS/MILE
XF=(D+AL*0.03035/(KK-10))*WT
C---- XL=LINE REACTANCE IN PU
GO TO 175
C----- XL=XX1 IS USED FOR FUNDAMENTAL FREQ ONLY
170 XL=XX1
GO TO 180
175 XL=XF*XL/BI
C---- YC=LINE SHUNT SUSCEPTANCE AT HARMONIC FREQ IN PU
180 YC=WT*XC1
C---- GO=LINE SHUNT CONDUCTANCE
116 GO=0.0
C---- D1=LINE SERIES IMPEDANCE IN PU
D1=CPLX(R1,XL)
C---- D2=LINE SHUNT ADMITTANCE IN PU
D2=CPLX(GO, YC)
D1=D1*D2
C---- DD=GAMMA*L (GAMMA=PROPAGATION CONSTANT, L=LINE LENGTH)
DD=CSORT(DD1)
DZ=D1/D2
C---- DZ=CHARACTERISTIC IMPEDANCE IN PU
DZ=CSORT(DZ1)
DE=CEXP(DD)
C---- DSH=SINH(GAMMA*L)
DSH=0.500*(DE-1.000/DE)
C---- DCH=COSH(GAMMA*L)
DCH=0.500*(DE+1.000/DE)
C---- DVS=PI LINE SHUNT ADMITTANCE IN PU
DVS=(1.000/DZ)*((DCH-1.000)/DSH)
C---- DZS=PI LINE SERIES IMPEDANCE IN PU
DZS=DZ*DSH
C---- DVZ=PI LINE SHUNT IMPEDANCE IN PU
DVZ=1.0/DVS
C---- RS1=REAL PART OF SERIES IMPEDANCE IN PU
RS1=REAL(DZS)
C---- RS2=REAL PART OF SHUNT IMPEDANCE IN PU
RS2=REAL(DVZ)
C---- XS1=IMAGINARY PART OF SERIES IMPEDANCE IN PU
XS1=AIMAG(DZS)
C---- XS2=IMAGINARY PART OF SHUNT IMPEDANCE IN PU
XS2=AIMAG(DVZ)
GO TO 117
110 IDSN=Z
C---- HARMONIC IS NEGATIVE SEQUENCE
C---- WHAT IS ELEMENT
IF(KJ-2)113,114,120
106 IDSN=1
C---- HARMONIC IS ZERO SEQUENCE
C---- WHAT IS ELEMENT
IF(KJ-2)118,121,122
C---- ZERO SEQ. TRANSMISSION LINE
C---- RROE=EARTH RESISTANCE COMPONENT AT 60 HZ IN PU
118 RROE=RFO-RR1
C---- RRWE=EARTH RESISTANCE COMPONENT AT 60 HZ IN PU
RRWE=RROE*WT
C---- R1=LINE RESISTANCE AT HARMONIC FREQ IN PU
R1=RR1+RRWE
C---- XL=LINE SERIES REACTANCE AT HARMONIC FREQ IN PU
XL=XX0*WT/100.0
C---- YC=LINE SHUNT SUSCEPTANCE AT HARMONIC FREQ IN PU
YC=WT*XC0
GO TO 116

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C---- POS. + NEG. SEQ. TRANSFORMER
C---- X53=HALF OF TX SERIES REACTANCE AT HARMONIC FREQ IN PU
114 X53=RR1*WT/2.0
C---- X54=TX SHUNT REACTANCE AT HARMONIC FREQ IN PU
127 X54=XC1*WT
C---- ASSUME SILICON STEEL W/ 3/1 HYS/EDDY LOSSES
C---- RR4=TX SHUNT RESISTANCE AT HARMONIC FREQ IN PU
C---- RR4=(3.0*RR0/(WT*4.0))*(RR0/(4.0*WT**2))
X55=0.0
RR3=0.0
DT1=CMPLX(RR4,X55)
DT2=CMPLX(RR3,X54)
DT3=TX SHUNT IMPEDANCE AT HARMONIC FREQ IN PU
DT3=(DT1*DT2)/(DT1+DT2)
RT1=REAL(DT3)
XT1=IMAGINARY PART OF TX SHUNT IMPEDANCE
GO TO 119
C---- ZERO SEQ. TRANSFORMER
121 IF(KK)143,142,143
142 IF(XX0-1.0)122,124,124
124 GO TO 11
123 IF(XX0-.70)125,125,126
125 X53=XX1*WT/2.0
GO TO 127
126 XT2=XX1*WT
IF(XX0-.90)128,128,129
143 XZ=XX1*WT/2.0
XT2=XZ*(XZ*XC0*WT)/(XZ+XC0*WT)
IF(KK-2)144,145,146
146 IF(KK-4)147,148,149
144 GO TO 128
145 GO TO 129
147 XT2=XZ+XC0*WT
GO TO 129
148 XT2=XZ+XC0*WT
GO TO 128
149 X53=XZ
RT1=0.0
XT1=XC0*WT
GO TO 119
C---- POS. SEQUENCE GENERATORS
C---- GENERATOR OR LOAD?
115 IF(KJ.GE.4)GO TO 444
C---- GENERATOR OR CAPACITOR?
C---- IF(KK.EQ.1)GO TO 500
XG1=GEN REACTANCE AT HARMONIC FREQ IN PU
XG1=XX1*WT
GO TO 130
C---- ZERO SEQUENCE GENERATORS
122 IF(KJ.EQ.4)GO TO 444
IF(KK.EQ.1)GO TO 500
XG1=XC1*WT
GO TO 130
C---- NEG SEQUENCE GENERATORS
120 IF(KJ.EQ.4)GO TO 444
IF(KK.EQ.1)GO TO 500
XG1=XX1*WT
GO TO 130
C---- SHUNT CAPACITORS
C---- XG1=CAP REACTANCE AT HARMONIC FREQ IN PU
500 XG1=XX1/WT
GO TO 130
C---- LOADS
C---- RESIDENTIAL, COMMERCIAL, OR INDUSTRIAL?

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444 IF (IW.EQ.1) GO TO 510
IF(KK-2)445,446,447
C--- RESIDENTIAL LOADS
C--- PMOT=MOTOR COMPONENT OF REAL POWER
445 PMOT=0.5*PR1
C--- PRES=RESISTIVE COMPONENT OF REAL POWER
PRES=0.5*RR1
GO TO 448
C--- COMMERCIAL LOADS
446 PMOT=0.6*PR1
PRES=0.4*RR1
GO TO 448
C--- INDUSTRIAL LOADS
447 PMOT=0.7*PR1
PRES=0.3*RR1
C--- XONE=MOTOR STATOR REACTANCE AT HARMONIC FREQ IN PU
448 XONE=XX1/(4.64*(PMOT**2+XX1**2))
XONE=XONE*WT
RHE=1.03/(0.03*PMOT)
C--- ASSUME SILICON STEEL W/ 3/1 HYS/EDDY LOSSES
RHE=MOTOR CORE LOSS RESISTANCE AT HARMONIC FREQ IN PU
RHE=(2.0*RHE/(WT*4.0))+ (RHE/(4.0*WT**2))
REOM=MOTOR EQUIV SERIES RESISTANCE IN PU
520 REOM=(XONE**2)*RHE/(RHE**2+XONE**2)
C--- XEQ=MOTOR EQUIV SERIES REACTANCE IN PU
XEQ=(RHE**2)*XONE/(RHE**2+XONE**2)+XONE
C--- PES=CONSTANT LOAD RESISTANCE
RES=1.0/PRES
DEQ=(REOM*RES)**2+XEQ**2
REON=(PES**2*REOM)+(REOM**2*RES)+(XEQ**2*RES)
XEQ=XEQ*RES**2
C--- REO=LOAD RESISTANCE AT HARMONIC FREQ IN PU
REO=REON/DEQ
C--- XEO=LOAD REACTANCE AT HARMONIC FREQ IN PU
XEO=XEQ/DEQ
GO TO 449
C----- LOAD SERIES RESISTANCE AND REACTANCE FOR FUNDAMENTAL FREQ
510 REO=RP1/(RR1**2+XX1**2)
XEO=XX1/(RR1**2+XX1**2)
GO TO 449
C--- ASSIGN TRANSMISSION LINE ELEMENTS
C--- M=ELEMENT FLAG
C--- O=SERIES ELEMENT
C--- 1='FROM' BUS SHUNT ELEMENT
C--- 2='TO' BUS SHUNT ELEMENT
117 M=0
139 IF(M-1)131,132,133
C--- JPS='FROM' BUS EXTERNAL NUMBER
131 JP=KJP
C--- JO='TO' BUS EXTERNAL NUMBER
JO=KJO
C--- JCT=CIRCUIT NUMBER
JCT=KCT
C--- RR=ELEMENT RESISTANCE IN PU
RR=RS1
C--- XX=XS1
XX=XS1
C--- ILINE=LINE FLAG
ILINE=1
GO TO 134
132 JP=KJP
JO=0
JCT=KCT
RR=RS2
XX=YS2
ILINE=0

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C--- I(LIN(NEL))=I(LINE)
C--- STORE CHARACTERISTIC IMPEDANCE FOR LINES
C--- Z0(NEL)=DZ
C--- STORE PROPAGATION CONSTANT FOR LINES
C--- GAML(NEL)=DD
C--- ALL ELEMENTS OF COMPONENT?
C--- IF(M-2)/138.11.11
C--- BUS NUMBER ERROR
C--- 40 WRITE(IWT,1001)JP,JO,JCT,RR,XX
C--- COUNT BUS NUMBER ERRORS
C--- ERROR=IERROR+1
C--- IF(M-2)/138.11.11
C--- INCREMENT ELEMENT FLAG
C--- 138 M=M+1
C--- LINE OR TRANSFORMER?
C--- IF(KJ-2)/139.140.140
C--- NORMAL RETURN
C--- 45 IF(ERROR.EQ.D)RETURN 1
C--- PRINT NUMBER OF BUS NUMBER ERRORS
C--- WRITE(IWT,1002)IERROR
C--- ABNORMAL RETURN
C--- RETURN 2
C--- LAST CARD (9999) NOT READ
C--- 50 WRITE(IWT,1003)
C--- TOO MANY BUSES
C--- 55 WRITE(IWT,1004)NBX
C--- RETURN 2
C--- TOO MANY ELEMENTS
C--- 60 WRITE(IWT,1005)NEX
C--- RETURN 2
1000 FORMAT(1,214.13.F10.4,F12.4,F10.8,F10.8,F10.8,F10.8,F12.F6.2)
1001 FORMAT('0*** BUS NUMBER ERROR - ',2(14.2X),12.2(4X,F6.2))
1002 FORMAT('0*** TOTAL NUMBER OF ERRORS = ',15)
1003 FORMAT('0*** UNEXPECTED END OF LINE DATA')
1004 FORMAT('0*** TOO MANY BUSES - MORE THAN ',14)
1005 FORMAT('0*** TOO MANY ELEMENTS - MORE THAN ',15)
1100 FORMAT('1, 2X, 'KJ', 2X, 'KJP', 2X, 'KCT', 6X, 'RR1', 11X, 'XX1',
112X, 'XC1', 12X, 'RO', 11X, 'XKO', 9X, 'XCO', 10X, 'KK', 4X, 'XLM')/
1200 FORMAT(4X,11.1X,14.1X,14.2X,13.1X,F10.4,2X,F12.4,
12X,F15.8,2(2X,F12.4),2X,F15.8,2X,12.2X,F6.2)
END
SUBROUTINE ORDER(IP,IQ,NLB,JP1,JP2,KP1,KP2,ISC,ILO,I90,*)
C--- CREATE ORDERED LISTS FOR BUSES AND ELEMENTS
C--- CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
C--- HARMONIC ORDER TO BE ANALYZED
C--- IMPLICIT INTEGER*4(I-N)
C--- INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,IW,IDSN
C--- COMMON /K1/IRD,IWT,IW,IDSN
C--- COMMON /KL/NEX,NEL
C--- COMMON /KB/NBH,NBS,NBX,MS,NLR
C--- DIMENSION IP(NEL),IQ(NEL),JP1(NEL),KP2(NEL),ILO(NEL)
C--- DIMENSION NLB(NBS),JPI(NBS),JP2(NBS),ISC(NBS),IBO(NBS)
C--- JPI=POINTER FROM BUS TO THE LINE 'FROM' BUS
C--- JP2=POINTER FROM BUS TO THE LINE 'TO' BUS
C--- KP1=POINTER FROM LINE TO THE NEXT LINE 'FROM' BUS
C--- KP2=POINTER FROM LINE TO THE NEXT LINE 'TO' BUS
C--- JPIR, JP2R= POINTERS FROM THE REFERENCE BUS
C--- ISC=THE ORDERING SCORE OF THE BUS
C--- IBO=THE BUS ORDER
C--- ILO=THE LINE ORDER
C--- DO 1 I=1,NBS
C--- JP1(I)=0
C--- JP2(I)=0
C--- 1 ISC(I)=0
C--- JPIR=0

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C---- JP2R=0
C---- CHAIN LINES BY BUS NUMBER
C---- DO 29 I=1,NEL
C---- KP=INTERNAL 'FROM' BUS NUMBER
C---- KP=IP(I)
C---- KO=INTERNAL 'TO' BUS NUMBER
C---- KO=IO(I)
C---- KP1(I)=0
C---- KP2(I)=0
C---- IS 'FROM' BUS REF NODE?
C---- IF(KP.NE.0)GO TO 13
C---- INCREMENT ORDERING SCORE OF 'TO' BUS
C---- ISC(KO)=ISC(KO)+1
C---- IF(JP1R.NE.0)GO TO 10
C---- JP1R=I
C---- GO TO 19
C---- 10 JP=JP1R
C---- 11 JO=KP1(JP)
C---- IF(JO.EQ.0)GO TO 12
C---- JP=JO
C---- GO TO 11
C---- 12 KP1(JP)=I
C---- GO TO 19
C---- 13 JP=JP1(KP)
C---- IF(JP.NE.0)GO TO 11
C---- JP1(KP)=I
C---- 19 IF(KO.NE.0)GO TO 23
C---- ISC(KP)=ISC(KP)+1
C---- IF(JP2R.NE.0)GO TO 20
C---- JP2R=I
C---- GO TO 29
C---- 20 JP=JP2R
C---- 21 JO=KP2(JP)
C---- IF(JO.EQ.0)GO TO 22
C---- JP=JO
C---- GO TO 21
C---- 22 KP2(JP)=I
C---- GO TO 29
C---- 23 JP=JP2(KO)
C---- IF(JP.NE.0)GO TO 21
C---- JP2(KO)=I
C---- 29 CONTINUE
C---- CREATE THE ORDERED LISTS
C---- ML=0
C---- MB=0
C---- MS=0
C---- 30 ISCH=0
C---- DO 33 I=1,NBS
C---- IF(ISCH(I)-ISCH)33,31,32
C---- 31 IF(ISCH.EQ.0)GO TO 32
C---- IF(NLB(N).GE.NLB(I))GO TO 33
C---- 32 N=I
C---- ISCH=ISCH(I)
C---- 33 CONTINUE
C---- ADD BUS N TO ORDERED BUS LIST
C---- IF(ISCH.EQ.0)GO TO 70
C---- ISCH=ISCH+1
C---- MB=MB+1
C---- MS=MS+ISCH*((MB*(MB+3))/2)
C---- IBC(MB)=N
C---- ISC(N)=-9999
C---- CHECK FOR LINES CONNECTED TO BUS N
C---- 51 IF(JP.EQ.0)GO TO 55
C---- KO=IO(JP)
C---- IF(KO.EQ.0)GO TO 52

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IF(ISC(KQ).LT.0)GO TO 52
ISC(KQ)=ISC(KQ)+1
GO TO 53
52 ML=ML+1
ILO(ML)=JP
53 JP=KP1(JP)
GO TO 51
55 JP=JP2(N)
56 IF(JP.EQ.0)GO TO 60
KP=IP(JP)
IF(IP.EQ.0)GO TO 57
IF(ISC(KP).LT.0)GO TO 57
ISC(KP)=ISC(KP)+1
GO TO 58
57 ML=ML+1
ILO(ML)=JP
58 JP=KP2(JP)
GO TO 56
60 IF(ML.LT.NEL)GO TO 30
RETURN
C---- ORDERED LISTS ARE COMPLETE IOB, IOL
70 WRITE(IWT,1000)
RETURN 2
1000 FORMAT('D*** SYSTEM IS NOT CONNECTED TOGETHER.')
END
SUBROUTINE ZBUS(IP,IQ,R,X,ILO,IBOR,RBUS,XBUS,RL,XL,NBE,*)
IMPLICIT INTEGER*(I-N)
INTEGER*4 IPR,IWT,NEX,NEL,NBH,NBS,NBX,MS,MBUS,IW,IDSN
COMMON /K1/IDR,IWT,IW,IDSN
COMMON /K2/NEX,NEL
COMMON /K3/NBH,NBS,NBX,MS,NLR
COMMON /K4/MBUS
DIMENSION IP(NEL),IQ(NEL),R(NEL),X(NEL),ILO(NEL)
DIMENSION IBOR(NBS),IBOR(NBS),NBE(NBS),RL(NBS),XL(NBS)
DIMENSION RBUS(MBUS),XBUS(MBUS)
RBUS=REAL PART OF ZBUS
XBUS=IMAGINARY PART OF ZBUS
IBOR=BUS ORDER LIST WITH INDEX AS INTERNAL BUS NUMBER
RL, XL=LINK IMPEDANCES
MB=0
DO 1 I=1,NBS
J=IBO(I)
IBOR(J)=I
1 READY TO START THE ALGORITHM
DO 40 I=1,NEL
II=ILO(I)
IPP=IP(II)
IF(IPP.EQ.0)GO TO 2
IPP=IBOR(IPP)
2 IOO=IO(II)
IF(IOO.EQ.0)GO TO 3
IOO=IBOR(IOO)
3 IF(IPP.LT.100)GO TO 6
IT=IOO
100=IPP
IPP=IT
C---- TEST FOR BRANCH OR A LINK
6 IF(100.LE.MB)GO TO 15
JJ=(MB*(MB+1))/2
C---- FOUND A BRANCH, TEST FOR REFERENCE
IF(IPP.NE.0)GO TO 9
C---- BRANCH TO REFERENCE
IF(MB.GT.0)GO TO 7
RBUS(1)=R(II)
XBUS(1)=X(II)
MB=1

```

```

GO TO 40
7 DO B J=1,MB
  JJ=JJ+J
  RBUS(JJ)=D.0
  B XBUS(JJ)=D.0
  JJ=JJ+1
  RBUS(JJJ)=R(II)
  XBUS(JJJ)=X(II)
  MB=MB+1
GO TO 40
C--- 9 BRANCH TO AN OLD BUS
      DO 12 J=1,MB
        JJ=JJ+J
        IF(IPP.LT.J)GO TO 10
        KK=J-(IPP*(IPP-1))/2
        GO TO 11
        10 KK=IPP+(J*(J-1))/2
        11 RBUS(JJJ)=RBUS(KK)
        12 XBUS(JJJ)=XBUS(KK)
        JJ=JJ+1
        KK=JJ+IPP
        RBUS(JJJ)=RBUS(KK)+R(II)
        XBUS(JJJ)=XBUS(KK)+X(II)
        MB=MB+1
GO TO 40
C--- 15 FOUND A LINK,TEST FOR REFERENCE
      IF(IPP.NE.0)GO TO 20
      LINK TO REFERENCE
C--- 18 J=1,MB
      DO 18 J=1,MB
        IF(100.LT.J)GO TO 16
        KK=J-(100*(100-1))/2
        GO TO 17
        16 KK=100+(J*(J-1))/2
        17 RL(J)=--RBUS(KK)
        18 XL(J)=--XBUS(KK)
        RLL=RL(100)+R(II)
        XLL=XL(100)+X(II)
        GO TO 30
C--- LINK BETWEEN OLD BUSES
20 DO 25 J=1,MB
  IF(IPP.LT.J)GO TO 21
  JJ=J+(IPP*(IPP-1))/2
  GO TO 22
  21 JJ=IPP+(J*(J-1))/2
  22 IF(100.LT.J)GO TO 23
  KK=J+(100*(100-1))/2
  GO TO 24
  23 KK=100+(J*(J-1))/2
  24 RL(J)=RBUS(JJ)--RBUS(KK)
  25 XL(J)=XBUS(JJ)--XBUS(KK)
  RLL=RL(IPP)--RL(100)+R(II)
  XLL=XL(IPP)--XL(100)+X(II)
  *RON REDUCTION
C--- 30 ZLL=RL*RLL+XLL*XLL
  IF(ZLL.LT.1.E-50)GO TO 50
  DO 32 J=1,MB
  JJ=(J*(J-1))/2
  RLJ=(RLL*RL(J)+XLL*XL(J))/ZLL
  XLJ=(RLL*XL(J)+XLL*XL(J))/ZLL
  DO 31 K=1,J
  KJ=JJ+K
  RBUS(KJ)=RBUS(KJ)--RLJ*RL(K)+XLJ*XL(K)
  31 XBUS(KJ)=XBUS(KJ)--RLJ*XL(K)-XLJ*RL(K)
  32 CONTINUE
  40 RETURN 1

```



```

50 IP=IP(I1)
I=NBE(IPP)
IOO=IO(I1)
J=NBE(IOO)
WRITE(IWT,1000)I1,I,J
RETURN 2
1000 FORMAT(0*** LINE NUMBER ',I4,' BETWEEN BUSES ',I4,' AND ',I4,' CA
USED A ZLL**2 DIVISOR IN THE KRON REDUCTION OF ',E12.5)
END
SUBROUTINE HARM1(IP,IQ,ICT,R,X,KP1,KP2,NB,NBE,JPT1,JPT2,IBOR,REBUS,
1XBUS,VR,VI,IILIN,ZO,VMSO,VVM1,GAML,*,*)
READ HARMONIC SOURCE LOCATION AND OPTIONS, PERFORM HARMONIC
LOADFLOW PRINT RESULTS
CALLED FROM HARMONIC LOADFLOW MAIN PROGRAM ONCE FOR EACH
HARMONIC ORDER TO BE ANALYZED
D
IMPLICIT INTEGER*(I-N)
INTEGER*4 IRD,IWT,NEX,NEL,NBH,NBS,NBX,MS,MBUS,IW,IDSN,FLAG
REAL*8 NAME,EE,EES,EE8,EE11,EE15,EE18,PSH,XSH,RSE,XSE
COMPLEX*8 CMPLX,SOURCE,FUND,ZO,GAML,DZ,DD,ZR,KR,IR
COMPLEX*8 IRPLUS,IRMIN,IMAX,VCK,VCL
COMMON /M1/IRD,IWT,IW,IDSN
COMMON /M2/NEX,NEL
COMMON /M3/NB,NBS,NBX,MS,NLR
COMMON /M4/MBUS
COMMON /CDC/SOURCE,VCK,LHARM,JJJ,IVC
COMMON /BASE/LLL,JJJ,IPT
DIMENSION IP(NEL),IO(NEL),ICT(NEL),R(NEL),X(NEL),KP1(NEL),KP2(NEL)
DIMENSION RBUS(MBUS),XBUS(MBUS),SOURCE(128,4),IILIN(NEL)
DIMENSION IBOR(NBS),NBE(NBS),NB(NBH),JPT1(NBS),JPT2(NBS)
DIMENSION SVR(9998),VI(NBS),ZO(NEL),GAML(NEL)
DIMENSION SVI(9998),SVI(9998),VMSQ(9998),VVM1(9998)
JJJ=COUNTER FOR NUMBER OF OPTIONS
JJJ=0
C--- FIRST TIME CALLED?
1 IF(LLL.GT.1)GO TO 700
IF(JJJ.GT.0)GO TO 3
DO 2 I=1,NBH
VMSQ(I)=0.
VVM1(I)=0.
2 CONTINUE
3 READ(IRD,1000,END=99)JF,NAME,IPT,PHA,FUND
NAME=BUS NAME
IPT=OPTION
D=ADJACENT BUSES ONLY
1=ALL BUSES
2=FIRST ENTRY FOR COMBINED ANALYSIS OF TWO HARMONIC SOURCES
3=SEC ENTRY FOR COMBINED ANALYSIS OF TWO HARMONIC SOURCES
PHA=PHASE ANGLE BETWEEN VOLTAGES FOR HARM SOURCES 2 & 3
FUND=FUNDAMENTAL COMPONENT OF HARMONIC SOURCE CURRENT (COMPLEX)
OPTION 2 OR 3?
IF(IPT.GT.1)GO TO 800
IF(JJJ.NE.0)GO TO 701
EE1=EE13=TEMPORARY STORAGE LOCATIONS FOR INPUT DATA
EE1=JF
EE2=NAME
EE3=IPT
SOURCE(2,1)=FUND
GO TO 705
701 IF(JJJ.NE.1)GO TO 702
EE2=JF
EE5=NAME
EE6=IPT
SOURCE(2,2)=FUND
GO TO 705
702 IF(JJJ.NE.2)GO TO 703

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EE7=JF
EE8=NAME
EE9=IOPT
SOURCE(2,3)=FUND
GO TO 705
EE10=JF
EE11=NAME
EE12=IOPT
SOURCE(2,4)=FUND
GO TO 705
704 EE13=JF
GO TO 705
C--- JJJ=COMBINED ANALYSIS CODE
C--- 1=COMBINED ANALYSIS (OPTION 2,3)
700 IF (JJJ.EQ.1)GO TO 802
IF (JJJ.NE.0)GO TO 708
RECOVER INPUT DATA
JF=EE1
NAME=EE2
IOPT=EE3
GO TO 705
708 IF (JJJ.NE.1)GO TO 709
JF=EE4
NAME=EE5
IOPT=EE6
GO TO 705
709 IF (JJJ.NE.2)GO TO 710
NAME=EE8
IOPT=EE9
GO TO 705
710 IF (JJJ.NE.3)GO TO 711
JF=EE10
NAME=EE11
IOPT=EE12
GO TO 705
711 JF=EE13
C--- END OF ANALYSIS?
705 IF (JF.EQ.9999)RETURN 1
JJJ=JJJ+1
C--- TOO MANY OPTIONS?
GO TO 707
706 WRITE(IWT,1009)
EE13=9999
RETURN 1
C--- HARMONIC SOURCE BUS EXISTS?
707 IF (JF.LE.0.OR.JF.GT.NBH)GO TO 90
KF=INTERNAL BUS # LOCATION OF HARMONIC SOURCE
KF=NB(JF)
C--- HARMONIC SOURCE BUS EXISTS?
LF=BUS ORDER NUMBER FOR HARMONIC SOURCE
LF=IBOR(KF)
C--- LL=INDEX TO HARMONIC SOURCE BUS IMPEDANCE (DIAGONAL ELEMENT
OF A LOWER TRIANGULARIZED MATRIX)
LL=(LF*(LF+1))/2
RX=XX=HARMONIC SOURCE BUS RESISTANCE AND REACTANCE
XX=XBUS(LL)
ZX=RX**2+XX**2
C--- CONVERT PHASE FROM DEGREES TO RADIAN
PH=PHA/57.29577951
VCL=VCK*CMPLX(COS(PHA),SIN(PHA))

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IF(IVC.EQ.0) GO TO 620
CR=REAL(VCL)
CI=AIMAG(VCL)
VRK=CR*RX-CI*XX
VIK=CR*XX+CI*RX
SOURCE(IW+1,JJJ)=CMPLX(VRK,VIK)
GO TO 621

C---- VRK=REAL COMPONENT OF HARMONIC SOURCE VOLTAGE
620 VRK=REAL(VCL)
C---- VIK=IMAGINARY COMPONENT OF HARMONIC SOURCE VOLTAGE
C---- VIK=AIMAG(VCL)
C---- CR=REAL COMPONENT OF HARMONIC SOURCE CURRENT
C---- CP=(VRK*RX+VIK*XX)/ZX
C---- CI=(VIK*RX-VRK*XX)/ZX
SOURCE(IW+1,JJJ)=CMPLX(CR,CI)
CALL MAGANG(CR,CI,CM,CA)
C---- CM=HARMONIC SOURCE CURRENT MAGNITUDE
C---- CA=HARMONIC SOURCE CURRENT ANGLE
CALL MAGANG(VRK,VIK,VKM,VKA)
C---- VKM=HARMONIC SOURCE VOLTAGE MAGNITUDE
C---- VKA=HARMONIC SOURCE VOLTAGE ANGLE
C---- PRINT HARMONIC SOURCE SUMMARY
WRITE(IWT,1001)JF,NAME,IOP1,PHA,FUND,CM,CA,VKM,VKA
IF(IW.GT.LHARM) GO TO 1
IF(IOP1.EQ.2)GO TO 804
IF(IOP1.EQ.3)GO TO 805
IF(IOP1.GT.0)GO TO 30
C---- CALCULATIONS FOR ADJACENT BUSES ONLY
C---- PRINT HEADING FOR ADJACENT BUS LOAD-FLOW SUMMARY
WRITE(IWT,1002)
C---- J='FROM' BUS OR 'TO' BUS FLAG
J#1
C---- JP=# OF FIRST ELEMENT CONNECTED 'FROM' HARMONIC SOURCE BUS
JP=J1(KF)
C---- ELEMENT EXISTS?
C---- IF(JP.EQ.0)GO TO 16
C---- KP=ADJACENT INTERNAL BUS #
9 KP=I(JP)
C---- SHUNT ELEMENT?
10 IF(KP.NE.0)GO TO 11
VRR=-VRK
VII=-VIK
N=0
GO TO 15
11 CALL VBUS(KP,KP,IBOR,LF,VR,VI,CR,CI,RBUS,VBUS)
C---- VR(KP)=REAL COMPONENT OF 'TO' BUS VOLTAGE
C---- VI(KP)=IMAGINARY COMPONENT OF 'TO' BUS VOLTAGE
CALL MAGANG(VR(KP),VI(KP),VMM,VAA)
C---- VMM='TO' BUS VOLTAGE MAGNITUDE
C---- VAA='TO' BUS VOLTAGE ANGLE
VRR=VR(KP)-VRK
VII=VI(KP)-VIK
C---- VII=IMAGINARY COMPONENT OF VOLTAGE DROP
C---- N=ADJACENT EXTERNAL BUS #
N=NB(KP)
C---- RX,XX=ELEMENT RESISTANCE AND REACTANCE
15 RX=R(JP)
XX=X(JP)
C---- ZX=SQARE OF ELEMENT IMPEDANCE MAGNITUDE
ZX=RX*RX+XX*XX
C---- CRL=REAL COMPONENT OF ELEMENT CURRENT
CRL=(VII*XX+VRR*RX)/ZX
C---- CIL=IMAGINARY COMPONENT OF ELEMENT CURRENT
CIL=(VII*RX-VRR*XX)/ZX

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IF(ILIN(JP),EQ,0) GO TO 14
DZ=Z0(JP)
DD=GAML(JP)
IF(J,EO,2) GO TO 12
JP=KPI(JP)
GO TO 13
12 JP=KP2(JP)
13 RXR(JP)
XX=X(JP)
ZXR=XX+XX*XX
CRL=CRL-(VIK*XX+VRK*RX)/ZX
CIL=CIL-(VIK*RX-VRK*XX)/ZX
CM=CRL-CIL+CIL*CIL
IF(CM,LT,1,E=8) GO TO 631
RX=(VRK*CRL+VIK*CIL)/CM1
XX=(VIN*CRL-VRK*CIL)/CM1
ZR=CMPLX(DX,XX)
631 RX=REAL(DZ)
XX=AIMAG(DZ)
CALL MAGANG(CRL,CIL,CMW,CAA)
WRITE(IWT,1003) N,VMM,VAA,ICT(JP),CMW,CAA,RX,XX
IF(CM1,LT,1,E=8) GO TO 604
KR=(ZR-DZ)/(ZR+DZ)
IR=CMPLX(CRL,CIL)
IRPLUS=IR/(1.-KR)
IRMIN=KR*IR/(KR-1.)
BL=AIMAG(DD)
WAVE=6.2831853/BL
IF (BL .EQ. 0.) CALL SDUMP
NLAH=0
603 XOL=(ANGLE(IRMIN)-ANGLE(IRPLUS))/(2.*BL)+NLAH*WAVE/2.
IF(XOL,GE,1.) GO TO 604
IF(XOL,LE,0.) GO TO 605
IMAX=(IR/(2.*DZ))*((ZR-DZ)*CEXP(DD*XOL)-(DZ-ZR)*CEXP(-DD*XOL))
C CMAX=CABS(IMAX)
C CMAX=ANGLE(IMAX)*57.29577951
C WRITE(IWT,1011) CMAX,CMAXA,XOL,WAVE
605 NLAH=NLAH+1
GO TO 603
14 CALL MAGANG(CRL,CIL,CMW,CAA)
C--- CMW=ELEMENT CURRENT MAGNITUDE
C--- CAA=ELEMENT CURRENT ANGLE
C--- SERIES OR SHUNT ELEMENT?
VMM=0.0
VAA=0.0
C--- PRINT SUMMARY FOR ELEMENT
900 WRITE(IWT,1003)N,VMM,VAA,ICT(JP),CMW,CAA,RX,XX
C--- 'FROM' BUS OR 'TO' BUS?
604 IF(J,EO,2)GO TO 18
C--- JP=# OF NEXT ELEMENT CONNECTED 'FROM' HARMONIC SOURCE BUS
JP=KPI(JP)
C--- ELEMENT EXISTS?
IF(JP,NE,0)GO TO 9
C--- COMPLETED SUMMARY OF ALL ELEMENTS CONNECTED 'FROM' HARMONIC
C--- SOURCE BUS
16 J=2
C--- JP=# OF FIRST ELEMENT CONNECTED 'TO' HARMONIC SOURCE BUS
JP=JP2(KF)
C--- ELEMENT EXISTS?
IF(JP,EO,0)GO TO 1
C--- KP=ADJACENT INTERNAL BUS #
17 KP=IP(JP)
GO TO 10
C--- JP=# OF NEXT ELEMENT CONNECTED 'TO' HARMONIC SOURCE BUS
18 JP=KP2(JP)

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C---- ELEMENT EXISTS?
IF (JP.NE.O)GO TO 17
GO TO 1
C---- CALCULATIONS FOR ALL BUSES
C---- CALCULATIONS FOR BUS VOLTAGES
30 NBDUM=NBS
JDUM=1
CALL VBUS(JDUM,NBDUM,IBOR,LF,VR,VI,CR,CI,RBUS,XBUS)
VR=REAL COMPONENT OF BUS VOLTAGE
VI=IMAGINARY COMPONENT OF BUS VOLTAGE
PRINT HEADING FOR ALL BUS LOADFLOW SUMMARY
WRITE(IWT,1004)
DO 50 J=1,NBS
J=EXTERNAL BUS #
KP=INTERNAL BUS #
KP=NB(J)
BUS EXISTS?
IF (KP.EQ.O)GO TO 50
CALL MAGANG(VR(KP),VI(KP),VVM,VVA)
VVM=BUS VOLTAGE MAGNITUDE
VVA=BUS VOLTAGE ANGLE
PRINT BUS VOLTAGE SUMMARY
WRITE(IWT,1005)J,VVM,VVA
IF (IW.EQ.1) GO TO 20
VMSO(J)=VMSO(J)+VVM*VVM
GO TO 25
20 VVM1(J)=VVM1(J)+VVM
25 CONTINUE
C---- WRITE(IWT,1012)J,VMSO(J),VVM1(J)
C---- K='FROM' BUS OR 'TO' BUS FLAG
K=1
C---- JP=# OF FIRST ELEMENT CONNECTED 'FROM' THE BUS
JP=J1(KP)
C---- ELEMENT EXISTS?
IF (JP.EQ.O)GO TO 39
C---- KO=INTERNAL 'TO' BUS #
KO=I0(JP)
35 RSH=0.0
36 XSH=0.0
RSE=0.0
XSE=0.0
C---- SHUNT ELEMENT?
VPR=0.0
VII=0.0
N=0
FLAG=0
GO TO 38
37 VRR=REAL COMPONENT OF ADJACENT BUS VOLTAGE
FLAG=1
VRR=VR(KO)
VII=VI(KO)
C---- N=ADJACENT EXTERNAL BUS #
N=NB(KO)
C---- VRR=REAL COMPONENT OF VOLTAGE DROP
VRR=VR(KP)-VRR
C---- VII=IMAGINARY COMPONENT OF VOLTAGE DROP
VII=VI(KP)-VII
C-----
IF (FLAG.GT.O) GO TO 26
C-----RSH,XSH ARE SHUNT ELEMENT RESISTANCE AND REACTANCE
RSH=R(JP)
XSH=X(JP)
GO TO 27
C-----RSE,XSE ARE SERIES ELEMENT RESISTANCE AND REACTANCE

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26 RSE=R(JP)
XSE=X(JP)
-----
C--- RX_XX=ELEMENT RESISTANCE AND REACTANCE
27 RX=R(JP)
XX=X(JP)
C--- ZX= SQUARE OF ELEMENT IMPEDANCE MAGNITUDE
ZX=RX*RX+XX*XX
C--- CRL=REAL COMPONENT OF ELEMENT CURRENT
CRL=(VI*XX+VR*RX)/ZX
C--- CIL=IMAGINARY COMPONENT OF ELEMENT CURRENT
CIL=(VI*RX-VR*XX)/ZX
IF(ILIN(JP).EQ.0) GO TO 42
DZ=Z0(JP)
DD=GAML(JP)
IF(K.EQ.2) GO TO 31
JP=KP1(JP)
GO TO 32
31 JP=KP2(JP)
32 RX=R(JP)
XX=X(JP)
ZX=RX*RX+XX*XX
RSH=R(JP)
XSH=X(JP)
CRL=CRL+(VI(KP)*XX-VR(KP)*RX)/ZX
CIL=CIL+(VI(KP)*RX-VR(KP)*XX)/ZX
CM2=CRL*CRL+CIL*CIL
IF(CM2.LT.1.E-8) GO TO 630
RX=(VR(KP)*CRL-VI(KP)*CIL)/CM2
XX=(VI(KP)*CRL-VR(KP)*CIL)/CM2
ZS=CMPLX(RX,XX)
630 RX=REAL(DZ)
XX=AIMAG(DZ)
CALL MAGANG(CRL,CIL,CCM,CCA)
WRITE(IWT,1006) N,ICT(JP),CCM,CCA,RSH,XSH,RSE,XSE
IF(CM2.LT.1.E-8) GO TO 601
KR=(ZR-DZ)/(ZR+DZ)
IRE=CMPLX(CRL,CIL)
IRPLUS=IR/(1.-KR)
IRMIN=KR*IR/(KR-1.)
BL=AIMAG(DD)
WAVE=6.2831853/BL
NLAM=0
600 XOL=(ANGLE(IRMIN)-ANGLE(IRPLUS))/(2.*BL)+NLAM*WAVE/2.
IF(XOL.GE.1.) GO TO 601
IF(XOL.LE.0.) GO TO 602
IMAX=(IR/(2.*DZ))*((ZR+DZ)*CEXP(DD*XOL)+(DZ-ZR)*CEXP(-DD*XOL))
C CMAX=CABS(IMAX)
C CMAXA=ANGLE(IMAX)*57.29577951
C WRITE(IWT,1010) CMAXM,CMAXA,XOL,WAVE
602 NLAM=NLAM+1
GO TO 600
42 CALL MAGANG(CRL,CIL,CCM,CCA)
C--- CCM=ELEMENT CURRENT MAGNITUDE
C--- CCA=ELEMENT CURRENT ANGLE
C--- PRINT SUMMARY FOR ELEMENT
WRITE(IWT,1006)N,ICT(JP),CCM,CCA,RSH,XSH,RSE,XSE
601 IF(K.EQ.2) GO TO 41
C--- JP=# OF NEXT ELEMENT CONNECTED 'FROM' THE BUS
JP=KP1(JP)
C--- ELEMENT EXISTS?
IF(JP.NE.0) GO TO 35
C--- COMPLETED SUMMARY OF ALL ELEMENTS CONNECTED 'FROM' THE BUS
39 K#2
C--- JP=# OF FIRST ELEMENT CONNECTED 'TO' THE BUS

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C--- JP=JP2(KP)
      ELEMENT EXISTS?
      IF(JP.EQ.0)GO TO 50
C--- KO=ADJACENT INTERNAL 'FROM' BUS #
      40 KO=IP(JP)
      GO TO 36
C--- JP=# OF NEXT ELEMENT CONNECTED 'TO' THE BUS
      41 JP=KP2(JP)
C--- ELEMENT EXISTS?
      IF(JP.NE.0)GO TO 40
      50 CONTINUE
      GO TO 1
C--- CALCULATIONS FOR COMBINED CONVERTER ACTION
      CONVERTER VOLTAGES AND CURRENTS
      800 JJJ=1
C--- FIRST OPTION?
      IF(JJJ.NE.0)GO TO 801
      EE14=EE20=TEMPORARY STORAGE LOCATIONS FOR INPUT DATA
      EE14=JF
      EE15=NAME
      EE16=IOPT
      SOURCE(2,1)=FUND
      JJJ=JJJ+1
      GO TO 1
      801 EE17=JF
          EE18=NAME
          EE19=IOPT
          EE20=PHA
          SOURCE(2,2)=FUND
          JJJ=0
      802 JF=EE14
          NAME=EE15
          IOPT=EE16
          PHA=0.0
          GO TO 705
      804 LF1=LF
          CR1=CR
          CI1=CI
          JF=EE17
          NAME=EE18
          IOPT=EE19
          PHA=EE20
          GO TO 705
C--- BUS VOLTAGES AND CURRENTS
      805 NBDUM=NBS
          JDUM=1
          CALL VBUS(JDUM,NBDUM,IBOR,LF1,SVR,SVI,CR1,CI1,RBUS,KBUS)
          CALL VBUS(JDUM,NBDUM,IBOR,LF,VR,VI,CR,CI,RBUS,KBUS)
      821 WRITE(IWT,1004)
C--- COMBINED HARMONIC SOURCE ANALYSIS USES SIMILAR PROCEDURE
      TO SINGLE HARMONIC SOURCE
      DO 850 J=1,NBH
      KP=NB(J)
      IF(KP.EQ.0)GO TO 850
      TVR=VR(KP)+SVR(KP)
      TVI=VI(KP)+SVI(KP)
      CALL MAGANG(TVR,TVI,VVM,VVA)
      Ns1
      JP=JP1(KP)
      IF(JP.EQ.0)GO TO 839
      835 KO=IO(JP)
      836 IF(KO.NE.0)GO TO 837
          VPR=0.0
          VII=0.0
          Ns0

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RETURN 2
1000 FORMAT(14,A7,I1,3F10.2)
1001 FORMAT('0*** CONVERTER AT BUS',I4,3X,A7,3X,'***',5X,'10PT' = ,
1 12.5X,'PHA' = ,F10.2,'FUND' = ,2F10.2,'HARMONIC CURRENT' = ,
2 10.4,'MAG' = ,F10.2,'ANG' = ,10X,'HARMONIC VOLTAGE' = ,
3 10.4,'MAG' = ,F10.2,'ANG' )
1002 FORMAT('0',11X,'ADJACENT ADJACENT BUS VOLTAGE CIRCUIT CUR
TENT TOWARD CONVERTER',6X,'LINE IMPEDANCE',/14X,'BUS',9X,'MAG',BX,
2'ANG',7X,'NUMBER',7X,'MAG',BX,'ANG',12X,'R',12X,'X')
C
C 4' MAX CURRENT FLOW',6X,'LOCATION WAVELENGTH')
1003 FORMAT(12X,I4,5X,F10.4,1X,F10.2,7X,12,6X,F10.4,1X,F10.2,5X,F10.4,3
1X,F10.4)
1004 FORMAT('0',BX,'FROM',9X,'BUS VOLTAGE',11X,'TO',5X,'CIRCUIT',5X,
1' TERM CURRENT FLOW',12X,'SHUNT ELEMENT',3X,'SERIES ELEMENT',/8X,
2'BUS',7X,'MAG',BX,'ANG',9X,'BUS NUMBER',7X,'MAG',BX,
3'ANG',12X,'R',12X,'X',12X,'R',12X,'X')
C
C 4' MAX CURRENT FLOW',BX,'LOCATION WAVELENGTH')
C
1005 FORMAT('0',9X,I4,3X,F10.4,1X,F10.2)
1006 FORMAT(42X,I4,5X,12,6X,F10.4,1X,F10.2,2(2X,F11.2),2(2X,F11.6))
1007 FORMAT('0*** CONVERTER BUS',I5,' IS NOT IN THE SYSTEM')
1008 FORMAT('0*** UNEXPECTED END OF CONVERTER BUS DATA')
1009 FORMAT('0*** ONLY FOUR CONVERTER OPTIONS CAN BE USED FOR ONE ZBUS')
C1010 FORMAT(62X,F10.4,1X,F10.2,5X,F10.4,3X,F10.2)
C1011 FORMAT(57X,F10.4,1X,F10.2,5X,F10.4,3X,F10.2)
C1012 FORMAT(1X,'VBUS',J,VMSQ(J),VVM1(J),14,5X,E17.4,5X,E17.4)
END
SUBROUTINE VBUS(J1,J2,IBOR,LF,VR,VI,CR,CI,PBUS,XBUS)
C--- CALCULATE HARMONIC BUS VOLTAGES
C--- CALLED FROM HARMI
IMPLICIT INTEGER*4(I-N)
INTEGER*4 NBH,NBS,NBX,MS,MBUS
COMMON /KB/NBH,NBS,NBX,MS,NLR
DIMENSION IBOR(NBS),VR(NBS),VI(NBS),RBUS(MBUS),XBUS(MBUS)
DO 30 J=J1,J2
J=INTERNAL BUS #'S
I=IBOR(J)
IF(I.LT.LF) GO TO 10
LL=INDEX TO IMPEDANCE BETWEEN BUSES
LL=LF+(I*(I-1))/2
GO TO 20
10 LL=(LF*(LF-1))/2
VR=REAL COMPONENT OF BUS VOLTAGE
20 VR(J)=CR*RBUS(LL)-CI*XBUS(LL)
C--- VI=IMAGINARY COMPONENT OF BUS VOLTAGE
VI(J)=CR*XBUS(LL)+CI*RBUS(LL)
30 CONTINUE
RETURN
END
SUBROUTINE MAGANG(REAL,AIMAG,AMAG,ANG)
C--- CALCULATE MAGNITUDE & ANGLE FROM REAL & IMAG COMPONENTS
C--- CALLED FROM HARMI
AMAG2=REAL*REAL+AIMAG*AIMAG
AMAG=SQRT(AMAG2)
ANG=0.
IF(REAL.EQ.0.)AND.(AIMAG.EQ.0.) GO TO 10
ANG=ATAN2(AIMAG,REAL)
10 ANG=ANG*57.29577951
RETURN
END
FUNCTION ANGLE(COMPLX)
COMPLEX*8 COMPLX
A=REAL(COMPLX)

```

```

B=AIMAG(COMPLX)
ANGLE=0.
IF(A.EQ.0..AND.B.EQ.0.) GO TO 10
ANGLE=ATAN2(B,A)
10 RETURN
END
SUBROUTINE FFTCC
WRITE(6,1000)
1000 FORMAT('H-.132(1H*)/62HOTHIS IS A DUMMY FFTCC ROUTINE TO SATISFY E
1XTERNAL REFERENCES./1H0.132(1H*)/1H0)
RETURN
END
SUBROUTINE GRAPH
WRITE(6,1000)
1000 FORMAT('H-.132(1H*)/62HOTHIS IS A DUMMY GRAPH ROUTINE TO SATISFY E
1XTERNAL REFERENCES./1H0.132(1H*)/1H0)
RETURN
END

```

XII. APPENDIX

E. TI-59 PROGRAM LISTINGS

TI-59 PROGRAM LISTING  
CALCULATES NEW IMPEDANCE VALUE

Where:

Button A is pressed to enter the old impedance value

Button B is pressed to enter the old voltage base

Button C is pressed to enter the old voltampere base

Button B' is pressed to enter the new voltage base

Button C' is pressed to enter the new voltampere base

and then:

Button E is pressed to calculate the new impedance

000	76	LBL	024	91	R/S
001	11	R	025	76	LBL
002	42	STD	026	15	E
003	00	00	027	43	RCL
004	91	R/S	028	00	00
005	76	LBL	029	65	*
006	12	B	030	53	(
007	42	STD	031	43	RCL
008	01	01	032	01	01
009	91	R/S	033	55	+
010	76	LBL	034	43	RCL
011	17	B'	035	02	02
012	42	STD	036	54	)
013	02	02	037	33	X <sup>2</sup>
014	91	R/S	038	65	*
015	76	LBL	039	43	RCL
016	13	C	040	03	03
017	42	STD	041	55	+
018	04	04	042	43	RCL
019	91	R/S	043	04	04
020	76	LBL	044	95	=
021	18	C'	045	22	INV
022	42	STD	046	57	ENG
023	03	03	047	91	R/S

TI-59 PROGRAM LISTING  
CALCULATES TRANSFORMER DATA VALUES

Where:

Button A' is pressed to enter the old voltampere base

Button B' is pressed to enter RR1 in % in the old base

Button C' is pressed to enter XX1 in % in the old base

Button D' is pressed to enter the magnetizing current in  
% at 100% voltage

Button E' is pressed to enter the no load losses in watts  
at 100% voltage

Button A is pressed to enter new voltampere base

and then:

Button B is pressed to calculate RR1 in % in the new base

Button C is pressed to calculate XX1 in % in the new base

Button D is pressed to calculate XC1 in % in the new base

Button E is pressed to calculate RR0 in % in the new base

000	76	LBL	015	76	LBL
001	16	A'	016	19	D'
002	42	STD	017	42	STD
003	00	00	018	03	03
004	91	R/S	019	91	R/S
005	76	LBL	020	76	LBL
006	17	B'	021	10	E'
007	42	STD	022	42	STD
008	01	01	023	04	04
009	91	R/S	024	91	R/S
010	76	LBL	025	76	LBL
011	18	C'	026	11	A
012	42	STD	027	42	STD
013	02	02	028	05	05
014	91	R/S	029	91	R/S

TI-59 PROGRAM LISTING  
CALCULATES TRANSFORMER DATA VALUES

(Continued)

030	76	LBL	071	43	RCL
031	12	B	072	05	05
032	43	RCL	073	55	+
033	05	05	074	43	RCL
034	55	+	075	00	00
035	43	RCL	076	54	)
036	00	00	077	95	=
037	95	=	078	65	*
038	65	*	079	01	1
039	43	RCL	080	00	0
040	01	01	081	00	0
041	95	=	082	95	=
042	22	INV	083	22	INV
043	57	ENG	084	57	ENG
044	91	R/S	085	91	R/S
045	76	LBL	086	76	LBL
046	13	C	087	15	E
047	43	RCL	088	43	RCL
048	05	05	089	04	04
049	55	+	090	55	+
050	43	RCL	091	43	RCL
051	00	00	092	00	00
052	95	=	093	95	=
053	65	*	094	35	1/X
054	43	RCL	095	65	*
055	02	02	096	53	<
056	95	=	097	43	RCL
057	22	INV	098	05	05
058	57	ENG	099	55	+
059	91	R/S	100	43	RCL
060	76	LBL	101	00	00
061	14	D	102	54	)
062	01	1	103	95	=
063	00	0	104	65	*
064	00	0	105	01	1
065	55	+	106	00	0
066	43	RCL	107	00	0
067	03	03	108	95	=
068	95	=	109	22	INV
069	65	*	110	57	ENG
070	53	<	111	91	R/S

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

Multiplies two 3 X 3 complex matrices [A] and [B] together

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}$$

and stores the new complex matrix [C] where complex matrix [A] was located. Complex matrix [B] is left undisturbed.

For computation, this program uses:

Storage Locations 00 through 37

Storage Locations 40 through 51

Also the following labels are used:

A, B, C, A', B', C', D', ln X,

Sin, Cos, tan, and log X.

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Where:

Complex Matrix [A] is stored in storage locations 00 through 17 by entering them directly to the storage locations.

Enter real part of	$a_{11}$	in storage location	00.
Enter imaginary part of	$a_{11}$	in storage location	01.
Enter real part of	$a_{12}$	in storage location	02.
Enter imaginary part of	$a_{12}$	in storage location	03.
Enter real part of	$a_{13}$	in storage location	04.
Enter imaginary part of	$a_{13}$	in storage location	05.
Enter real part of	$a_{21}$	in storage location	06.
Enter imaginary part of	$a_{21}$	in storage location	07.
Enter real part of	$a_{22}$	in storage location	08.
Enter imaginary part of	$a_{22}$	in storage location	09.
Enter real part of	$a_{23}$	in storage location	10.
Enter imaginary part of	$a_{23}$	in storage location	11.
Enter real part of	$a_{31}$	in storage location	12.
Enter imaginary part of	$a_{31}$	in storage location	13.
Enter real part of	$a_{32}$	in storage location	14.
Enter imaginary part of	$a_{32}$	in storage location	15.



TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Enter real part of	$a_{33}$	in storage location	16.
Enter imaginary part of	$a_{33}$	in storage location	17.

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Where:

Complex Matrix [B] is stored in storage locations 20 through 37 by entering them directly to the storage locations.

Enter real part of	$b_{11}$	in storage location 20.
Enter imaginary part of	$b_{11}$	in storage location 21.
Enter real part of	$b_{12}$	in storage location 22.
Enter imaginary part of	$b_{12}$	in storage location 23.
Enter real part of	$b_{13}$	in storage location 24.
Enter imaginary part of	$b_{13}$	in storage location 25.
Enter real part of	$b_{21}$	in storage location 26.
Enter imaginary part of	$b_{21}$	in storage location 27.
Enter real part of	$b_{22}$	in storage location 28.
Enter imaginary part of	$b_{22}$	in storage location 29.
Enter real part of	$b_{23}$	in storage location 30.
Enter imaginary part of	$b_{23}$	in storage location 31.
Enter real part of	$b_{31}$	in storage location 32.
Enter imaginary part of	$b_{31}$	in storage location 33.
Enter real part of	$b_{32}$	in storage location 34.
Enter imaginary part of	$b_{32}$	in storage location 35.

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Enter real part of  $b_{33}$  in storage location 36.

Enter imaginary part of  $b_{33}$  in storage location 37.

and then:

Button E is pressed to calculate  $[A] \times [B] = [C]$ , which takes approximately 3 minutes.

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Where:

Complex Matrix [C] is found stored in storage locations 00 through 17, where the previous Complex Matrix [A] was located. Then:

Pressing RCL 00 displays the real part of  $C_{11}$ .

Pressing RCL 01 displays the imaginary part of  $C_{11}$ .

Pressing RCL 02 displays the real part of  $C_{12}$ .

Pressing RCL 03 displays the imaginary part of  $C_{12}$ .

Pressing RCL 04 displays the real part of  $C_{13}$ .

Pressing RCL 05 displays the imaginary part of  $C_{13}$ .

Pressing RCL 06 displays the real part of  $C_{21}$ .

Pressing RCL 07 displays the imaginary part of  $C_{21}$ .

Pressing RCL 08 displays the real part of  $C_{22}$ .

Pressing RCL 09 displays the imaginary part of  $C_{22}$ .

Pressing RCL 10 displays the real part of  $C_{23}$ .

Pressing RCL 11 displays the imaginary part of  $C_{23}$ .

Pressing RCL 12 displays the real part of  $C_{31}$ .

Pressing RCL 13 displays the imaginary part of  $C_{31}$ .

Pressing RCL 14 displays the real part of  $C_{32}$ .

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

Pressing RCL 15 displays the imaginary part of  $C_{32}$

Pressing RCL 16 displays the real part of  $C_{33}$

Pressing RCL 17 displays the imaginary part of  $C_{33}$

000	76	LBL	035	71	SBR
001	15	E	036	23	LNK
002	43	RCL	037	71	SBR
003	00	00	038	28	LDG
004	32	XIT	039	71	SBR
005	43	RCL	040	39	ODS
006	01	01	041	43	RCL
007	71	SBR	042	18	18
008	11	A	043	42	STD
009	43	RCL	044	02	02
010	02	02	045	43	RCL
011	32	XIT	046	19	19
012	43	RCL	047	42	STD
013	03	03	048	03	03
014	71	SBR	049	71	SBR
015	12	B	050	23	LNK
016	43	RCL	051	71	SBR
017	04	04	052	28	LDG
018	32	XIT	053	71	SBR
019	43	RCL	054	30	TAN
020	05	05	055	43	RCL
021	71	SBR	056	18	18
022	13	C	057	42	STD
023	71	SBR	058	04	04
024	23	LNK	059	43	RCL
025	71	SBR	060	19	19
026	38	SIN	061	42	STD
027	43	RCL	062	05	05
028	18	18	063	43	RCL
029	42	STD	064	06	06
030	00	00	065	32	XIT
031	43	RCL	066	43	RCL
032	19	19	067	07	07
033	42	STD	068	71	SBR
034	01	01	069	11	A

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

070	43	RCL	111	23	LNK
071	08	08	112	71	SBR
072	32	XIT	113	28	LDG
073	43	RCL	114	71	SBR
074	09	09	115	30	TAN
075	71	SBR	116	43	RCL
076	12	B	117	18	18
077	43	RCL	118	42	STD
078	10	10	119	10	10
079	32	XIT	120	43	RCL
080	43	RCL	121	19	19
081	11	11	122	42	STD
082	71	SBR	123	11	11
083	13	C	124	43	RCL
084	71	SBR	125	12	12
085	23	LNK	126	32	XIT
086	71	SBR	127	43	RCL
087	38	SIN	128	13	13
088	43	RCL	129	71	SBR
089	18	18	130	11	A
090	42	STD	131	43	RCL
091	06	06	132	14	14
092	43	RCL	133	32	XIT
093	19	19	134	43	RCL
094	42	STD	135	15	15
095	07	07	136	71	SBR
096	71	SBR	137	12	B
097	23	LNK	138	43	RCL
098	71	SBR	139	16	16
099	28	LDG	140	32	XIT
100	71	SBR	141	43	RCL
101	39	CDS	142	17	17
102	43	RCL	143	71	SBR
103	18	18	144	13	C
104	42	STD	145	71	SBR
105	08	08	146	23	LNK
106	43	RCL	147	71	SBR
107	19	19	148	38	SIN
108	42	STD	149	43	RCL
109	09	09	150	18	18
110	71	SBR	151	42	STD

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

152	12	12			
153	43	RCL			
154	19	19			
155	42	STD			
156	13	13			
157	71	SBR			
158	23	LN $\bar{X}$			
159	71	SBR			
160	28	LDG			
161	71	SBR			
162	39	CDS			
163	43	RCL			
164	18	18			
165	42	STD			
166	14	14			
167	43	RCL			
168	19	19			
169	42	STD			
170	15	15			
171	71	SBR			
172	23	LN $\bar{X}$			
173	71	SBR			
174	28	LDG			
175	71	SBR			
176	30	TAN			
177	43	RCL			
178	18	18			
179	42	STD			
180	16	16			
181	43	RCL			
182	19	19			
183	42	STD			
184	17	17			
185	91	R/S			
186	76	LBL			
187	11	A			
188	22	INV			
189	37	F/R			
190	42	STD			
191	41	41			
192	42	STD			
			193	47	47
			194	32	X/T
			195	42	STD
			196	40	40
			197	42	STD
			198	46	46
			199	92	RTN
			200	76	LBL
			201	12	B
			202	22	INV
			203	37	F/R
			204	42	STD
			205	43	43
			206	42	STD
			207	49	49
			208	32	X/T
			209	42	STD
			210	42	42
			211	42	STD
			212	48	48
			213	92	RTN
			214	76	LBL
			215	13	C
			216	22	INV
			217	37	F/R
			218	42	STD
			219	45	45
			220	42	STD
			221	51	51
			222	32	X/T
			223	42	STD
			224	44	44
			225	42	STD
			226	50	50
			227	92	RTN
			228	76	LBL
			229	16	A*
			230	22	INV
			231	37	F/R
			232	44	SUM
			233	41	41

TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

234	32	X:T	276	43	RCL
235	49	PRD	277	45	45
236	40	40	278	37	F/R
237	43	RCL	279	71	SBR
238	40	40	280	19	D*
239	32	X:T	281	92	RTN
240	43	RCL	282	76	LBL
241	41	41	283	19	D*
242	37	F/R	284	44	SUM
243	71	SBR	285	19	19
244	19	D*	286	32	X:T
245	92	RTN	287	44	SUM
246	76	LBL	288	18	18
247	17	B*	289	92	RTN
248	22	INV	290	76	LBL
249	37	F/R	291	23	LNx
250	44	SUM	292	25	CLR
251	43	43	293	42	STD
252	32	X:T	294	18	18
253	49	PRD	295	42	STD
254	42	42	296	19	19
255	43	RCL	297	92	RTN
256	42	42	298	76	LBL
257	32	X:T	299	38	SIN
258	43	RCL	300	43	RCL
259	43	43	301	20	20
260	37	F/R	302	32	X:T
261	71	SBR	303	43	RCL
262	19	D*	304	21	21
263	92	RTN	305	71	SBR
264	76	LBL	306	16	A*
265	18	C*	307	43	RCL
266	22	INV	308	26	26
267	37	F/R	309	32	X:T
268	44	SUM	310	43	RCL
269	45	45	311	27	27
270	32	X:T	312	71	SBR
271	49	PRD	313	17	B*
272	44	44	314	43	RCL
273	43	RCL	315	32	32
274	44	44	316	32	X:T
275	32	X:T	317	43	RCL



TI-59 PROGRAM LISTING  
MATRIX PROGRAM

(Continued)

318	33	33	358	43	RCL
319	71	SBR	359	31	31
320	18	C*	360	71	SBR
321	92	RTN	361	17	B*
322	76	LBL	362	43	RCL
323	39	CDS	363	36	36
324	43	RCL	364	32	XIT
325	22	22	365	43	RCL
326	32	XIT	366	37	37
327	43	RCL	367	71	SBR
328	23	23	368	18	C*
329	71	SBR	369	76	LBL
330	16	A*	370	28	LDG
331	43	RCL	371	43	RCL
332	28	28	372	47	47
333	32	XIT	373	42	STO
334	43	RCL	374	41	41
335	29	29	375	43	RCL
336	71	SBR	376	46	46
337	17	B*	377	42	STO
338	43	RCL	378	40	40
339	34	34	379	43	RCL
340	32	XIT	380	49	49
341	43	RCL	381	42	STO
342	35	35	382	43	43
343	71	SBR	383	43	RCL
344	18	C*	384	48	48
345	92	RTN	385	42	STO
346	76	LBL	386	42	42
347	30	TAN	387	43	RCL
348	43	RCL	388	51	51
349	24	24	389	42	STO
350	32	XIT	390	45	45
351	43	RCL	391	43	RCL
352	25	25	392	50	50
353	71	SBR	393	42	STO
354	16	A*	394	44	44
355	43	RCL	395	92	RTN
356	30	30			
357	32	XIT			

TI-59 PROGRAM LISTING  
CALCULATES STAR TO DELTA TRANSFORMATION

Where:

Button A' is pressed to enter  $Z_H$

Button B' is pressed to enter  $Z_X$

Button C' is pressed to enter  $Z_Y$

and then:

Button A is pressed to calculate  $Z_{HX}$

Button B is pressed to calculate  $Z_{HY}$

Button C is pressed to calculate  $Z_{HY}$

000	76	LBL	026	43	RCL
001	16	A'	027	01	01
002	42	STD	028	85	+
003	00	00	029	43	RCL
004	91	R/S	030	00	00
005	76	LBL	031	95	=
006	17	B'	032	91	R/S
007	42	STD	033	76	LBL
008	01	01	034	12	B
009	91	R/S	035	43	RCL
010	76	LBL	036	01	01
011	18	C'	037	65	*
012	42	STD	038	43	RCL
013	02	02	039	02	02
014	91	R/S	040	55	+
015	76	LBL	041	43	RCL
016	11	A	042	00	00
017	43	RCL	043	85	+
018	00	00	044	43	RCL
019	65	*	045	02	02
020	43	RCL	046	85	+
021	01	01	047	43	RCL
022	55	+	048	01	01
023	43	RCL	049	95	=
024	02	02	050	91	R/S
025	85	+			

TI-59 PROGRAM LISTING  
CALCULATES STAR TO DELTA TRANSFORMATION

(Continued)

051	76	LBL
052	13	C
053	43	RCL
054	00	00
055	65	*
056	43	RCL
057	02	02
058	55	+
059	43	RCL
060	01	01
061	85	+
062	43	RCL
063	02	02
064	85	+
065	43	RCL
066	00	00
067	95	=
068	91	R/S

TI-59 PROGRAM LISTING  
CALCULATES CAPACITIVE ELEMENT REACTANCE

Where:

Button A' is pressed to enter the frequency  
 Button B' is pressed to enter the 3-phase VARS  
 Button A is pressed to enter the line to line voltage base  
 Button B is pressed to enter the 3-phase voltampere base

then:

Button C is pressed to calculate capacitance single phase  
 Button D is pressed to calculate  $X_{C_{1\text{-phase}}}$  in ohms  
 Button E' is pressed to calculate  $X_{C_{1\text{-phase}}}$  in per unit  
 Button D' is pressed to calculate  $X_{C_{1\text{-phase}}}$  in %  
 Button E is pressed to calculate impedance base

000	76	LBL	015	76	LBL
001	11	A	016	17	B'
002	42	STD	017	42	STD
003	00	00	018	03	03
004	91	R/S	019	91	R/S
005	76	LBL	020	76	LBL
006	16	A'	021	13	C
007	42	STD	022	43	RCL
008	01	01	023	03	03
009	91	R/S	024	55	+
010	76	LBL	025	53	(
011	12	B	026	43	RCL
012	42	STD	027	00	00
013	02	02	028	33	% <sup>2</sup>
014	91	R/S	029	65	*

TI-59 PROGRAM LISTING  
 CALCULATES CAPACITIVE ELEMENT REACTANCE

(Continued)

030	02	2			
031	65	*			
032	89	#			
033	65	*			
034	43	RCL			
035	01	01			
036	54	)			
037	95	=			
038	57	ENG			
039	91	R/S			
040	76	LBL			
041	14	D			
042	43	RCL			
043	00	00			
044	33	X <sup>2</sup>			
045	55	+			
046	43	RCL			
047	03	03			
048	95	=			
049	22	INV			
050	57	ENG			
051	91	R/S			
052	76	LBL			
053	15	E			
054	43	RCL			
055	00	00			
056	33	X <sup>2</sup>			
057	55	+			
058	43	RCL			
059	02	02			
060	95	=			
061	22	INV			
062	57	ENG			
063	91	R/S			
064	76	LBL			
065	10	E*			
066	53	(			
067	43	RCL			
068	00	00			
069	33	X <sup>2</sup>			
070	55	+			
071	43	RCL			
072	03	03			
073	54	)			
074	55	+			
075	53	(			
076	43	RCL			
077	00	00			
078	33	X <sup>2</sup>			
079	55	+			
080	43	RCL			
081	02	02			
082	54	)			
083	95	=			
084	22	INV			
085	57	ENG			
086	91	R/S			
087	76	LBL			
088	19	D*			
089	53	(			
090	43	RCL			
091	00	00			
092	33	X <sup>2</sup>			
093	55	+			
094	43	RCL			
095	03	03			
096	54	)			
097	55	+			
098	53	(			
099	43	RCL			
100	00	00			
101	33	X <sup>2</sup>			
102	55	+			
103	43	RCL			
104	02	02			
105	54	)			
106	95	=			
107	65	*			
108	01	1			
109	00	0			
110	00	0			
111	95	=			
112	22	INV			
113	57	ENG			
114	91	R/S			

TI-59 PROGRAM LISTING  
CALCULATES INDUCTIVE ELEMENT REACTANCE

Where:

Button A' is pressed to enter the frequency  
 Button B' is pressed to enter the 3-phase VARS  
 Button A is pressed to enter the line to line voltage base  
 Button B is pressed to enter the 3-phase voltampere base

then:

Button C is pressed to calculate inductance single phase  
 Button D is pressed to calculate  $X_{L_{1\text{-phase}}}$  in ohms  
 Button E' is pressed to calculate  $X_{L_{1\text{-phase}}}$  in per unit  
 Button D' is pressed to calculate  $X_{L_{1\text{-phase}}}$  in %  
 Button E is pressed to calculate impedance base

000	76	LBL	015	76	LBL
001	11	R	016	17	B'
002	42	STD	017	42	STD
003	00	00	018	03	03
004	91	R/S	019	91	R/S
005	76	LBL	020	76	LBL
006	16	R'	021	13	C
007	42	STD	022	43	RCL
008	01	01	023	00	00
009	91	R/S	024	33	%
010	76	LBL	025	55	+
011	12	B	026	53	(
012	42	STD	027	02	2
013	02	02	028	65	x
014	91	R/S	029	89	π

TI-59 PROGRAM LISTING  
 CALCULATES INDUCTIVE ELEMENT REACTANCE

(Continued)

030	65	*			
031	43	RCL			
032	01	01			
033	65	*			
034	43	RCL			
035	03	03			
036	54	)			
037	95	=			
038	57	ENG			
039	91	R/S			
040	76	LBL			
041	14	D			
042	43	RCL			
043	00	00			
044	33	X <sup>2</sup>			
045	55	+			
046	43	RCL			
047	03	03			
048	95	=			
049	22	INV			
050	57	ENG			
051	91	R/S			
052	76	LBL			
053	15	E			
054	43	RCL			
055	00	00			
056	33	X <sup>2</sup>			
057	55	+			
058	43	RCL			
059	02	02			
060	95	=			
061	22	INV			
062	57	ENG			
063	91	R/S			
064	76	LBL			
065	10	E <sup>*</sup>			
066	53	(			
067	43	RCL			
068	00	00			
069	33	X <sup>2</sup>			
070	55	+			
071	43	RCL			
072	03	03			
073	54	)			
074	55	+			
075	53	(			
076	43	RCL			
077	00	00			
078	33	X <sup>2</sup>			
079	55	+			
080	43	RCL			
081	02	02			
082	54	)			
083	95	=			
084	22	INV			
085	57	ENG			
086	91	R/S			
087	76	LBL			
088	19	D <sup>*</sup>			
089	53	(			
090	43	RCL			
091	00	00			
092	33	X <sup>2</sup>			
093	55	+			
094	43	RCL			
095	03	03			
096	54	)			
097	55	+			
098	53	(			
099	43	RCL			
100	00	00			
101	33	X <sup>2</sup>			
102	55	+			
103	43	RCL			
104	02	02			
105	54	)			
106	95	=			
107	65	*			
108	01	1			
109	00	0			
110	00	0			
111	95	=			
112	22	INV			
113	57	ENG			
114	91	R/S			

TI-59 PROGRAM LISTING  
 CALCULATES PER UNIT VOLTAGE OR CURRENT PROGRAM INPUT VALUES  
 FROM HARMONIC MEASUREMENTS GIVEN IN DECIBELS

Where:

Button A is pressed to enter decibel value

Button B is pressed to enter per unit  $V_2$

and then:

Button E is pressed to obtain per unit value

Formula used is:

$$V_1 \text{ pu} = (V_2) \times \left[ \text{antilog} \left( \frac{\text{db}}{20} \right) \right] \text{ pu}$$

where:

$$V_2 = \frac{\text{Actual Voltage}}{\text{Base Voltage}}$$

or

$$V_2 = \frac{\text{Actual Current}}{\text{Base Current}}$$

```
000 76 LBL
001 11 R
002 42 STD
003 00 00
004 99 PRT
005 91 R/S
006 76 LBL
007 12 B
008 42 STD
009 01 01
010 99 PRT
011 91 R/S
012 76 LBL
013 15 E
014 43 RCL
015 00 00
```

```
016 55 +
017 02 2
018 00 0
019 95 =
020 22 INV
021 28 LOG
022 95 =
023 65 *
024 43 RCL
025 01 01
026 95 =
027 99 PRT
028 98 ADV
029 98 ADV
030 91 R/S
```



TI-59 PROGRAM LISTING  
CALCULATES HARMONIC DISTORTION FACTORS  
UP TO THE 35th ORDER HARMONIC

Where:

Each harmonic is stored in its respective storage location.

Enter harmonic of order 1 and press STO 01.  
Enter harmonic of order 2 and press STO 02.  
Enter harmonic of order 3 and press STO 03.  
Enter harmonic of order 4 and press STO 04.  
Enter harmonic of order 5 and press STO 05.  
Enter harmonic of order 6 and press STO 06.  
Enter harmonic of order 7 and press STO 07.  
Enter harmonic of order 8 and press STO 08.  
Enter harmonic of order 9 and press STO 09.  
Enter harmonic of order 10 and press STO 10.  
Enter harmonic of order 11 and press STO 11.  
Enter harmonic of order 12 and press STO 12.  
Enter harmonic of order 13 and press STO 13.  
Enter harmonic of order 14 and press STO 14.  
Enter harmonic of order 15 and press STO 15.  
Enter harmonic of order 16 and press STO 16.  
Enter harmonic of order 17 and press STO 17.  
Enter harmonic of order 18 and press STO 18.  
Enter harmonic of order 19 and press STO 19.  
Enter harmonic of order 20 and press STO 20.  
Enter harmonic of order 21 and press STO 21.  
Enter harmonic of order 22 and press STO 22.

TI-59 PROGRAM LISTING  
 CALCULATES HARMONIC DISTORTION FACTORS  
 UP TO THE 35th ORDER HARMONIC

(Continued)

Enter harmonic of order 23 and press STO 23.  
 Enter harmonic of order 24 and press STO 24.  
 Enter harmonic of order 25 and press STO 25.  
 Enter harmonic of order 26 and press STO 26.  
 Enter harmonic of order 27 and press STO 27.  
 Enter harmonic of order 28 and press STO 28.  
 Enter harmonic of order 29 and press STO 29.  
 Enter harmonic of order 30 and press STO 30.  
 Enter harmonic of order 31 and press STO 31.  
 Enter harmonic of order 32 and press STO 32.  
 Enter harmonic of order 33 and press STO 33.  
 Enter harmonic of order 34 and press STO 34.  
 Enter harmonic of order 35 and press STO 35.

```

000 76 LBL
001 15 E
002 43 RCL
003 02 02
004 33 X²
005 55 ÷
006 43 RCL
007 01 01
008 33 X²
009 85 +
010 43 RCL
011 03 03
012 33 X²

```

```

013 55 ÷
014 43 RCL
015 01 01
016 33 X²
017 85 +
018 43 RCL
019 04 04
020 33 X²
021 55 ÷
022 43 RCL
023 01 01
024 33 X²
025 85 +

```

TI-59 PROGRAM LISTING  
 CALCULATES HARMONIC DISTORTION FACTORS  
 UP TO THE 35th ORDER HARMONIC

(Continued)

026	43	RCL	065	85	+
027	05	05	066	43	RCL
028	33	X <sup>2</sup>	067	10	10
029	55	+	068	33	X <sup>2</sup>
030	43	RCL	069	55	+
031	01	01	070	43	RCL
032	33	X <sup>2</sup>	071	01	01
033	85	+	072	33	X <sup>2</sup>
034	43	RCL	073	85	+
035	06	06	074	43	RCL
036	33	X <sup>2</sup>	075	11	11
037	55	+	076	33	X <sup>2</sup>
038	43	RCL	077	55	+
039	01	01	078	43	RCL
040	33	X <sup>2</sup>	079	01	01
041	85	+	080	33	X <sup>2</sup>
042	43	RCL	081	85	+
043	07	07	082	43	RCL
044	33	X <sup>2</sup>	083	12	12
045	55	+	084	33	X <sup>2</sup>
046	43	RCL	085	55	+
047	01	01	086	43	RCL
048	33	X <sup>2</sup>	087	01	01
049	85	+	088	33	X <sup>2</sup>
050	43	RCL	089	85	+
051	08	08	090	43	RCL
052	33	X <sup>2</sup>	091	13	13
053	55	+	092	33	X <sup>2</sup>
054	43	RCL	093	55	+
055	01	01	094	43	RCL
056	33	X <sup>2</sup>	095	01	01
057	85	+	096	33	X <sup>2</sup>
058	43	RCL	097	85	+
059	09	09	098	43	RCL
060	33	X <sup>2</sup>	099	14	14
061	55	+	100	33	X <sup>2</sup>
062	43	RCL	101	55	+
063	01	01	102	43	RCL
064	33	X <sup>2</sup>	103	01	01

TI-59 PROGRAM LISTING  
 CALCULATES HARMONIC DISTORTION FACTORS  
 UP TO THE 35th ORDER HARMONIC

(Continued)

104	33	X <sup>2</sup>		
105	85	+		
106	43	RCL		
107	15	15		
108	33	X <sup>2</sup>		
109	55	+		
110	43	RCL		
111	01	01		
112	33	X <sup>2</sup>		
113	85	+		
114	43	RCL		
115	16	16		
116	33	X <sup>2</sup>		
117	55	+		
118	43	RCL		
119	01	01		
120	33	X <sup>2</sup>		
121	85	+		
122	43	RCL		
123	17	17		
124	33	X <sup>2</sup>		
125	55	+		
126	43	RCL		
127	01	01		
128	33	X <sup>2</sup>		
129	85	+		
130	43	RCL		
131	18	18		
132	33	X <sup>2</sup>		
133	55	+		
134	43	RCL		
135	01	01		
136	33	X <sup>2</sup>		
137	85	+		
138	43	RCL		
139	19	19		
140	33	X <sup>2</sup>		
141	55	+		
142	43	RCL		
143	01	01		
144	33	X <sup>2</sup>		
145	85	+		
146	43	RCL		
147	20	20		
148	33	X <sup>2</sup>		
149	55	+		
150	43	RCL		
151	01	01		
152	33	X <sup>2</sup>		
153	85	+		
154	43	RCL		
155	21	21		
156	33	X <sup>2</sup>		
157	55	+		
158	43	RCL		
159	01	01		
160	33	X <sup>2</sup>		
161	85	+		
162	43	RCL		
163	22	22		
164	33	X <sup>2</sup>		
165	55	+		
166	43	RCL		
167	01	01		
168	33	X <sup>2</sup>		
169	85	+		
170	43	RCL		
171	23	23		
172	33	X <sup>2</sup>		
173	55	+		
174	43	RCL		
175	01	01		
176	33	X <sup>2</sup>		
177	85	+		
178	43	RCL		
179	24	24		
180	33	X <sup>2</sup>		
181	55	+		

TI-59 PROGRAM LISTING  
 CALCULATES HARMONIC DISTORTION FACTORS  
 UP TO THE 35th ORDER HARMONIC

(Continued)

182	43	RCL				222	43	RCL
183	01	01				223	01	01
184	33	X <sup>2</sup>				224	33	X <sup>2</sup>
185	85	+				225	85	+
186	43	RCL				226	43	RCL
187	25	25				227	30	30
188	33	X <sup>2</sup>				228	33	X <sup>2</sup>
189	55	+				229	55	+
190	43	RCL				230	43	RCL
191	01	01				231	01	01
192	33	X <sup>2</sup>				232	33	X <sup>2</sup>
193	85	+				233	85	+
194	43	RCL				234	43	RCL
195	26	26				235	31	31
196	33	X <sup>2</sup>				236	33	X <sup>2</sup>
197	55	+				237	55	+
198	43	RCL				238	43	RCL
199	01	01				239	01	01
200	33	X <sup>2</sup>				240	33	X <sup>2</sup>
201	85	+				241	85	+
202	43	RCL				242	43	RCL
203	27	27				243	32	32
204	33	X <sup>2</sup>				244	33	X <sup>2</sup>
205	55	+				245	55	+
206	43	RCL				246	43	RCL
207	01	01				247	01	01
208	33	X <sup>2</sup>				248	33	X <sup>2</sup>
209	85	+				249	85	+
210	43	RCL				250	43	RCL
211	28	28				251	33	33
212	33	X <sup>2</sup>				252	33	X <sup>2</sup>
213	55	+				253	55	+
214	43	RCL				254	43	RCL
215	01	01				255	01	01
216	33	X <sup>2</sup>				256	33	X <sup>2</sup>
217	85	+				257	85	+
218	43	RCL				258	43	RCL
219	29	29				259	34	34
220	33	X <sup>2</sup>				260	33	X <sup>2</sup>
221	55	+				261	55	+

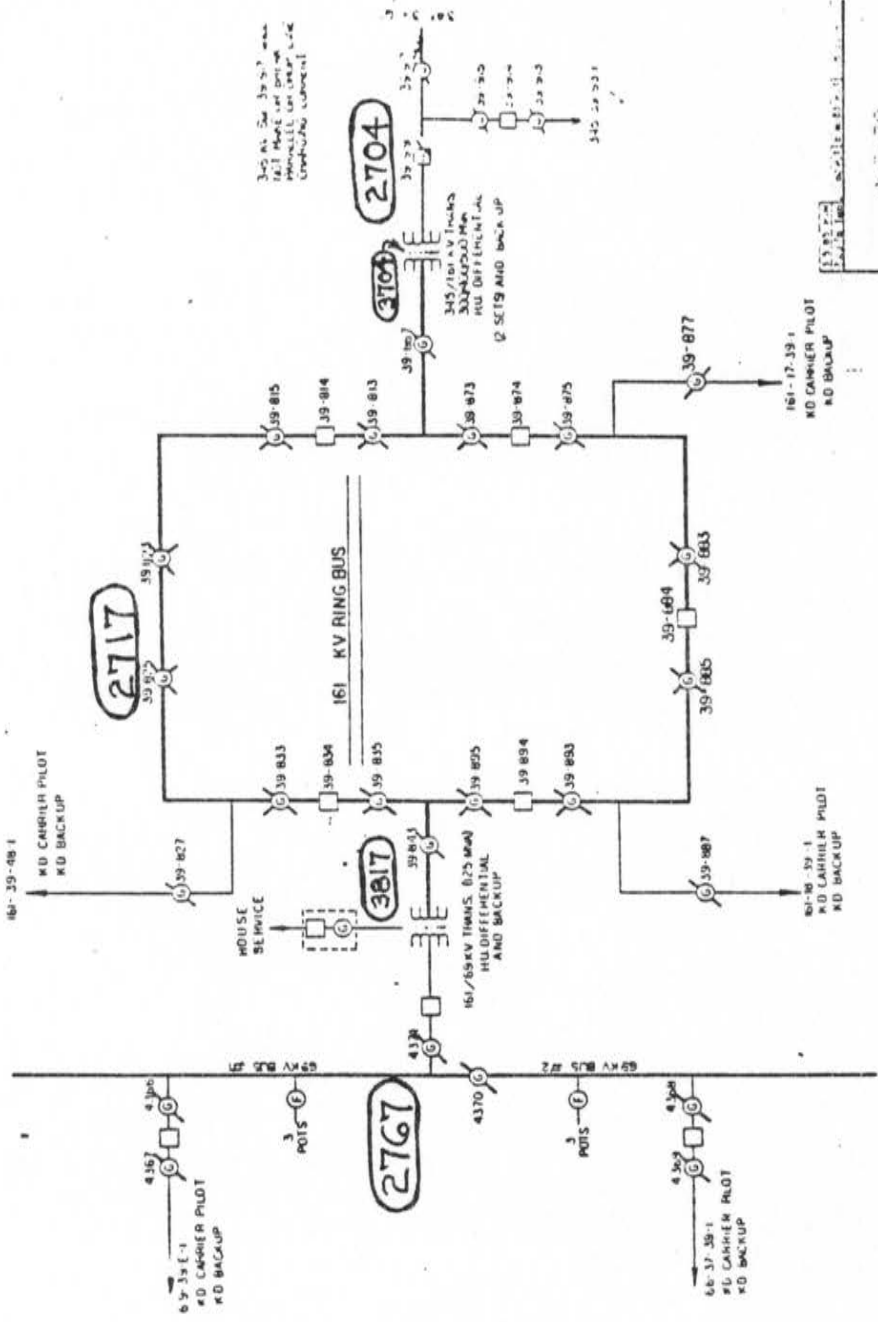
TI-59 PROGRAM LISTING  
CALCULATES HARMONIC DISTORTION FACTORS  
UP TO THE 35th ORDER HARMONIC

(Continued)

```
262 43 RCL
263 01 01
264 33 X²
265 85 +
266 43 RCL
267 35 35
268 33 X²
269 55 +
270 43 RCL
271 01 01
272 33 X²
273 95 =
274 34 IX
275 91 R/S
```

XIII. APPENDIX

F. THREE-WINDING TRANSFORMER EXAMPLE



345 AT 39 39-1  
 345-10-11 BACKS  
 345-10-11 MVA  
 NO DIFFERENTIAL  
 2 SETS AND BACK UP  
 345-10-11

345-10-11  
 345-10-11  
 345-10-11

**SUB 39**  
 345-10-11  
 SINGLE LINE DIAGRAM  
 161 KV RING BUS  
 6-24-76





REPORT OF TRANSFORMER TESTS  
FORM 4000



Westinghouse Electric Corporation

SHARE TRANSFORMER  
37

Test No. 1-20-66 Purchaser's Order No. 63759 No. DP-18400 S.O. No. NSR086  
 Type OA/100A/10A AUTO Phase 3 Cycles 60 Insulating Fluid Oil L. Spec. NSR086-06 Pressure Sec. I.P.  
 Winding H Winding X Winding Y  
 Kva 300000/400000/500000 Kva 300000/400000/500000 Kva 64500/86000/107500  
 Voltage 345000 Grd. Y Voltage 161000 Grd. Y Voltage 13200  
 For polarity, additional tap voltages and connections, see Instruction Plate NSR086-10.

RESISTANCES, EXCITING CURRENT, LOSSES AND IMPEDANCE—Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the resistances are the sum of the three phases in series.

SERIAL NO.	RESISTANCE IN OHMS AT 75°C			% EXCITE CURRENT AT 100% RATED VOLTAGE	NO. LOAD LOSS WATTS AT 100% RATED VOLTAGE	345 Kv		161 Kv		13.2 Kv	
	WINDINGS					TO	TO	TO	TO	TO	TO
	H	X	Y			300000 Kva	64500 Kva	64500 Kva	64500 Kva		
7001054	.5676	.4443	.0251	.78	25794.0	369423	5.94	123495	11.42	135845	9.93
AVERAGE				.78	25794.0	627363	5.94	381435	11.42	393785	9.93
GUARANTEE				.77	28600.0	641000	6.0	—	10.7-12.9	—	8.6-10.75

TEMPERATURE RISE—Average rise in degrees C., corrected to instant of shutdown, of transformer.  
 Serial No. 7001054 with windings connected and loaded as follows:  
 H Winding 362.25 Kv 478 Amps X Winding 161 Kv 845 Amps  
 Y Winding 13.2 Kv 282 Amps  
 Amp. until constant temperature rise was reached.

Load	RISE OF WINDINGS BY RESISTANCE				TOP FLUID RISE	AMBIENT TEMP.			WATER	
	H	X	Y	GUARANTEE		INDUING WATER	DIFF. 64 ROOM	RISE	GALLONS PER MIN.	POUNDS PRESSURE
100%	44.0	47.5	48.0	65	58.0		25.0			
133-1/3%	54.7	49.9	64.7	65	42.7		27.0			
166-2/3%	53.1	48.2	64.6	65	38.4		25.8			

APPLIED POTENTIAL TESTS (Voltage applied between each winding and all other windings connected to core and ground.)	WINDING		VOLT RATING	TEST VOLTAGE APPLIED IN Kv	DURATION OF TEST IN SECONDS
	H	X	Y	345000 161000 13200	50 50 34
Wiring, Pans	6. Rungs			1.5	60

INDUCED POTENTIAL \* TEST — times rated voltage across full winding, 460 Kv from 327.75 Kv  
 Line terminal to ground at 180 cycles per second for 7200 cycles

REMARKS  
 \* Also induced 575 KV line to line (3 Phase Test)  
 See separate report for results of ASA Impulse Tests and Switching Surge Tests.

I hereby certify that this is a true report based on factory tests made in accordance with the latest Transformer Test Code C57 of the American Standards Association, and that each transformer withstood the above insulation tests.

Signed *Allyson* Date February 2, 1968 Approved *Glenn*  
 Page 1 of 3 Pages

REPORT OF TESTS  
FORM 3513-1

Westinghouse

DATE February 2, 1968

ORDER NO. \_\_\_\_\_ WESTINGHOUSE GENERAL ORDER NO. DP-18400

APPARATUS Class OA/FOA/FOA Shell, Form Autotransformer SHOP ORDER NO. MR086

RATING 300000/400000/500000 KVA - 345000 Grd. Y/161000 Grd. Y/13200 Volts, 3 Phase, 60 Cycles

Exciting Current and No Load Loss Measurements

% Rated Voltage	% Exciting Current		No Load Loss, Watts	
	Measured	Guaranteed	Measured	Guaranteed
110%	2.2	2.0	415526	428000
115%	3.5	3.2	482000	500000

Additional Impedance and Load Loss Measurements at 75°C

Voltage Connection	N1/C		% Impedance	Load Loss, Watts
	Pos.	KVA		
362250 - 161000	1	300000	6.08	393159
353625 - 161000	2	300000	5.96	384668
336375 - 161000	4	300000	5.93	371899
327750 - 161000	5	300000	6.04	384803
362250 - 13200	1	64500	11.84	127355
353625 - 13200	2	64500	11.59	123335
336375 - 13200	4	64500	11.23	123856
327750 - 13200	5	64500	11.04	124239

Zero Sequence Impedance Measurements

Voltage Connection	N1/C Pos.	KVA	% Impedance
362250 - 161000	1	300000	6.07
353625 - 161000	2	300000	5.88
345000 - 161000	3	300000	5.90
336375 - 161000	4	300000	5.82
327750 - 161000	5	300000	5.96
362250 - 13200	1	64500	11.59
353625 - 13200	2	64500	11.24
345000 - 13200	3	64500	11.37
336375 - 13200	4	64500	11.24
327750 - 13200	5	64500	10.99
161000 - 13200	-	64500	9.56

Pump and Fan Losses

230 Volts, 3 Phase, 60 Cycles

	T.W.	A.W.
Measured	30160	43150
Guaranteed	63500	-----

Additional Losses

	345/161 KV @ 500 MVA	345/13.2 KV @ 107.5 MVA
Load Loss (Watts)	1026175	343042
No Load Loss (Watts)	257940	257940
Total	1284115	600982
Guaranteed	1273000	610000

THE ABOVE IS A TRUE AND CORRECT RECORD OF DATA OBTAINED FROM TESTS AT THE MURCIE PLANT OF WESTINGHOUSE ELECTRIC CORPORATION.  
PAGE 2 OF 3 PAGES. SIGNED Attagiro

REPORT OF TESTS  
FORM 4422

# Westinghouse

DATE February 2, 1968

APPLICATOR \_\_\_\_\_ WESTINGHOUSE GENERAL ORDER NO. DP-18400  
 APPARATUS Class ON/FOA/FOA Shell Form Autotransformer SHOP ORDER NO. MGRO86  
 RATING 300000/400000/500000 KVA - 345000 Grd. Y/161000 Grd. Y/13200 Volts, 3 Phase, 60 Cycle

**Efficiencies at 300000 KVA**  
(Power for cooling not included)

Load	Full	3/4	1/2	1/4
Measured	99.79	99.79	99.77	99.62
Guaranteed	99.78	99.78	99.75	99.59

**Ratio Test**

H.V.-NLTC Volt. Pos.	100 Volts Applied On High Voltage Measured On Low Voltage		
	Ph. A	Ph. B	Ph. C
1	44.56	44.56	44.56
2	45.54	45.54	45.54
3	46.67	46.67	46.67
4	47.86	47.86	47.86
5	49.11	49.11	49.11
	250 Volts Applied On High Voltage Measured On Tertiary Voltage		
5	17.36	17.36	17.36

**Corona Tests**

% Induced Test	Microvolts		
	H1	H2	H3
50	35	12.2	1.6
70	125	204	188
100	300	306	242
100	300	102	161
70	125	81.6	97
50	90	25.5	97
0	0	0	0
50	70	127	2.7
70	85	178	2.7

THE ABOVE IS A TRUE AND CORRECT RECORD OF DATA OBTAINED FROM TESTS AT THE MURKIE PLANT OF  
 WESTINGHOUSE ELECTRIC CORPORATION.  
 PAGE 3 OF 3 PAGES SIGNED Atkinson ENCL.

$$\begin{array}{c}
 [A] \\
 \left[ \begin{array}{ccc}
 .5 & .5 & -.5 \\
 .5 & -.5 & .5 \\
 -.5 & .5 & .5
 \end{array} \right]
 \end{array}
 \times
 \begin{array}{c}
 [B] \\
 \left[ \begin{array}{c}
 Z_{HX(H)} \\
 Z_{HY(H)} \\
 Z_{XY(H)}
 \end{array} \right]
 \end{array}
 =
 \begin{array}{c}
 [C] \\
 \left[ \begin{array}{c}
 Z_{H_{1,2}} \\
 Z_{X_{1,2}} \\
 Z_{Y_{1,2}}
 \end{array} \right]
 \end{array}$$

USING MATRIX PROGRAM -- which multiplies two 3 X 3 complex matrices together

PRESS 2nd CMS TO CLEAR ALL MEMORY STORAGE LOCATIONS .

ENTER MATRIX [A] (see Anderson (4), Page 246 for this example) by the following steps:

```

ENTER .5 and PRESS STO 00
ENTER .5 and PRESS STO 02
ENTER -.5 and PRESS STO 04
ENTER .5 and PRESS STO 06
ENTER -.5 and PRESS STO 08
ENTER .5 and PRESS STO 10
ENTER -.5 and PRESS STO 12
ENTER .5 and PRESS STO 14
ENTER .5 AND PRESS STO 16

```

ENTER MATRIX [B] by the following steps:

```

ENTER ZHX(H) VALUE and PRESS STO 20
ENTER ZHY(H) VALUE and PRESS STO 26
ENTER ZXY(H) VALUE and PRESS STO 32

```

PRESS BUTTON E TO EXECUTE.

AFTER PROGRAM EXECUTION CEASES (Approximately 3 minutes):

PRESS RCL 00 to Find  $Z_{H_{1,2}}$  VALUE

PRESS RCL 06 to Find  $Z_{X_{1,2}}$  VALUE

PRESS RCL 12 to Find  $Z_{Y_{1,2}}$  VALUE

SUB 39  
345/161/13.8 KV XFMR

FROM THE TRANSFORMER TEST REPORT

345 KV to 161 KV

$$Z_{HX(H)_{1,2}} = 5.9400\% @ 300 \text{ MVA}$$

345 KV to 13.8 KV

$$Z_{HY(X)_{1,2}} = 11.4200\% @ 64.5 \text{ MVA}$$

161 KV to 13.8 KV

$$Z_{XY(Y)_{1,2}} = 9.9300\% @ 64.5 \text{ MVA}$$

TRANSFERRING EVERYTHING TO THE H-WINDING VOLTAMPERE  
BASE YIELDS:

$$Z_{HX(H)_{1,2}} = 1.9800\% @ 100 \text{ MVA}$$

$$Z_{HY(H)_{1,2}} = 17.7054\% @ 100 \text{ MVA}$$

$$Z_{XY(H)_{1,2}} = 15.3953\% @ 100 \text{ MVA}$$

CHANGING TO PER UNIT EQUIVALENT CIRCUIT VALUES

$$Z_{H_{1,2}} = 2.1451\% @ 100 \text{ MVA}$$

$$Z_{X_{1,2}} = -.1651\% @ 100 \text{ MVA}$$

$$Z_{Y_{1,2}} = 15.5604\% @ 100 \text{ MVA}$$

PERFORMING STAR TO DELTA CONVERSION

$$Z_{HX} = 1.9572\% @ 100 \text{ MVA}$$

$$Z_{XY} = 14.1977\% @ 100 \text{ MVA}$$

$$Z_{HY} = -184.4666\% @ 100 \text{ MVA}$$

SUB 39  
345/161/13.8 KV XFMR

FROM THE TRANSFORMER TEST REPORT

345 KV to 161 KV

$$Z_{HX(H)}_0 = 5.9000\% @ 300 \text{ MVA}$$

345 KV to 13.8 KV

$$Z_{HY(Y)}_0 = 11.3700\% @ 64.5 \text{ MVA}$$

161 KV to 13.8 KV

$$Z_{XY(X)}_0 = 9.5600\% @ 64.5 \text{ MVA}$$

TRANSFERRING EVERYTHING TO THE H- WINDING VOLTAMPERE  
BASE YIELDS:

$$Z_{HX(H)}_0 = 1.9667\% @ 100 \text{ MVA}$$

$$Z_{HY(H)}_0 = 17.6279\% @ 100 \text{ MVA}$$

$$Z_{XY(H)}_0 = 14.8217\% @ 100 \text{ MVA}$$

CHANGING TO PER UNIT EQUIVALENT CIRCUIT VALUES

$$Z_{H_0} = 2.3865\% @ 100 \text{ MVA}$$

$$Z_{X_0} = -.4198\% @ 100 \text{ MVA}$$

$$Z_{Y_0} = 15.2415\% @ 100 \text{ MVA}$$

PERFORMING STAR TO DELTA CONVERSION

$$Z_{HX} = 1.9010\% @ 100 \text{ MVA}$$

$$Z_{xy} = 12.1406\% @ 100 \text{ MVA}$$

$$Z_{HY} = -69.0176\% @ 100 \text{ MVA}$$

SUB 39 345/161/13.8 KV XFRM  
USING 3 INDIVIDUAL TRANSFORMER REPRESENTATION

Given: SHELL FORM XFMR  
2 WDG XFMR  
300 MVA

345 KV GRD WYE to 161 KV GRD WYE

Impedance =

$Z_0$  =

$I_{\text{Magnetizing Current @ 100\% Voltage}} = .78\% @ 300 \text{ MVA}$

No Load Losses @ 100% Voltage = 257940 Watts @ 300 MVA

From Bus 2704

To Bus 2717

RR1 =	1.9572	% @ 100 MVA
XX1 =	1.9010	% @ 100 MVA
XC1 =	4273.5043	% @ 100 MVA
RR0 =	38768.7059	% @ 100 MVA
KK =	0	
XX0 =	.7	
XC0 =	4273.5043	% @ 100 MVA



SUB 39 345/161/13.8 KV XFRM  
USING 3 INDIVIDUAL TRANSFORMER REPRESENTATION

Given: SHELL FORM XFMR  
2 WDG XFMR  
64.5 MVA

345 GRD WYE to 13.8 KV DELTA

Impedance =

$Z_0$  =

$I$  Magnetizing Current @ 100% Voltage =  $1 \times 10^{-95} \%$   
@ 64.5 MVA

No Load Losses @ 100% Voltage =  $1 \times 10^{-89}$  Watts  
@ 64.5 MVA

From Bus 2704

To Bus 3704

RR1 = -184.4666 % @ 100 MVA

XX1 = - 69.0176 % @ 100 MVA

XC1 =  $1.5504 \times 10^{99} \%$  @ 100 MVA

RR0 =  $1.0000 \times 10^{99} \%$  @ 100 MVA

KK = 0

XX0 = .8

XC0 =  $1.5504 \times 10^{99} \%$  @ 100 MVA

SUB 39 345/161/13.8 KV XFMR  
USING 3 INDIVIDUAL TRANSFORMER REPRESENTATION

Given: SHELL FORM XFMR  
2 WDG XFMR  
64.5 MVA

161 KV GRD WYE to 13.8 KV DELTA

Impedance =

$Z_0$  =

$I_{\text{Magnetizing Current @ 100\% Voltage}} = 1 \times 10^{-95} \%$   
@ 64.5 MVA

No Load Losses @ 100% Voltage =  $1 \times 10^{-89}$  Watts  
@ 64.5 MVA

From Bus 2717

To Bus 3704

RR1 = 14.1977 % @ 100 MVA

XX1 = 12.1406 % @ 100 MVA

XC1 =  $1.5504 \times 10^{99}$  % @ 100 MVA

RR0 =  $1.0000 \times 10^{99}$  % @ 100 MVA

KK = 0


XX0 = .8

XC0 =  $1.5504 \times 10^{99}$  % @ 100 MVA


XIV. APPENDIX

G. THREE-TWO PHASE TRANSFORMER EXAMPLE





# Westinghouse



**6000 KV-A**  
13200 TO 4800 VOLTS  
60 CYCLES

IMPEDANCE  %  
AT ABOVE RATING

L. SPEC. 338696

**THREE-TWO PHASE  
TRANSFORMER**

OIL INSULATED  
SELF COOLED

FULL LOAD CONTINUOUSLY  
55°C. RISE

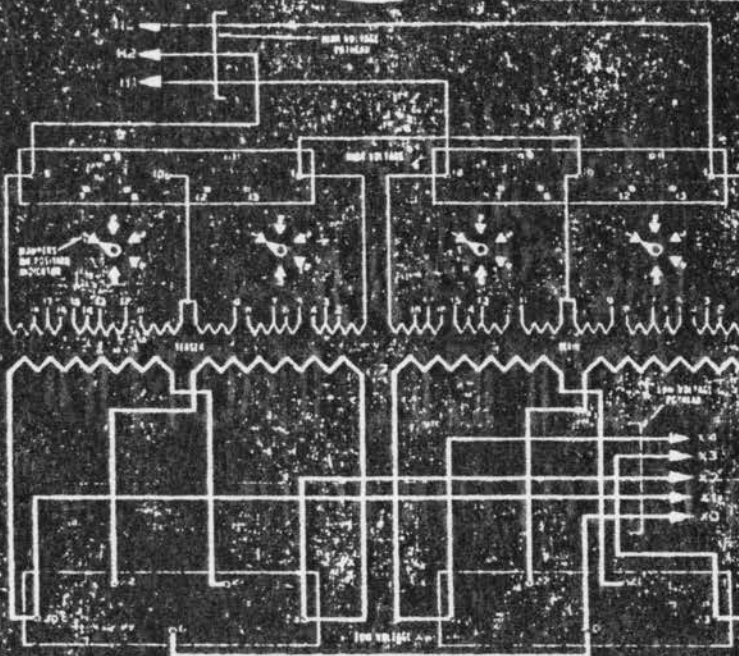
GALLONS OIL

SERIAL

MAIN UNIT

SERIAL

TEASER UNIT




PLAN VIEW

WINDING	VOLTS	AMPERES	TAP CHANGERS					FUNCTION			LEADS ON
			POSITION	CONNECTS	MAIN UNIT	TEASER UNIT	INTERPHASE				
HIGH VOLTAGE SCOTT CONNECTED THREE PHASE	13200	250	1	4 10 6, 13 19 15							
	13200	250	2	3 10 5, 14 10 17	8 10 8	7 10 9	30 ON MAIN UNIT 30 1 ON TEASER UNIT		SEE PLAN VIEW		
	12000	265	3	3 10 6, 14 10 17	11 10 12	11 10 13					
	12000	265	4	7 10 6, 14 10 18							
LOW VOLTAGE TWO PHASE	4800	625			21 10 0	21 10 0			SEE PLAN VIEW		
	4800	625			10 22	10 22					
	2400	1250			20 10 27	20 10 27					
					21 10 23	21 10 23					

AMPERE RATING GIVEN IS MAXIMUM CURRENT IN OUTLET LEADS FOR CONTINUOUS OPERATION WITHOUT AIR BLAST.  
 THIS TRANSFORMER IS DESIGNED SO THAT AIR BLAST COOLING EQUIPMENT MAY BE ADDED LATER WITH THE EQUIPMENT THE RATING  
 MAY BE INCREASED TO 8000 KV-A. AT NORMAL VOLTAGE AND FREQUENCY WITH A TEMPERATURE RISE NOT EXCEEDING 55°C.  
 CONNECTIONS FOR HIGH VOLTAGE TAPS ARE MADE BY TAP CHANGERS OPERATED OUTSIDE THE CASE.  
 TRANSFORMER MUST BE DISCONNECTED FROM LINES WHEN THESE DEVICES ARE OPERATED.  
 ALL HIGH VOLTAGE TAP CHANGERS MUST BE ON THE SAME POSITION.  
 DATE OF MANUFACTURE:   
 FULL TRANSFORMER AND TERMINAL CHANNELS WITH "MILMED C" OIL UNTIL GAGES INDICATE 55°C. LEVEL.  
 NEVER OPERATE TRANSFORMER WHEN ANY GAGE IS BELOW BOTTOM OF SCALE.

POLARITY:



APPROX WEIGHT IN LBS TRANSFORMER  CASE  COIL  TOTAL

PATENTS 1274551-1274552-1274553-1274554-1274555-1274556-1274557-1274558-1274559-1274560-1274561-1274562-1274563-1274564-1274565-1274566-1274567-1274568-1274569-1274570-1274571-1274572-1274573-1274574-1274575-1274576-1274577-1274578-1274579-1274580-1274581-1274582-1274583-1274584-1274585-1274586-1274587-1274588-1274589-1274590-1274591-1274592-1274593-1274594-1274595-1274596-1274597-1274598-1274599-1274600-1274601-1274602-1274603-1274604-1274605-1274606-1274607-1274608-1274609-1274610-1274611-1274612-1274613-1274614-1274615-1274616-1274617-1274618-1274619-1274620-1274621-1274622-1274623-1274624-1274625-1274626-1274627-1274628-1274629-1274630-1274631-1274632-1274633-1274634-1274635-1274636-1274637-1274638-1274639-1274640-1274641-1274642-1274643-1274644-1274645-1274646-1274647-1274648-1274649-1274650-1274651-1274652-1274653-1274654-1274655-1274656-1274657-1274658-1274659-1274660-1274661-1274662-1274663-1274664-1274665-1274666-1274667-1274668-1274669-1274670-1274671-1274672-1274673-1274674-1274675-1274676-1274677-1274678-1274679-1274680-1274681-1274682-1274683-1274684-1274685-1274686-1274687-1274688-1274689-1274690-1274691-1274692-1274693-1274694-1274695-1274696-1274697-1274698-1274699-1274700-1274701-1274702-1274703-1274704-1274705-1274706-1274707-1274708-1274709-1274710-1274711-1274712-1274713-1274714-1274715-1274716-1274717-1274718-1274719-1274720-1274721-1274722-1274723-1274724-1274725-1274726-1274727-1274728-1274729-1274730-1274731-1274732-1274733-1274734-1274735-1274736-1274737-1274738-1274739-1274740-1274741-1274742-1274743-1274744-1274745-1274746-1274747-1274748-1274749-1274750-1274751-1274752-1274753-1274754-1274755-1274756-1274757-1274758-1274759-1274760-1274761-1274762-1274763-1274764-1274765-1274766-1274767-1274768-1274769-1274770-1274771-1274772-1274773-1274774-1274775-1274776-1274777-1274778-1274779-1274780-1274781-1274782-1274783-1274784-1274785-1274786-1274787-1274788-1274789-1274790-1274791-1274792-1274793-1274794-1274795-1274796-1274797-1274798-1274799-1274800-1274801-1274802-1274803-1274804-1274805-1274806-1274807-1274808-1274809-1274810-1274811-1274812-1274813-1274814-1274815-1274816-1274817-1274818-1274819-1274820-1274821-1274822-1274823-1274824-1274825-1274826-1274827-1274828-1274829-1274830-1274831-1274832-1274833-1274834-1274835-1274836-1274837-1274838-1274839-1274840-1274841-1274842-1274843-1274844-1274845-1274846-1274847-1274848-1274849-1274850-1274851-1274852-1274853-1274854-1274855-1274856-1274857-1274858-1274859-1274860-1274861-1274862-1274863-1274864-1274865-1274866-1274867-1274868-1274869-1274870-1274871-1274872-1274873-1274874-1274875-1274876-1274877-1274878-1274879-1274880-1274881-1274882-1274883-1274884-1274885-1274886-1274887-1274888-1274889-1274890-1274891-1274892-1274893-1274894-1274895-1274896-1274897-1274898-1274899-1274900-1274901-1274902-1274903-1274904-1274905-1274906-1274907-1274908-1274909-1274910-1274911-1274912-1274913-1274914-1274915-1274916-1274917-1274918-1274919-1274920-1274921-1274922-1274923-1274924-1274925-1274926-1274927-1274928-1274929-1274930-1274931-1274932-1274933-1274934-1274935-1274936-1274937-1274938-1274939-1274940-1274941-1274942-1274943-1274944-1274945-1274946-1274947-1274948-1274949-1274950-1274951-1274952-1274953-1274954-1274955-1274956-1274957-1274958-1274959-1274960-1274961-1274962-1274963-1274964-1274965-1274966-1274967-1274968-1274969-1274970-1274971-1274972-1274973-1274974-1274975-1274976-1274977-1274978-1274979-1274980-1274981-1274982-1274983-1274984-1274985-1274986-1274987-1274988-1274989-1274990-1274991-1274992-1274993-1274994-1274995-1274996-1274997-1274998-1274999-1275000

WESTINGHOUSE ELECTRIC & MANUFACTURING CO., U. S. A.

"P"  
MOL.  
H.S.  
POWER  
TRANS.  
# 4



# Westinghouse



6000 KV-A.  
13200 TO 4800 VOLTS  
60 CYCLES

IMPEDANCE  %  
AT ABOVE RATING

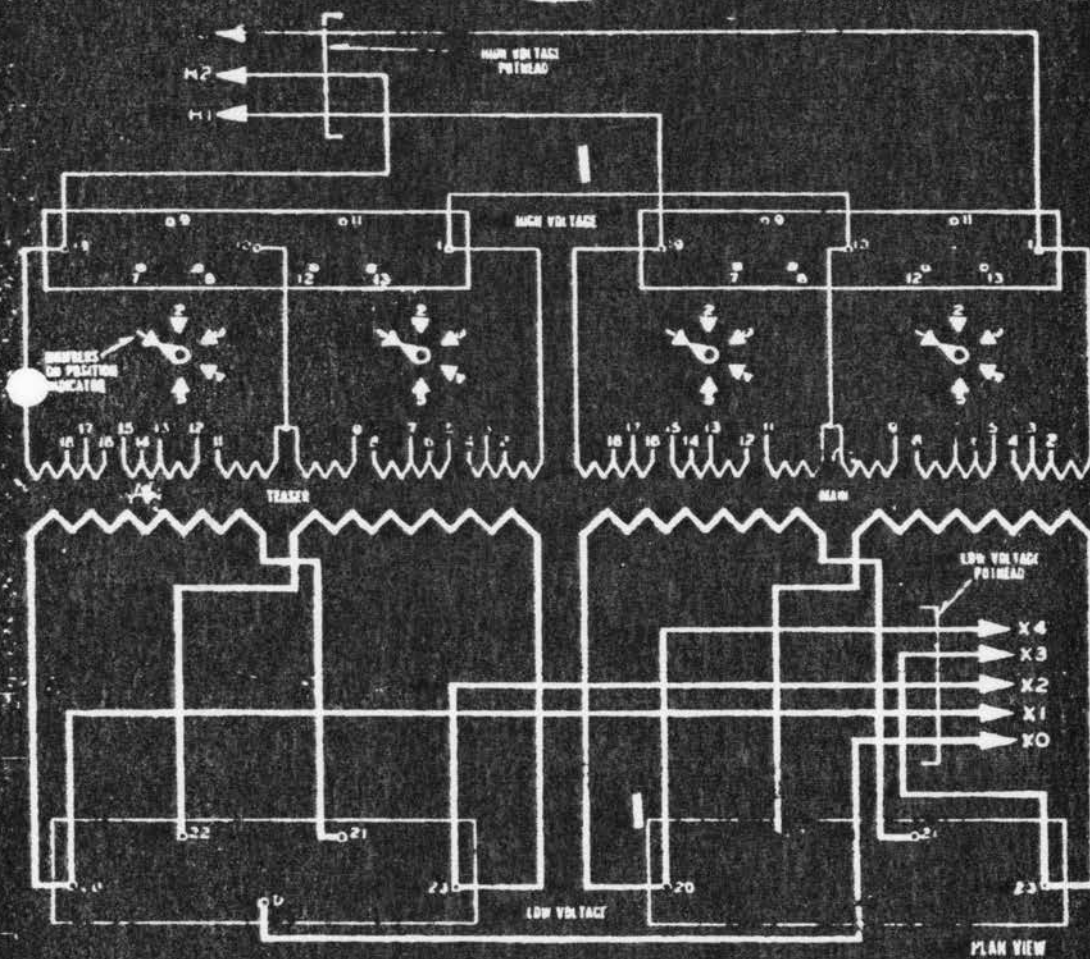
L. SPEC. 338696

THREE-TWO PHASE  
**TRANSFORMER**  
OIL INSULATED  
SELF COOLED

MADE IN U.S.A.

FULL LOAD  
CONTINUOUSLY  
55°C. RISE

GALLONS OIL   
SERIAL MAIN UNIT   
SERIAL TEASER UNIT



CONNECTIONS

WINDING	VOLTS	AMPERES	TAP CHANGERS		CONNECT			LEADS ON
			POSITION	CONNECTS	MAIN UNIT	TEASER UNIT	INTERPHASE	
HIGH VOLTAGE	13860	250	1	4 TO 5, 15 TO 16	6 TO 9 11 TO 12	7 TO 8 11 TO 13	10 ON MAIN UNIT TO 1 ON TEASER UNIT	SEE PLAN VIEW
SCOTT	13530	266	2	3 TO 5, 15 TO 17				
CONNECTED	12700	262	3	3 TO 6, 14 TO 17				
TAP	12170	289	4	2 TO 6, 14 TO 18				
PHASE	12530	270	5	2 TO 7, 13 TO 18				

Form 1162-1-2

ALLIS-CHALMERS MANUFACTURING COMPANY  
MILWAUKEE, WISCONSIN



TRANSFORMER TEST REPORT Spec. 11626

Purchaser: Moline Rock Island Manufacturing Company *MOLINE I.S.*  
 Date of Test: 11-9-40 Purchaser's Order No. 59613 A.C Order No. 8170Y-1  
 Type: OISC 55° C Rise Phase 3-2 Cycles 60 Insulating Fluid ACU #3 Oil  
 Winding (1) 4800 Volts (2) 480 Volts (3) \_\_\_\_\_ Volts  
 (1) 1250 Kva (2) 1250 Kva (3) \_\_\_\_\_ Kva

Taps: (1) F.C. 5040, 4920, 4680, 4560 (2) Scott Taps \*  
 RESISTANCES, EXCITING CURRENT, LOSSES AND IMPEDANCE—Based on Normal Rating unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the resistances given are the sum of the three phases in series.

Main and Teaser mounted in same tank.

Serial No.	Resistance in Ohms at 75° C			Exciting Current Per Cent at 100% Voltage	No Load Loss in Watts at 100% Voltage	Watts Loss and Impedance at 75° C					
	(1)	(2)	(3)			4800 V		480 V		1250 Kva	
	Total	Total		30	30	MAIN		TEASER		Total	Avg.
1722132-3	.255	.00255		1.50	3440	5374	4.01	6163	4.47	15120	4.21
1722134-5	.250	.00254		1.70	3470	5336	4.02	6094	4.33	14894	4.18
Average				1.60	3455	7104	4.02	7880	4.37	15007	4.20
Guarantee				3.00	4020					15460	

REGULATION AT 75° C	100% Pf			
	Average		Guarantee	
	1.00	3.25	1.10	4.00

TEMPERATURE RISES are average rises in degrees C corrected to instant of shutdown.

Serial No. 1722132-3 with windings connected and loaded as follows:  
 (1) 4560 Volts 137 Amp. (2) 480 Volts 1500 Amp  
 (3) \_\_\_\_\_ Volts \_\_\_\_\_ Amp. until constant temperature has been reached.

	Temp. Rise of Windings by Resistance				Top Fluid Temp. Rise	Ambient Temp.		Water			Hot Spot Detector
	(1)	(2)	(3)	Guarantee		Ingoing Water	Idler or Room	Temp. Rise	Gallons per Min.	Pounds Pressure	
	36.3	39.6		55	37.5		17.5				

INSULATION TESTS—If Impulse Tests are required, see separate Transformer Impulse Test Report.

APPLIED POTENTIAL TESTS <small>Voltage applied between each winding and all other windings connected to core and ground.</small>	Voltage Rating of Winding Tested	Test Voltage Applied	Duration of Test in Seconds
		4800	26000
	480	10000	60

INDUCED POTENTIAL TESTS	200 cycles per sec.	2 times rated voltage across full winding
	for 7200 cycles	kv from _____ kv line terminal to ground

REMARKS: \* See Connection Diagram Dwg. G-931759 % Ex. Current 30

% Efficiencies @ 75° C @100% PF.

Load	5/4	4/4	3/4	1/2	1/4	% Ex. Current
Average	98.67	98.84	98.97	99.01	98.68	@90% E.
Guarantee	98.63	98.79	98.91	98.92	98.51	Avg. 1.0
						Guar. 1.9
						@110% E.
						Avg. 2.8
						Guar. 5.3

I hereby certify this is a true report based on factory tests made in accordance with the Transformer Test Code C57.2 current edition of the American Institute of Electrical Engineers transformer withstood the above insula

Sign: blb 8-24-50 Approved

Copied from Test Report dated 11-27-40



**REPORT OF TESTS**  
WESTINGHOUSE FORM 3411 B

PURCHASER Peoples Light Co.

DATE \_\_\_\_\_

WESTINGHOUSE GENERAL ORDER NO. DP-28612

RATUM \_\_\_\_\_

SHOP ORDER NO. 22-R-48

**ADDITIONAL TEST DATA**

Serial	Watts Iron Loss 90% Voltage	% Exciting Current 90% Voltage
2351494	5500 Watts	1.14%
2351495	5700 Watts	1.17%
Total 2 Units Guar.	11200 Watts 1327.0 Watts	1.16% 1.5%

Serial	Watts Iron Loss 110% Voltage	% Exciting Current 110% Voltage
2351494	9600 Watts	1.92%
2351495	9900 Watts	1.75%
Total 2 Units Guar.	19500 Watts 21460 Watts	1.83% 7.3%

**RATIO TESTS**

Volts Applied	Applied on H.V. Term.	H.V. Tap Changer Position	Meas. On L.V. Term.	Volts Measured	
				Serial 2351494	Serial 2351495
500	1, 8-9, 19 11-12	1	20, 21-22, 23	173.00	173.00
"	"	2	"	177.82	177.81
"	"	3	"	181.86	181.85
"	"	4	"	186.09	186.10
"	"	5	"	191.63	191.63
"	1, 8-9, 19 11-13	5	"	206.50	206.48
"	1, 7-9, 19 11-13	5	"	222.28	222.25
"	"	5	20-22, 21-23	111.13	111.12

ABOVE IS A TRUE AND CORRECT RECORD OF DATA OBTAINED FROM TESTS AT THE WORKS OF WESTINGHOUSE ELECTRIC CORPORATION



REPORT OF TRANSFORMER TESTS  
FORM 43-B

WESTINGHOUSE  
ELECTRIC CORPORATION

P.M.O.L.  
#324  
A.S. TRANS #5



Customer: Peoples Light Co.

Test - Customer's Order No. - G.O. DP-28612 S.O. No. 22-R-48 L-Spec. 338696  
 OISC-R Duplex Phase 3/2 Cycles 60 Insulating Fluid 011  
 Winding (1) 13200 Volts 4800 Volts  
 6000 Kva (2) 6000 Kva (3) \_\_\_\_\_ Kva  
 Taps (1) 13860 - 13530 - 12870 - 12530 F.C.  
 Taps (2) 2400 By series parallel

RESISTANCES, EXCITING CURRENT, LOSSES AND IMPEDANCE—Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the resistances are the sum of the three phases in series.

SERIAL NO.	RESISTANCE IN OHMS AT 75°C			% EXCITE CURRENT AT 100% RATED VOLTAGE	NO LOAD LOSS WATTS AT 100% RATED VOLTAGE	13.2 Kv		4.8 Kv		6000 (D) Kva		6000 (C) Kva	
	(1)	(2)	(3)			TO 4.8 Kv	TO 4.8 Kv	LOAD LOSS WATTS 75°C	% IMP 75°C	LOAD LOSS WATTS 75°C	% IMP 75°C	LOAD LOSS WATTS 75°C	% IMP 75°C
2351491 (A)	1301	01798		2.4	7150	14690	3.19						
2351495 (B)	1299	01777		2.5	7400	14680	3.22	32300	3.38				
				(E)	(E)	TOTAL LOSS WATTS 75°C		TOTAL LOSS WATTS 75°C		TOTAL LOSS WATTS 75°C		TOTAL LOSS WATTS 75°C	
AVERAGE				2.45	14550								
GUARANTEE				3.0	16380								
REGULATION AT 75°C						100% PF (D)		% PF		80% PF (D)		% PF	
						AVERAGE .54				2.33			
						GUARANTEE .7				3.0			

TEMPERATURE RISES—Average rise in degrees C., corrected to instant of shutdown, of transformer.

No. 2351491 - 5 with windings connected and loaded as follows:  
 12.53 Kv 276 Amp. (2) 24 Kv 1250 Amp.  
 Kv Amp. until constant temperature rise was reached.

	RISE OF WINDINGS BY RESISTANCE				TOP FLUID RISE	AMBIENT TEMP.		WATER		
	(1)	(2)	(3)	(4) GUARANTEE		INCOMING WATER	IDLER OR ROOM	RISE	GALLONS PER MIN.	POUNDS PRESSURE
*	49.5	44.5	48.5	48.3	55	46.5	26			

INSULATION TESTS

APPLIED POTENTIAL TESTS	VOLTAGE RATING OF WINDING TESTED	TEST VOLTAGE APPLIED IN KV	DURATION OF TEST IN SECONDS
(Voltage applied between each winding and all other windings connected to core and ground.)	13200 4800	34 26	60 60
INDUCED POTENTIAL TEST	2 times rated voltage across full winding; kv from _____ kv line terminal to ground; at 120 cycles per second for 7200 cycles.		

REMARKS \* Winding identified as follows:  
 (1) H.V. Main unit (2) L.V. main unit (3) H.V. teaser unit (4) LV teaser unit  
 (A) Main Unit (B) Teaser Unit  
 (C) Main and Teaser Units connected for 3/2 phase operation  
 (D) As single phase units (E) Total for two units

I hereby certify that this is a true report based on factory tests made in accordance with the latest Transformer Test Code C57.2 of the American Standards Association; and that each transformer withstood the above insulation tests.

Signed \_\_\_\_\_ Date July 15, 1938 Approved \_\_\_\_\_  
 Page 1 of 2 Pages TRANSFORMER ENG. DEPT

SUB P  
TRANSFORMER #4

NOTE: This is a three-winding three to two-phase transformer

GIVEN: ? Form Transformer  
3 WDG Transformer  
6 MVA Transformer

13.2 KV DELTA to 4.8 KV STAR GROUNDED

Impedance = 3.38 % @ 13.2 KV @ 6 MVA  
Impedance = 3.0925% @ 13.8 KV @ 6 MVA

$Z_0$  = 3.38 % @ 13.2 KV @ 6 MVA  
 $Z_0$  = 3.0925% @ 13.8 KV @ 6 MVA

$I$  Magnetizing Current @ 100% Voltage = 2.4+2.5% @ 6 MVA  
= 4.9% @ 6 MVA

No Load Losses @ 100% Voltage = 7150+7400 Watts @ 6 MVA  
= 14550 Watts @ 6 MVA

Assume Shell Form Transformer

FROM 3008

TO 5008

RR1 = 51.5413 % @ 100 MVA  
XX1 = 51.5413 % @ 100 MVA  
XC1 = 34013.6054 % @ 100 MVA  
RR0 = 687285.2234 % @ 100 MVA  
KK = 0  
XX0 = .9  
XC0 = 34013.6054 % @ 100 MVA

XV. APPENDIX

H. GROUNDING TRANSFORMER EXAMPLE

REPORT OF TRANSFORMER TESTS

WESTINGHOUSE  
ELECTRIC CORPORATION



Date of Test: 9-27-51 Customer's Order No. - G.O. 4-3330 S.O. No. 52-n-780 L-Spec. 350338  
 Type: SL - Grounding Phase: 3 Cycles: 60 Insulating Fluid: Oil  
 Windings (1) 13800 Volts \_\_\_\_\_ Volts \_\_\_\_\_ Volts \_\_\_\_\_  
 (1) 7970 to neutral Kva (2) \_\_\_\_\_ Kva (3) \_\_\_\_\_ Kva  
for 1 min.

RESISTANCES, EXCITING CURRENT, LOSSES AND IMPEDANCE—Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the resistances are the sum of the three phases in series.

SERIAL NO.	RESISTANCE IN OHMS AT 75°C			% EXCITE CURRENT AT 100% RATED VOLTAGE	NO LOAD LOSS WATTS AT 100% RATED VOLTAGE	H-2		Kv		Kv		Kv	
	(1)	(2)	(3)			TO	TO	TO	TO	TO	TO		
3012677	3.32 Total			.263	1950	11150	76.2						
TOTAL LOSS WATTS 75°C						113100							
AVERAGE						113100							
REGULATION AT 75°C													

TEMPERATURE RISES—Average rise in degrees C., corrected to instant of shutdown, of transformer.

Serial No. 3012677 with windings connected and loaded as follows:  
 (1) 13.8 Kv 335 Amp. (2) \_\_\_\_\_ Kv \_\_\_\_\_ Amp.  
 (3) \_\_\_\_\_ Kv \_\_\_\_\_ Amp. until constant temperature rise was reached.

SERIAL NO.	RISE OF WINDINGS BY RESISTANCE			TOP FLUID RISE	AMBIENT TEMP.		WATER	
	H2 W/O	H1 W/O	H3 W/O		INGOING WATER	IDLER OR ROOM	RISE	GALLONS PER MIN.
3012677	38.5	39.5	37.5			27		

INSULATION TESTS

APPLIED POTENTIAL TESTS	VOLTAGE RATING OF WINDING TESTED	TEST VOLTAGE APPLIED IN KV	DURATION OF TEST IN SECONDS
(Voltage applied between each winding and all other windings connected to core and ground.)	13800	34	60
INDUCED POTENTIAL TEST	_____ times rated voltage across full winding; _____ kv from _____ kv line terminal to ground at _____ cycles per second for <u>1 min.</u> cycles		

REMARKS

I hereby certify that this is a true report based on factory tests made in accordance with the latest Transformer Test Code C57.2 of the American Standards Association; and that each transformer withstood the above insulation tests.

Signed \_\_\_\_\_ Date 8/28/50 Approved \_\_\_\_\_  
 Page 1 of 1 Pages TRANSFORMER ENG. DEPT.

# Westinghouse

8000 KV-A.  
13800 VOLTS  
60 CYCLES  
IMPEDANCE  %  
AT ABOVE RATING  
L. SPEC. 388338

THREE PHASE  
TYPE S1  
GROUNDING  
**TRANSFORMER.**  
OIL INSULATED  
SELF COOLED

NO LOAD  
CONTINUOUSLY  
35°C. RISE  
GALLONS OIL   
SERIAL

ZIG ZAG  
TR # 1  
13 Kv  
BUS # 1  
(1975)

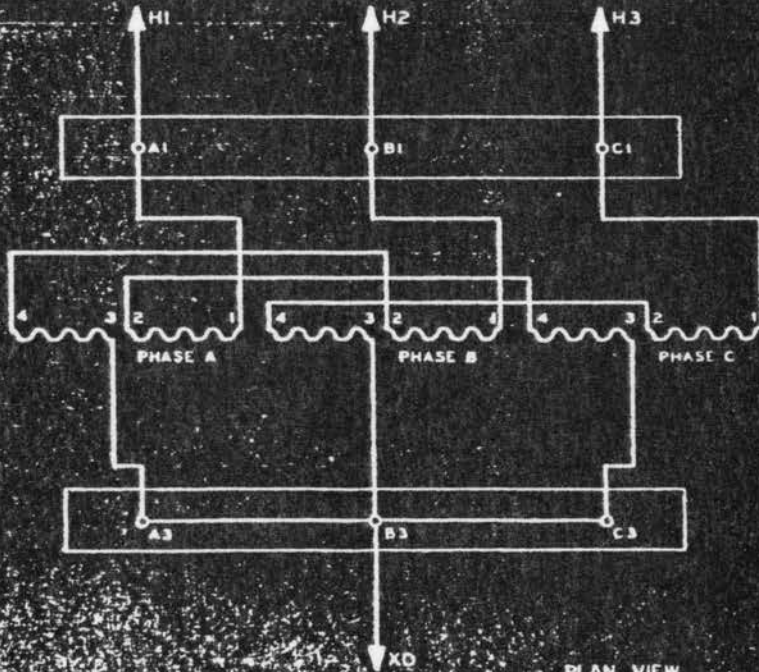
FULL WAVE IMPULSE STRENGTH: HIGH VOLTAGE 110 KV, LOW VOLTAGE 110 KV.

SEE INSTRUCTION BOOK 5094

APPROX WEIGHT IN  LBS. TRANSFORMER CASE  IN  TOTAL

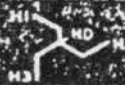
PATENTS 1454826-1460135-1490229-1492136-1492161-1552007-1557092-1565537-1587284  
1587285-1599539-1601308-1601326-1605026-1621039-1699763-1725078-1751223  
1802754-1827813-1834114-1899720

MADE IN U.S.A. WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY 334 KP-70



1000 AMPERES IS MAXIMUM CURRENT IN GROUNDING LEAD FOR ONE MINUTE WITH SAFE TEMPERATURE RISE.  
FILL TRANSFORMER WITH "WEMCO C" OR OTHER GAGE INDICATES 25°C. LEVEL.  
NEVER OPERATE TRANSFORMER WHEN THE INDICATOR IS BELOW THE BOTTOM OF THE SCALE.

POLARITY:



SUB A GROUNDING TRANSFORMER  
(Treat Like Linear Element to Ground)

- NOTE: 1. Put in "Small" values for RR1. (This doesn't exist in transformer model.)  
 2. Put in "Large" values for XX1. (This is equivalent to XC1 in transformer model.)  
 3. Put in "Small" values for XC1. (This is equivalent to RR1 in transformer model.)  
 4. Show linear element as connected in shunt to ground; i.e., KJQ = 0.  
 5. Only Zero sequence values need be used.  
 6. RR1 and XC1 are series impedance values of grounding transformer.

$$R_{\text{Series}} = 3.32 \text{ ohms}$$

$$Z_{1,2,0} = 76.2 \% @ 13.8 \text{ KV @ } 8 \text{ MVA}$$

$$I_{\text{Exciting @ 100\% V}} = .263 \%$$

$$\text{Losses}_{\text{N.L. @ 100\% V}} = 1950 \text{ Watts}$$

Bus # 3763

$$RR1 = 174.3331 \% @ 100 \text{ MVA}$$

$$XX1 = 475285.1711 \% @ 100 \text{ MVA}$$

$$XC1 = 952.5000 \% @ 100 \text{ MVA}$$

$$\begin{aligned} Z \text{ (pu)} &= \frac{Z \text{ ohms}}{Z \text{ base}} = \frac{3.32 \text{ ohms}}{23.805 \text{ ohms}} = .1395 \text{ pu @ } 8 \text{ MVA} \\ &= 1.7438 \text{ pu @ } 100 \text{ MVA} \\ &= 174.3331 \% @ 100 \text{ MVA} \end{aligned}$$

XVI. APPENDIX

I. REVISED HARMONIC ANALYSIS PROGRAM INSTRUCTIONS

## HARMONIC ANALYSIS PROGRAM

The harmonic analysis program developed at Iowa State University accepts data input in a formatted card image form. Several options exist in the type of harmonic analysis to be made. The selection of a particular option will influence the type, amount, and order of input data. The different options are described first, followed by the required input data for each of the possible combinations of options.

Card Image #1

The first card image read by the program has the following format:

N	VCBASE	LHARM	IPLOT	IVC	IUNIT
I3	F10.2	I3	I3	I3	I3

The first option which must be specified is whether a sampled waveform or a converter current waveform is to be used as the harmonic source. The option is specified in the IVC field of the first card image as follows:

IVC = integer $\leq -1$	current harmonic magnitudes
IVC = -1	voltage harmonic magnitudes
IVC = 0	voltage waveform
IVC = 1	converter current source
IVC = any other integer	current waveform

The choice of harmonic source type determines the interpretation of input variables N and VCBASE as follows:

For IVC = integer less than -1 (current harmonic magnitudes)

N = ignored

VCBASE = base value of current

For IVC = -1 (voltage harmonic magnitudes)

N = ignored

VCBASE = base value of voltage

For IVC = 0 (voltage waveform)

N = number of sampled data points

VCBASE = base value of voltage

For IVC = 1 (converter current source)

N = number of pulses per cycle

VCBASE = base value of voltage



For IVC = any other integer (current waveform)

N = number of sampled data points

VCBASE = base value of current

The remaining input variables on the first card image are defined as:

LHARM = highest order harmonic to be analyzed

IPLOT = 0 no plots generated

IPLOT = any other integer plots of voltage or current waveforms at the harmonic source will be generated

IUNIT = 0 input data is assumed to be actual quantities

IUNIT = any other integer input data is assumed to be in per unit

### Card Images #2

If the converter current source option is selected (IVC = 1 on the first card), then the second card has the following format.

POW	ALFA	OVL P
F10.2	F10.2	F10.2

POW = power rating of the converter in MW

ALFA = delay angle in degrees

OVL P = overlap angle in degrees

If either the voltage waveform or current waveform option is selected (IVC = 0 or integer greater than 1 on the first card), then Card Images 2 through 1 + N/8 have the following format.

A(K)	A(K+1)	A(K+2)	A(K+3)	A(K+4)	A(K+5)	A(K+6)	A(K+7)
F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2

A(K) = K<sup>th</sup> value of the sampled waveform.

If either the voltage harmonic magnitudes or current harmonic magnitudes option is selected (IVC = -1 or integer less than -1 on the first card), then the next set of card images have the following format.

	IY		VCM		VCA
3X	I3	2X	F12.8	2X	F12.8

where IY = harmonic order  
VCM = magnitude of harmonic component  
VCA = phase of harmonic component

The program will continue reading this type of card image until a card with IY = 999 is read.

Card Images #3

The card images following the converter or waveform specification are the power system element specification cards. All impedance values are entered in % on a 100 MVA base. The format for these cards is:

KJ	KJP	KJQ	KCT	RRI	XXI	XCI	RRO	XXO	XCO	KK	XLM
11	14	14	12	F10.4	F12.4	F10.8	F9.4	F9.4	F10.8	12	F6.4

The type of element is defined by the KJ field as follows:

KJ  $\leq$  1    transmission lines  
 KJ = 2    transformers  
 KJ = 3    generators or linear elements  
 KJ  $\geq$  4    loads

The definitions of the remaining fields depends on the element type selected.

Transmission lines (KJ  $\leq$  1)

KJP = node number at one end of the line  
 KJQ = node number at the other end of the line  
 KCT = circuit number  
 RRI = positive/negative sequence resistance in %  
 XXI = positive/negative sequence reactance in %  
 XCI = positive/negative sequence susceptance in %  
 RRO = zero sequence resistance in %  
 XXO = zero sequence reactance in %  
 XCO = zero sequence susceptance in %  
 KK = voltage and bundle code

first digit	voltage (KV)
1	69
2	115
3	132
4	138
5	161
6	230
7	345
8	500
9	13.80

second digit = number of  
bundles per conductor

XLM = length in miles



RRO = ignored  
 XX0 = ignored  
 XCO = ignored  
 KK  $\neq$  1 for generator or inductive element  
     = 1 for capacitive element  
 XLM = ignored

Loads (KJ  $\geq$  4)

KJP = node number of load  
 KJQ = 0 (connected to ground)  
 KCT = circuit number  
 RR1 = power in MW  
 XXI = reactive volt-amperes in MVAR  
 XC1 = ignored  
 RRO = ignored  
 XX0 = ignored  
 XCO = ignored  
 KK = type code  
     KK  $\leq$  1 residential, 50% motor load  
     KK = 2 commercial, 60% motor load  
     KK  $\geq$  3 industrial, 70% motor load  
 XLM = ignored

The end of the power system element specification card images is determined by a card image with KJP = 9999. All other fields on this card image are ignored.

Card Image #4

The fourth type of card image specifies the location and other information about the harmonic source. The format for these cards is:

JF	NAME	IOPT	PHA	FUND	(complex)
14	47	11	F10.2	F10.2	F10.2

JF = harmonic source bus number location

NAME = bus name at harmonic source

IOPT = analysis option code

IOPT  $\leq$  0 print harmonic analysis for elements adjacent to the harmonic source bus only.

IOPT = 1 print harmonic analysis for all elements in the system

With either of these options, up to four different card images may be inserted to analyze the system with the harmonic source in different locations. To end the harmonic source specification card images, the last card should have JF = 9999. All other fields on this card are ignored.

IOPT = 2    combined analysis of two harmonic sources

IOPT = 3    combined analysis of two harmonic sources

Identical harmonic sources may be placed at two separate locations simultaneously with these options. IOPT = 2 card image specifies the first location, and the IOPT = 3 card image specifies the second. It is not necessary to follow these cards with an end card with JF = 9999.

PHA = phase angle of the harmonic source waveforms

This field is intended for use with the combined analysis option to specify a phase difference between the two sources.

FUND = the complex magnitude of the fundamental component of the harmonic source waveform in per unit.

This field is required to achieve a reasonable plot of the harmonic source waveform. If no plot is to be made, then this field may be left blank.

#### Size Limits

This program will accept up to 500 nodes. A node is any place where two or more elements connect (usually a bus). However, each transformer requires one internal node in this program. Therefore, the number of buses plus the number of transformers will be the number of nodes required.

With this program, each transmission line is represented as three elements, each transformer is represented as three elements, each generator or linear element is represented as one element; and each load is represented as one element. Therefore, the total number of elements need will be:

$$\text{Total Number of Elements} = 3 \times (\text{number of transmission lines} + \text{number of transformers}) + \text{number of generators} + \text{number of linear elements} + \text{number of loads.}$$

This program will accept up to 4000 elements.

The size limits are determined by the array dimensions in the program and could be increased or decreased. The limits selected above were arbitrarily chosen as large enough to accommodate most studies of harmonic propagation in power systems.

#### Distribution Systems

The same techniques used for harmonic analysis of transmission systems may be used to analyze distribution systems. The program has been used to determine where harmonic resonance occurs on industrial plant distribution systems, and to verify the effectiveness of corrective actions.

## NOTES:

1. On the connection code for transformers, the program assigns the first bus number entered to correspond to the first type of winding. The second bus number entered corresponds to the last type of winding (see Page 4).

As an example:  $KK = 0$  and  $0.9 \leq XX0 < 1.0$

The first bus number entered would go with the DELTA winding. The second bus number entered would go with the grounded wye.

2. The program as it is currently set up uses a 100 Mega-voltampere base.

XVII. APPENDIX

J. SAMPLE PROGRAM OUTPUT

The output data shown in this appendix correspond to the case where the harmonic source values are entered as the measured voltage harmonic values at Substation A.



N = 0 VBASE = 13.80 LARM = 15 TPLT = 0 IVC = -1 IUNIT = 1

HARMONIC VALUES

HARMONIC ORDER	MAG	ANG
1	1.0000	0.00
2	0.0063	0.00
3	0.0040	0.00
4	0.0050	0.00
5	0.0055	0.00
6	0.0025	0.00
7	0.0089	0.00
8	0.0016	0.00
9	0.0025	0.00
10	0.0040	0.00
11	0.0026	0.00
12	0.0011	0.00
13	0.0045	0.00
14	0.0018	0.00
15	0.0020	0.00

KJ KJP KJU KKT KRI  
 1 2701 2702 1 0.0590  
 0.6380 10.83190980 0.6180 2.3750 6.89290047 72 12.74  
 ( ALL BUT THE FIRST ANG LAST LINES OF SYSTEM DATA WERE DELETED HERE FOR CLARITY )  
 A BUS 0 1 1.0000 0.00000000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000  
 XXX HARMONICS OF ORDER 2

\*\*\* CONVERTER AT BUS 3763 CONVERT \*\*\* IOPT = 1 PHA = 0.00000000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000  
 HARMONIC CURRENT FROM BUS MAG ANG TO CIRCUIT NUMBER TERM CURRENT FLOW SHUNT ELEMENT SERIES ELEMENT  
 15 0.0000 -6.81 4650 1 0.0033 -96.20 0.00 0.00 0.00 0.000000 0.035637  
 2660 1 0.0000 -66.14 0.00 36.08 64.22 0.000000 0.000000  
 50 0.0016 -6.60 3766 1 0.0001 -61.12 0.00 0.00 0.00 0.000000 0.372000  
 2766 1 0.0001 -58.95 0.00 431.81 559.75 0.000000 0.000000  
 ( ALL BUT THE FIRST TWO AND LAST TWO BUS DATA VALUES WERE DELETED HERE FOR CLARITY )  
 5763 0.0019 0.08 0 12 0.0001 -33.90 14.15 9.54 0.000000 0.000000  
 0 13 0.0001 -33.90 14.15 9.54 0.000000 0.000000  
 0 15 0.0001 -33.90 14.15 9.54 0.000000 0.000000  
 3763 12 0.0001 145.67 -4.13 -13330.21 0.690848 0.441552  
 3763 13 0.0001 145.63 -4.78 -13340.32 0.689743 0.441552  
 3763 15 0.0001 147.08 -2.62 -13332.40 0.763293 0.461555  
 8776 0.0000 0.00 0 1 0.0000 0.00 0.00 4.81 0.000000 0.000000  
 804 1 0.0000 0.00 0.00 0.00 0.000000 0.267082

HARMONIC DISTORTION FACTOR

BUS	PDF (%)
75	0.1485
108	0.4181
109	0.4184
135	0.1238
140	0.1692
171	0.2093
181	0.1700
184	0.1700
187	0.1700
195	0.1349

330	0.1275
391	0.1484
394	0.2443
561	0.1405
564	0.1587
567	0.1587
801	0.1200
804	0.1177
807	0.1227
810	0.1227
910	0.1302
2081	0.2034
2087	0.2093
2471	0.1137
2472	0.1138
2481	0.1525
2524	0.2074
2652	0.2050
2658	0.1775
2660	0.1505
2668	0.1716
2695	0.1612
2761	0.1290
2761	0.1240
2762	0.1262
2767	0.1114
2768	0.1027
2769	0.1201
2711	0.1522
2712	0.1366
2713	0.1445
2714	0.1730
2715	0.2079
2716	0.1683
2717	0.1699
2719	0.1911
2720	0.1743
2721	0.1382
2723	0.1509
2724	0.1374
2725	0.1398
2726	0.1388
2727	0.1430
2728	0.1409
2729	0.1441
2730	0.1611
2731	0.1790
2732	0.1671
2735	0.1740
2736	0.1435
2737	0.1522
2739	0.2322
2740	0.1654
2741	0.1499
2742	0.4783
2743	0.6737
2744	0.4021
2745	0.4078
2746	0.0000
2747	0.4485
2748	0.1747
2749	0.1654
2750	0.1712
2751	0.1732
2752	0.1610
2753	0.7804

2754	0.4424
2755	0.6961
2756	0.3947
2757	0.1932
2758	0.7810
2759	0.1630
2760	0.1470
2761	0.1721
2762	0.0000
2763	0.7064
2764	0.6583
2765	0.4210
2766	0.4762
2767	0.3362
2768	0.2627
2769	0.1675
2770	0.1660
2771	0.2010
2772	0.2242
2773	0.3007
2774	0.1839
2775	0.1598
2776	0.1177
2777	0.1227
2778	0.1227
2779	0.1449
2780	0.0600
2781	0.1032
2782	0.1440
2783	0.1386
2784	0.1258
2785	0.1404
2786	0.1371
2787	0.1193
2788	0.1135
2789	0.3334
2790	0.6764
2791	0.8008
2792	0.5186
2793	0.2750
2794	0.5152
2795	0.3790
2796	0.2280
2797	0.6064
2798	0.2750
2799	0.2121
2800	0.3706
2801	0.0000
2802	0.1392
2803	0.1717
2804	0.0000
2805	0.2632
2806	0.3193
2807	0.1358
2808	0.0794
2809	0.1364
2810	0.1379
2811	0.1494
2812	0.0955
2813	0.1420
2814	0.1392
2815	0.5083
2816	0.5683
2817	0.2202
2818	0.2976

3730	0.6887
3731	0.3997
3732	0.3934
3740	0.1837
3742	0.4435
3743	1.1172
3744	0.8794
3746	0.0000
3747	1.6192
3748	0.3427
3749	0.5163
3750	0.3990
3751	0.2641
3752	0.2997
3753	0.7664
3754	3.6621
3755	0.6023
3756	2.0076
3757	0.6489
3758	1.4795
3759	0.3774
3760	0.1784
3763	4.7698
3764	1.2624
3765	0.1379
3766	0.8711
3768	1.0964
3769	1.1180
3770	0.4473
3771	0.3023
3773	0.1223
3776	0.1130
3813	0.2944
3821	0.1381
3825	0.0000
3827	0.3589
3828	0.2243
3829	0.2652
3844	0.8693
3848	0.6250
3851	0.2925
3854	0.5908
3855	0.6032
3856	1.2617
3857	0.3569
3859	0.4151
3863	1.9370
3866	0.9200
3868	0.5108
3869	0.6377
3872	2.7880
3873	0.1235
3925	0.1392
3953	0.4012
4007	0.1159
4008	0.1122
4018	0.0768
4028	0.0768
4471	0.0566
4660	0.0933
4763	3.6615
4802	0.0000
4903	0.0387
4905	0.0752
5008	0.0494
5763	4.6963

0.1177

8776