(L)oad-flow, (F)ault & (H)armonic Program

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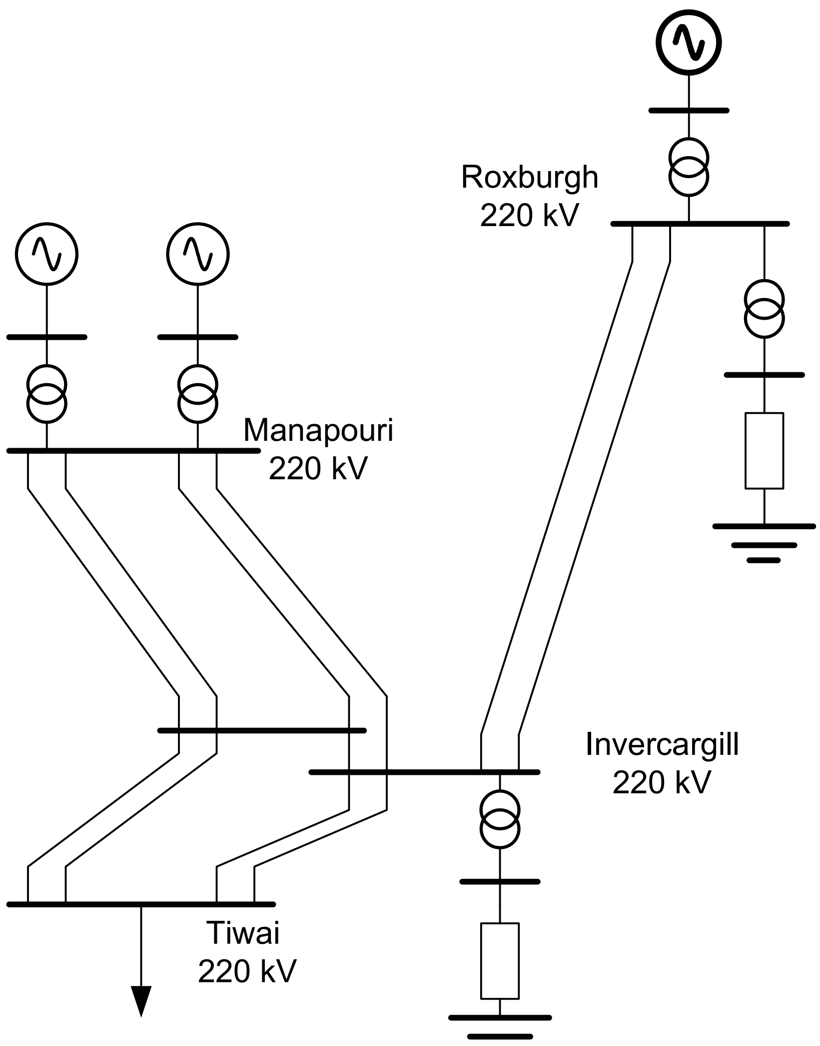

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Contents

Notation

Abbreviations

B	=	Susceptance
BR	=	Breurer's Constant
C	=	Capacitance
f	=	Frequency
G	=	Conductance
j	=	Complex operator = $\sqrt{-1}$
L	=	Inductance
p.u.	=	per unit
R	=	Resistance
s	=	Induction Motor slip
SR	=	Skin Ratio
	=	1./ (Resistance per unit-length)
X	=	Reactance
Y	=	Admittance
Z	=	Impedance

Subscripts

base	=	Base quantity
bf	=	Quantity at base frequency
f	=	Quantity at a given frequency
dc	=	Quantity at dc
pu	=	Per unit
%	=	percent Off-nominal (tap position)
	or	percentage of base impedance (impedance)

1 Introduction

LFH was developed in 1988 to teach power system analysis using both a VAX/VMS system and IBM-AT's. Previous work had developed stand-alone programs for various power system analysis, however, data preparation was time-consuming. The ability to analyse power systems for load-flow (or Power-flow), faults and harmonics, with a common integrated data base was a distinct advantage.

A number of excellent and very sophisticated graphical versions of LFH have been developed over the years, such as DISPLAYPOWER and PSDRAFT. However the problem has always been that of having the time and expertise to maintain the program properly. For example the demise of DISPLAYPOWER occurred with the switching from VAX/VMS system to SUN/UNIX system. Graphical programs need more maintenance as hardware and graphics software quickly date.

LFH consists of a positive-sequence (single-phase) Load-flow & Harmonic algorithm and a Sequence Component Fault analysis.

This software and manual are supplied to accompany the book Power System Harmonics (2nd edition) by John Wiley & Sons (2003), to enable its readers to perform demonstration studies so as to enable a better understanding to be reached. The authors and publisher accept no liability for damages, direct or indirect, resulting from the use of the software or manual.

2 Running LFH

This section gives details on installing the LFH program onto the hard disk of your computer. The basic running instructions and the demonstration programs are also described. Win32 version is called LFHw31.exe. Note that the program requires the dll library (salflibc.dll) to be either in the same directory as the executable or preferably in the appropriate system directory (e.g. `c:\WINNT`) so that the system can automatically find it. If is recommended that the window height be enlarged to 60 lines when running LFH. This is achieved by right clicking on the window banner and selecting **properties**, then making the appropriate changes to the height values (Window Size and Screen Buffer Size).

After the program logo and licensing details, the main menu is displayed. The whole package is menu driven and the user is not required to memorize any special key sequences. The necessary key entries for all operations are displayed on the screen with the menu and are all either 3 or 4 characters followed by 'return'. Escape from all menus including the main menu by typing 'EXIT' or in some cases 'EXI'. Pressing the `<Return>` key on a blank line will also escape from any menu except the main menu.

3 Program Operation

The first step is always to enter the network data into LFH's data storage arrays. This can be performed by reading in network data files or entering a new network via edit. The next step is to

```
LL          FFFFFFFF   HH    HH
LL          FF         HH    HH
LL          FFFFFF     HHHHHHHH
LL          FF         HH    HH
LL          FF         HH    HH
LLLLLLLL    FF         HH    HH

           Version : 6.06
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```

Figure 1: First Page Displayed

```
               M A I N   M E N U
               ===================
----------------------------------------+------
     DESCRIPTION                          ENTRY
----------------------------------------+------
READ NETWORK FROM DATABASE...............[READ]
ENTER SYSTEM TITLE.......................[TITL]
LIST NETWORK.............................[LIST]
EDIT NETWORK.............................[EDIT]
SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
LOAD-FLOW ANALYSIS.......................[LOAD]
FAULT ANALYSIS...........................[FAUL]
HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
CHANGE DATABASE..........................[CHAN]
SUMMARY OF NETWORK.......................[SUMM]
SET BASE POWER...........................[POWR]
HELP FACILITY............................[HELP]
TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
----------------------------------------+------

Command >
```

Figure 2: Main Menu

enter a title for the system. Then use the Edit facility to modify the system as needed, and branch to the required analysis. For a detail sample of the program operation, see the Appendices 1 and 2. Appendix 1 contains the commands used, with comments add on the right hand side. Appendix 2 shows how the program appears when given these commands.

The READ command is dealt with in detail while little is said about the SAVE command. This is because many of the features are common to both, and some of the other options (such as LIST and EDIT).

3.1 Read Network (READ)

The first read operation will cause the program to prompt for the directory where the data files are situated. If none is entered then the data files are assumed to be in the directory the program is being run from. The directory entered remains the default directory until such time as it is changed using the change directory (CHAN) command from the main menu. This directory is also used by the SAVE command, however, a directory specification is prompted for, each time a SAVE operation is requested. This then will affect the directory for subsequent READ commands.

As the user becomes familiar with the operation of the LFH program, the number of prompts that need to be answered can be reduced. For example, by putting more information on the line, some of the subsequent prompts can be avoided.

```
> READ
READ WHAT? > GEN
```

can be reduced to:

```
> READ GEN
```

This is also true for LIST ,EDIT and SAVE operations.

Table 1 displays the allowable response to the `READ WHAT? >` prompt.

The program looks at the first three characters, so if LOAD is entered rather than LOA the program will still recognise it. If an incorrect entry is detected the program will display the allowable entries and reprompt.

LFH looks for the presence of these files, if a file does not exist then it assumes there is none of these types of component in the system. It also notifies the user that the file was not found so do not worry about the warning messages, if there are suppose to be none of these components, as the program is designed to work in this manner.

Once the system has been read in, variations from the base case can be analysed by Editing network data or reading in a new file. For instance to try a different generator scheduling a different generator file can be read in. The second generator file can either have the default name (GENR.DAT) and be stored in another directory, in which case the CHAN command followed by a read is required, or else its name is different to the default name. In this case the SPFILE qualifier is required so that the program prompts for the filename.

Table 1: Short forms for Component Types.

Short Form	Component Type	Default File Name
SYS		SYSP.DAT
BUS	Busbars	BUS.DAT
LIN	Lines	LIND.DAT
TR2	2-Winding Transformers	XFR2.DAT
LOA	Load	LOAD.DAT
SHU	Shunt	SHUN.DAT
GEN	Generator	GENR.DAT
IND	Induction Motor	INDM.DAT
ALL	All the above	

For Example :-

```
Command > READ GEN SPFILE
```

For more details please refer to the section on Data Management

3.2 List Network (LIST)

The 'LIST' command either, displays on the screen, or writes to a file, the parameters of each component. When displaying components, only a screen-full (page) is shown at a time. Some components however, have too many parameters to display on one line. Therefore, for clarity, the parameters are displayed in logical groups (windows). For example, generators have their power output and limits in window 1 and resistances/reactances in window 2. It is a simple operation to skip forward or back through the pages and select alternative windows.

3.3 Edit Network (EDIT)

When edit option is invoked from the main menu the Edit menu (see Fig. 3) will appear. The User then selects what component is to be operated on.

The three Edit operations are :-

- (A)dd component
- (R)emove component
- (C)hange component

Although the program prompts for operation flag and component details, it will prompt for any information it finds to be deficient once it enters each option. For example instead of :

```
    E D I T    M E N U
    ------------------
BUSBAR.................[BUS]
TRANSMISSION LINE......[LIN]
2-WINDING TRANSFORMER..[TR2]
SHUNT ELEMENT..........[SHU]
LOAD...................[LOA]
GENERATOR..............[GEN]
INDUCTION MOTOR........[IND]
FILTER.................[FIL]
EXIT FROM EDIT.........[EXI]
EDIT WHAT >
```

Figure 3: Edit Menu

```
ENTER: A/R/C, NAME, No.
EDIT GENERATOR >  C MANAPOUR1014 1
```

the User can enter C and the program will prompt for the rest, as shown below.

```
Enter: A/R/C, NAME, NO. (or LIST)
EDIT GENERATOR >  C

BUSBAR NAME ? > MANAPOUR1014

ENTER UNIT No. > 1
```

Note: Edit short-cut

The components can be listed by entering **LIST** at the edit prompt.

```
ENTER: A/R/C, NAME, No.
EDIT GENERATOR > LIST
```

Once the appropriate component is identified it can be edited by specifying its line number. For example edit component 6 then enter operation **LN** to indicate that line mode is being used and the line number.

```
ENTER: A/R/C, NAME, No.
EDIT GENERATOR >  C LN 6
```

This will bring up the the 6^{th} generator for editing.

A component can be taken out of service by setting its status flag to zero. This is performed in the (C)hange option. All the remainder of the component data remains resident and can be re-enabled at any time. When the SAVE option is used components that are out of service are saved in the Network data files. When these data files are re-read at the start of a new session they are still in the out-of-service state but can be easily returned to service by modifying the status flag. To permanently remove the components, the (R)emove option should be used which deletes components from the program variables permanently.

Since often several components are identical, to save having to reenter the save values a copy command is available. One syntax for copying data is:

```
COPY LN FromNumber ToNumber
```

This copies the data in component number *FromNumber* to component number *ToNumber*. It is also possible to copy as well as add a component, e.g.

```
A Busbar1 Busbar2 Unitno COPY Number
```

When specifying busbar names they must be spelt exactly correct (although not case sensitive). When working with a system often then busbar numbers often are remembered. Hence `B#No` is an alternative to typing busbar name (e.g. `B#9` for busbar 9). Special commands are: LIST, HELP (? or H) and FIND. FIND is used to determine the busbar number (e.g. FIND Tiwai—-220).

Due to the complexity of the filter components the Editing of them is slightly different. To change the status of the components the (C)hange option is invoked and status changed, however when the status of a filter is to be changed there is a separate (S)tatus option that is used.

When LFH is prompting for a quantity, the units are indicated in the brackets. For example :-

```
+ve Sequence Reactance (p.u.) ? > 1.0
```

If other units are used, a qualifier is then added to inform the program to convert to what units it needs to perform the calculations. The valid qualifiers are shown is table 3.8. Please refer to *Answering Program Prompts* for more details.

3.4 Entering a DOS Command (EDOS)

This operation allows the user to perform DOS commands without exiting from the LFH program. For example, if the user needs to delete some files before saving new ones, then this can be done easily.

If only one DOS command is required, then it is entered at the prompt. For example:-

```
e.g. EDOS
     > DEL C:\DATA\*.*
```

After performing the DOS command, control is automatically passed back to the program.

If several DOS commands are required, the word COMMAND is typed in response to the prompt. Then the DOS command sequence can be performed. To return control back to the program, type 'EXIT'.

```
EDOS
COMMAND
C:\> DIR
C:\> DEL TMP.OUT
EXIT
```

3.5 Summary of Network Command (SUMM)

The quantity of each type of component in the network under consideration can be displayed by typing 'SUMM' at the main menu.

3.6 Show Busbars (SHWBUS)

This is a global command and can be entered at any time. Its action is to display the busbars in the data base in alphabetical order. This is especially useful when editing, to find the correct spelling of a busbar name.

3.7 Back-step (DELETE)

The DELETE command causes the program to back-step to the previous prompt. If the User enters an option and then realizes he picked the wrong option or he notices an incorrect entry to an earlier prompt then a several DELETE commands can be entered to step-back to the required point in the program. DELETE is not global in the same way as SHWBUS is, however, as far as the User is concerned it will work at any prompt (except for when entering a Study title).

3.8 Answering Program Prompts

The " >" symbol indicates the program is waiting for the User to respond. The valid options are often shown in paranthesis(e.g. (Y/N) or (1-9)). If default values are present then they are given either on the line above the prompt or in square brackets. For example:-

```
(No. Defaults =   50.0000    ,   1250.00    ,   50.0000    )
 ENTER: MIN FREQUENCY,MAX/,(INCREMENT)  >
```

or

```
Do you want it removed (Y/N) [N] ? >
```

When LFH is prompting for a numerical quantity, the units are indicated in the brackets. For example, when entering zero sequence resistance:

```
Zero Sequence Resistance (p.u.) ? > 1.0
```

If other units are used, a qualifier is then added to inform the program to convert to what units it needs to perform the calculations. See table 3.8 for valid qualifiers. For example, if a unit "Ohms" is used, this unit has to be typed in as follows:

```
Zero Sequence Resistance (p.u.) ? > 484 ohms
```

In the example above `484 ohms` is entered, as when $V_{base} = 220$ kV and $S_{base} = 100$ MVA, then 1 p.u. is equivalent to 484 ohms.

It should be noted that in the units used, either lower or upper case characters can be used. The only exception to the use of these qualifiers is in the filter routines, as the data must be entered in actual values, not in per-unit.

Table 2: The Default and Qualifier Units Available in LFH.

QUANTITY	UNITS			
	Default	Qualifier		
Resistance	p.u.	Ohms		
Reactance	p.u.	Ohms	H	mH
Conductance	p.u.	mohms		
Susceptance	p.u.	mohms	F	uF
Tap positions	percent	p.u.		
Voltage	p.u.	kV	V	
Active power	MW	p.u.		
Reactive power	MVAR	p.u.		

3.9 Default Values

If default values are present then they will be displayed. For example in the Harmonic and Audio Frequency Analysis the minimum, maximum and interval frequencies have default values 50,1250 and 50 Hz respectively, as shown below.

```
(No. Defaults =   50.0000    ,   1250.00    ,   50.0000    )
 ENTER: MIN FREQUENCY,MAX/,(INCREMENT)  >
```

To vary the minimum frequency only the required minimum frequency is entered as the other two numbers will remain unchanged. If the maximum frequency is to be changed to 550 Hz for example, the User would enter:-

```
(No. Defaults =   50.0000    ,   1250.00    ,   50.0000    )
 ENTER: MIN FREQUENCY,MAX/,(INCREMENT)  > * 550
```

The '*' character is the default character for numbers and causes the appropriate variable to remain unchanged. Therefore only those values that are required to be different from the default settings need to be entered. The '#' character works in the same way for character entries.

3.10 Response Files

If a command sequence is needed numerous times, it is worthwhile creating a response file containing the command sequence. To create a response file, type CREATERFL and enter the filename. Then enter the command sequence to be saved and type CLOSERFL to terminate the response file creation. Alternatively, a standard editor can be used to create a response file.

To use a response file, type `@` in front of the filename. This will redirect the program to extract its input from the file rather than keyboard. When the end of file is reached, control is passed back to the keyboard. A message will be displayed to inform the user of this:

```
e.g. > @SOMEC.RFL
```

3.11 Slack Busbar

This can easily be changed from the "loadflow control parameter" menu at any point. When a network is read in it, and if a SYSP.DAT file does not exist, LFH uses its default by setting slack busbar to be where the first generator in memory is connected to. Therefore it is advisable to put the generation at the slack busbar at the top of the generator file (GENR.DAT) if no SYSP.DAT file is to be used.

3.12 Setting Base Parameters (POWR and BFREQ)

The power and frequency base to be used for the analysis are stored in the file SYSP.DAT. If no SYSP.DAT file is present the base frequency and power default to 50 Hz and 100 MVA respectively. To inspect and alter the base frequency type `FREQ` at the main menu level. Similarly the base power can be inspected and changed by entering `POWR` at the main menu level.

3.13 Checking Network for Errors (CHEC)

This commands checks the network for three common types of errors.

1. A Split Network
2. Isolated Busbars
3. Transmission line connected between two busbars of different nominal voltages.

This error check is not automatic as it takes a significant amount of time to check for these errors and it would be wasteful to needlessly perform it. Therefore if the load-flow has difficulty in converging then a check can be made.

4 Data Management

There are two ways in which network data can be entered into the program, either by reading previously stored network data files or via edit facility. Note that the use of response files when editing is valuable in safeguarding data against something unforseen happening before the system is saved.

Individual files can be read at any time. This allows several files for a given component type to be available, and picked up when needed. For example:

```
> READ GEN SPFILE
```

where the SPFILE signals the program to ask the User to specify a filename.

This command cause the LFH to read a generator file and prompt for the filename. Note that some words are reserved for FORTRAN and specifying a file of the same name can cause errors. Usually this only occurs if the program's default directory is the same as the directory from which LFH is being run (i.e. the directory specification is " "). Examples of reserved words are LINE and BASE and therefore it is unwise to use LINE.DAT and BASE.DAT as filenames. Filenames must also conform to all DOS standards.

When the first READ command is entered, the program prompts for the data file directory. For all subsequent READ's, it assumes the files are in this directory. To change the current directory specification, use the CHAN command.

The SAVE command prompts for directory each time it is entered. Note that specifying directory here also changes the directory for the READ operation.

The program takes the absence of a data file to mean there are none of those components in the system, and notifies the user that no files were found.

When writing out data and result files will overwriting an existing file if they have the same filename (Warning is given if this occurs and must confirm before the overwriting occurs). This means that the network data files must be saved in a different directory from where the files are originally situated. This serves as a form of backup, as the original copy of the data is preserved.

For example, the directory structure could be:

```
                        |--- \COPY1
                        |
        |--- \DATA -------|--- \COPY2
        |                 |
        |                 |--- \COPY3
  C: ---|                 |
        |                 |--- \BASE
        |
        |--- \LFH
```

4.1 Suggested Operation

A directory structure with three working directories is recommended. If the data is read from `C:\DATA\COPY1`, then after modification it should be saved in `C:\DATA\COPY2`. Next time LFH is used, the user reads from `C:\DATA\COPY2` and writes to `C:\DATA\COPY3`. The following time, the user reads from `C:\DATA\COPY3` and writes to `C:\DATA\COPY1`, after deleting the original data files in `C:\DATA\COPY1`.

Response files are also useful if many variations of a base system are to be studied. Only one set of network data files is required and one response file for each variation.

5 Component Data and Models

In this section the various components and their data requirements are presented. The various Components are :-

- Busbar
- Generator
- 2-Winding Transformer
- Line
- Shunt
- Induction Motor
- Filter

Other components can be represented by these. For instance, a Synchronous Condensor can be modelled as a generator with zero real power generation. A Series element can be represented as a line with no shunt susceptance and a 3-Winding Transformer as three 2-winding transformers and a Tee busbar.

Some of the data can be discussed independent of the component they represent. All Busbar names are of 12 characters or less in length. The "Status" variable allows a component to be quickly removed from the study and reinstated after it.

5.1 Busbars

The Busbar data must be entered before any other component can be entered.

Busbar Data:-

- Busbar Name
- Area Number
- Status
- Nominal Voltage (kV)
- Voltage magnitude (p.u.)
- Voltage angle (deg.)

The Busbar area number (0 to 9) allows the program user to print the results of a particular area rather than the whole system every time. The Voltage magnitude and angle are used in the load-flow as initial conditions, and are up-dated after completion only if requested. In the fault and harmonic analysis the voltage magnitude is used to convert the loading into the equivalent admittance representation.

The Nominal voltage is used to check for incorrect data and as the base voltage where a conversion between the actual and per-unit quantities is required.

5.2 Generators

Generator Data:-

- Name of Busbar Generator is connected to
- Unit Number
- Status
- Real Power Generation (MW)
- Reactive Power Generation (MVAR)
- Positive Sequence Resistance (p.u.)
- Synchronous Reactance (p.u.)
- Sub-Transient Reactance (p.u.)
- Transient Reactance (p.u.)
- Zero sequence Resistance (p.u.)
- Zero sequence Reactance (p.u.)
- Negative sequence Resistance (p.u.)
- Negative sequence Reactance (p.u.)
- Minimum Reactive Power Generation (MVAR)
- Maximum Reactive Power Generation (MVAR)

The minimum and maximum reactive power generation is used to inform the user of the total of each limit at each busbar when the reactive power control is selected. However, this is as a guide for the user and the values entered under the Q control are used by the load-flow algorithm, not the sum of the individual generator limits entered as generator data.

5.3 2-Winding Transformers

2-Winding Transformer Data:-

- High Voltage Busbar Name

- Low Voltage Busbar Name
- Unit Number
- Status
- Positive Sequence Resistance (p.u.)
- Positive Sequence Reactance (p.u.)
- Zero sequence Resistance (p.u.)
- Zero sequence Reactance (p.u.)
- Negative sequence Resistance (p.u.)
- Negative sequence Reactance (p.u.)
- Rating (MVA)
- High voltage winding connection code
- Low voltage winding connection code
- Location of ON-LOAD tap changer
- Specified Voltage (p.u.)
- Location of where specified voltage applies to
- Tap Position (%)
- Minimum Tap position (%)
- Maximum Tap position (%)
- Tap step (%)
- Rate of change of reactance with tap position

5.3.1 Per-Unit and Percentage Values

It is common practice to express some quantities as percentages, they therefore need to be converted to p.u. on the system studies power. The percentage value specifies the proportion of the base quantity (1 p.u. = 100%). Therefore dividing the percentage value by 100.0 gives the p.u. on the transformer power base. The conversion is :-

$$X_{p.u.} = X_{\%}/100$$

The per-unit value needs to be converted to a per-value based on the systems base power rather than the transformers, before being entered into LFH. This is accomplished by the following formulae :-

$$Z_{p.u.}^{new} = Z_{p.u.}^{old}(S_{base}^{new}/S_{base}^{old})$$

or

$$Y_{p.u.}^{new} = Y_{p.u.}^{old}(S_{base}^{old}/S_{base}^{new})$$

5.3.2 On-load Tap Changers

The On-load tap changing information is important in load-flow studies to enable the algorithm to calculate the correct tap position. If the specified voltage is less than 0.5 fixed tap operation is adopted. For fixed tap operation only tap position need be specified. For voltage control by automatic tap changing, tap position, tap range and tap step need to be specified. If the specified tap position is outside the tap range, the tap position is used as the limit. If the specified tap step is less than 0.01 it will be set to 0.01.

The rate of change of reactance with tap position (DX/DTAP) is used in load-flow studies to update the transformer reactance based on the tap position. For example if the transformer reactance decreases by 1% for each 4% increase in tap value then DX/DTAP = -1/4 = -0.25

5.3.3 Representing Off-Nominal Tap Positions

The per-unit system simplifies the circuit models for transformers by eliminating the ideal transformer as a necessary circuit component. However to realize this simplification the ratio of the base voltages on either side must be equal to the actual turns ratio of the transformer. There are situations where this is impractical or even impossible. For instance, it is impractical to redefine the voltage base every time a tap position changed on an ON-load tap changer. It is impossible to achieve if two transformers of slightly different turns ratio are connected in parallel on both sides. In these cases it is desirable to maintain the base voltages on either side fixed and add a factor to account for the actual turns ratio being different to the base voltage ratio.

Let $t = \frac{N_i}{N_j}$ = transformer turns ratio

Let $b = \frac{V_{i\ base}}{V_{j\ base}}$ = base voltage (or system) ratio

In actual units

$V_i = tV_j$

Converting to per-unit gives :-

$$\frac{V_i}{V_{i\ base}} = \frac{tV_j}{bV_{j\ base}}$$

or

$$V_{i\ pu} = \frac{t}{b} V_{j\ pu}$$

$a = \frac{t}{b} = a_{pu}$ = per-unit turns ratio

Therefore a nominal turns ratio is when a_{pu} =1 (i.e. when $t = b$). The percentage Off-nominal tap positions (denoted $a_{\%}$), required as input to LFH, can be calculated via the following formula:-

$a_{\%} = (a_{pu} - 1.0)100$

The transformer equivalent circuit is shown in Fig. 4

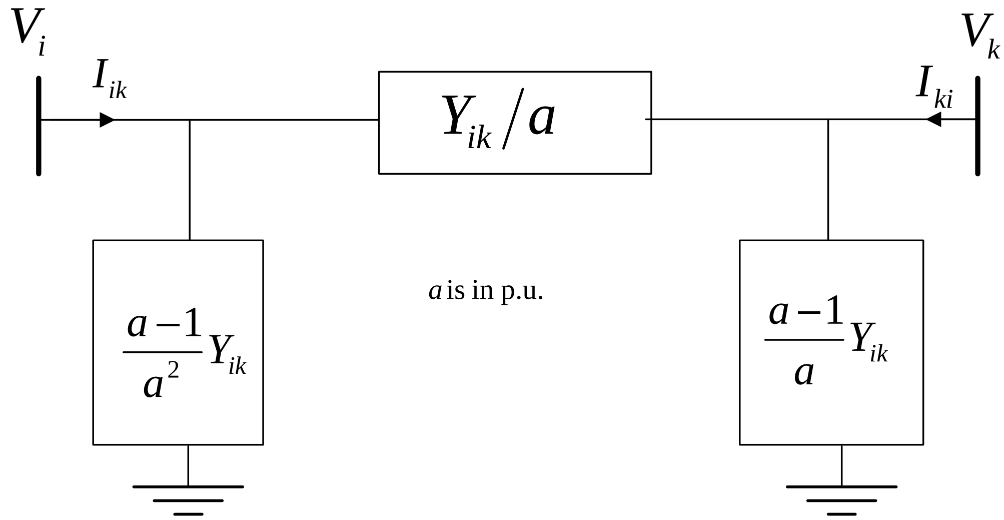


Figure 4: 2-Winding Transformer

5.4 Lines

Line Data:-

- Sending Busbar Name
- Receiving Busbar Name
- Unit Number
- Status
- Positive Sequence Resistance (p.u.)
- Positive Sequence Reactance (p.u.)
- Zero sequence Resistance (p.u.)
- Zero sequence Reactance (p.u.)
- Negative sequence Resistance (p.u.)
- Negative sequence Reactance (p.u.)
- Line Length (km)
- Summer Rating (MVA)
- Winter Rating (MVA)

If summer or winter ratings are entered, the load-flow solution will be automatically compared with these values and overloads flagged when viewing the load-flow results. An error will be flagged if both the positive sequence resistance and reactance are zero. The zero and negative sequence resistance and reactances are used in the fault analysis and if they are not specified, the posistive sequence values will be taken. The line length is used in the Harmonic and Audio frequency analysis to derive *Skin ratios*, that are used to model the skin effect in the lines. If the line length is zero, no skin effect correction is calculated.

Fig. 5 shows the transmission line model used in Load-flow and Fault analysis. Fig. 27 displays the transmission line model used for *Harmonic & Audio Frequency Analysis*. Note the model in Fig. 27 uses hyperbolic functions to correct for long line affects. Moreover the series resistance is frequency dependent in order to model skin effect.

To model a series capacitor a negative series reactance is entered. A simple series element is obtained by setting the shunt susceptance and line length to zero. Note the series resistance or reactance can be zero but not both. The sending and receiving busbars must not be set to the same busbar, if a shunt element is needed use the shunt component model.

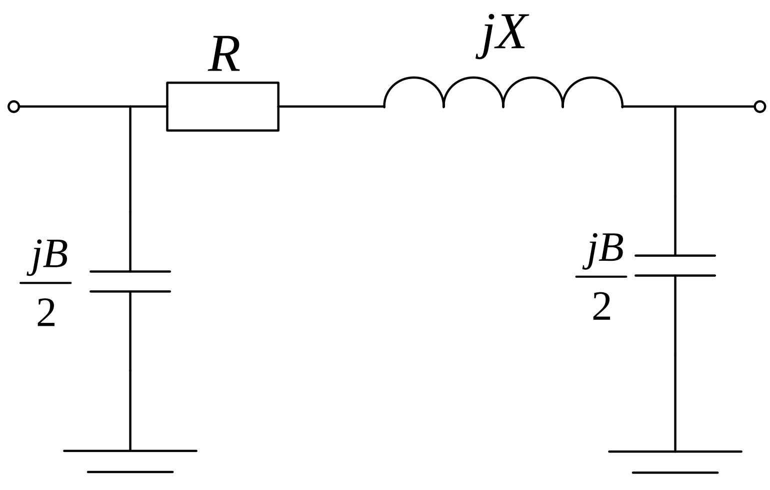


Figure 5: Transmission Line Model for Load-flow and Fault Analysis

5.5 Shunts

Shunt Data:-

- Busbar Name shunt is connected to
- Unit Number
- Status
- Resistance (p.u.)

- Reactance (p.u.)
- Susceptance (p.u.)

The shunt element is an RLC element connected between each phase and earth, as shown in Fig. 6. If the Resistance, Reactance or Capactance is not present a zero value is entered, however all three can not be zero.

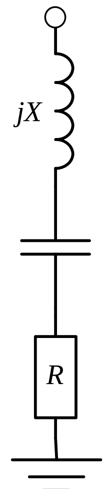


Figure 6: Shunt Component

5.6 Induction Motor

Induction Motor Data:-

- Busbar Name Induction Motor is connected to
- Unit Number
- Status
- Stator Resistance (p.u.)
- Stator Reactance (p.u.)
- Magnetising Reactance (p.u.)
- Inner Squirrel Cage Resistance (p.u.)
- Inner Squirrel Cage Reactance (p.u.)
- Outer Squirrel Cage Resistance (p.u.)
- Outer Squirrel Cage Reactance (p.u.)
- Slip (%)
- Mechanical Power Output (MW)

- Power or Slip Mode

If outer cage resistance and reactance values are not specified, a single cage equivalent is adopted. If the induction motor is a single cage machine the Inner cage parameters must be specified and the outer cage parameters left at zero.

There are two modes, either Power (P) or slip (S). In the power mode, the load-flow will take the given mechanical power and calculate (iteratively) for the slip, at each load-flow iteration. In the slip mode, the load-flow will take the slip as the given quantity. This is useful in calculating the voltage dip due to motor starting as a slip of 100% can be specified. If the mechanical power is set to zero the program will calculate the losses if the stator and magnetising reactance is given, otherwise zero electrical loading from induction motor. If either of the inner cage parameters (resistance or reactance) are zero the losses are neglected and the mechanical power is used with a 0.9 power factor assumed.

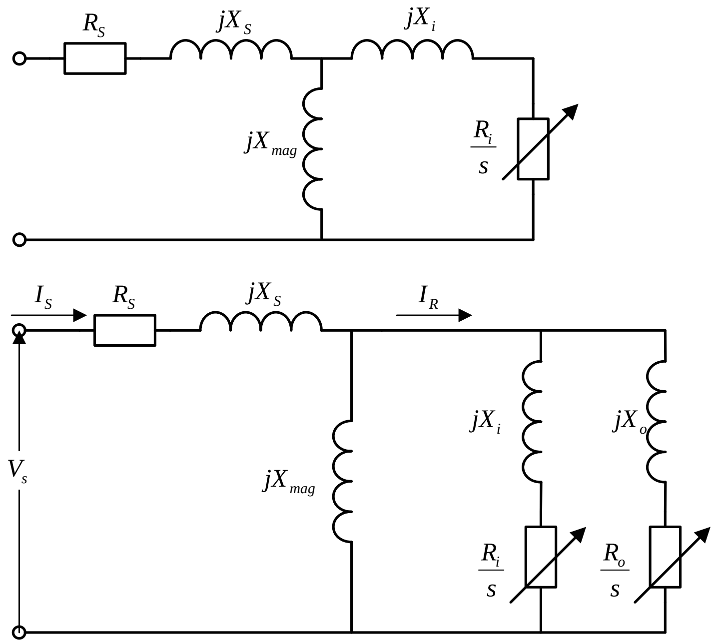


Figure 7: Induction Motor Model

5.7 Filters

Only one filter component can be attached to any busbar, but one filter component can consist of many filters. To enter a filter component a diagram is first drawn and the nodes identified and numbered. The number "1" always refers to the busbar and "0" to earth. Each connection between nodes is entered by entering the two node numbers and the R,L and C values. Note if R,L and C are all specified then it connects the R,L and C in Parallel to each other and from node 1 to node 2. If no R,L or C is required between the two nodes a zero value is entered.

Data Requirement :-

First Line.

```
A/C/R/S Busbar-Name
```

If (A)dd or (C)hange were specified then the second and successive lines of input (any number up to the set Maximum) are:-

```
Node 1   Node 2  R  L  C
```

Note that the units of R, L and C are Ohms, milliHenries, and microFarads respectively.

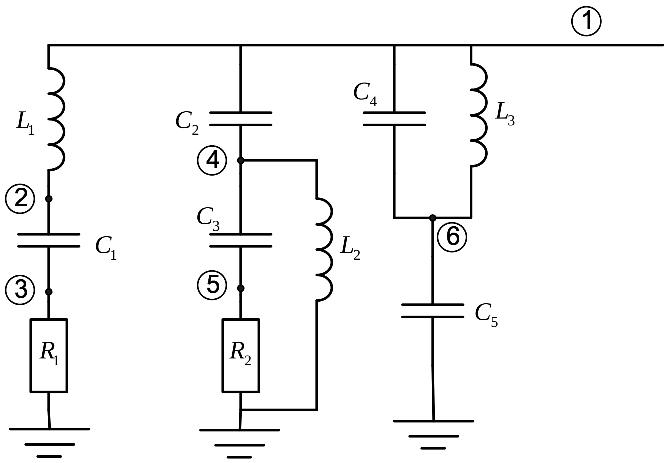


Figure 8: Example of a Filter Component

For example, to enter the filter component shown in Fig. 8 the following sequence would be entered.

Line Number	Entry
1	`A TIWAI----220`
2	`1 2 0  L1`
3	`2 3 0  0  C1`
4	`3 0 R1`
5	`1 4 0  0  C2`
6	`4 5 0  0  C3`
7	`5 0 R2`
8	`4 0 0  L2`
9	`1 6 0  L3 C4`
10	`6 0 0  0  C5`
11	`<Return> to end input`

Summary:-

1. R,L and C are three parallel components
2. Infinite R and L is represented by a value of zero

3. By definition Node 1 = bus, Node 0 = star point (or earth)
4. Maximum node number = 20
5. A branch between two nodes replaces any previous branch data between those nodes
6. Only one filter component can be connected to a busbar

There are a few hidden features. Firstly, when in EDIT FILTER option there are two extra commands, TEST and SHOW. Secondly, when changing a filter if only the two node numbers are entered, the program displays the present component values between these two nodes before prompting for their new values. Test option calculates the admittance of the filters at the designated frequency. This admittance is incorporated into the system matrices for all three analysis.

6 Load-flow

6.1 Introduction

LFH uses the fast-decoupled Newton-Raphson algorithm (FDNR). This method is far superior to the Gauss-Seidel algorithm which is prone to convergence problems. The Gauss-Seidel method is computationally slow and the number of iterations is dependent on system size. The fast-decoupled method is computational more efficiency and more robust than both the Gauss-Seidel and even the full Newton-Raphson method. The paper by Keyhani *et al.* [1] gives an excellent comparison of the various algorithms.

The fast-decoupled Newton-Raphson algorithm can fail to converge when either the decoupling assumptions are violated (i.e. R/X is not small) or when a load is specified that can not physically be supplied by the network (i.e. load is large than the maximum power that can be transferred through the line or network to it).

When the Load-flow option is invoked from the main menu the following menu will appear.

```
            L O A D - F L O W    M E N U
            =============================

    -------------------------------------+------
         DESCRIPTION                       ENTRY
    -------------------------------------+------
    CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
    CONTROL V OR Q.........................[CON]
    PRINT LOG OF INPUT DATA................[PLI]
    RUN LOAD-FLOW..........................[RUN]
    DISPLAY LOADFLOW RESULTS...............[DIS]
    UP-DATE DATABASE.......................[UPD]
    EXIT TO MAIN MENU......................[EXI]
    -------------------------------------+------

    Command >
```

Figure 9: Main Load-flow Menu

Each of these options will be discussed in the next few sections.

6.2 Control Menu

When the control menu is selected from the load-flow menu, LFH displays; the slack busbar, convergence tolerance, maximum number of iterations, percentage load and percentage generation. To change any of these parameters, type the letters in the square brackets and the program will prompt for the appropriate value.

```
   L O A D - F L O W   C O N T R O L   D A T A
   ==============================================

----------------------------------------+-----------
    VARIABLE               PRESENT VALUE  ENTRY TO ALTER
----------------------------------------+-----------
SLACK BUSBAR..................BENMORE-1016..[SLKBS]
CONVERGENCE TOLERANCE (MVA)........0.100000..[CONVT]
MAXIMUM NUMBER OF ITERATIONS........... 40..[MAXIT]
PERCENTAGE LOAD......................100.0..[LOAD]
PERCENTAGE GENERATION................100.0..[GENR]
RETURN TO LOAD-FLOW MENU....................[EXIT]
----------------------------------------+-----------

Change What? >
```

Figure 10: Load-flow Control Data Menu

Please note that each time the load-flow menu is accessed from the main menu the percentage load and percentage generation are set back to 100%. The percentage values allow a quick and easy way of simulation lightly and heavily loaded conditions without having to set up a load or generation file for each case. This option scales the loading and generation by the factor given. A value of 100% corresponds to no scaling of the data read from the files.

If a slack busbar is not specified then the program chooses the busbar where the first generator in the data file (GENR.DAT) is connected to.

6.3 Voltage and Reactive Power Constraints

When V or Q control is selected the menu shown is Fig. 11 is displayed. The control data can be entered by either reading a previously saved control data file or by using Edit to type in. Note that the control data file can only be read and saved from this menu. Edit also allows control data already in memory to be altered or removed. Editing of load-flow control data is performed in the same way as the component data is edited. List displays to the screen (or file) the current V and Q controls. Save writes the current load-flow control data into a file. The default file name is CTRL.DAT, however this can easily be changed by using the SPFILE qualifier.

Control features include: reactive power limits on generators, local or remote voltage control. Note that Voltage constraints can only be placed on PQ busbars. Reactive Power (Q) constraints can be placed at PV or voltage constrained PQ busbars. It is important that the user ensures all the controls specified are reasonable. The three types of control are:-

1. Local Voltage Control : Voltage limits are entered to impose local voltage control on a PQ busbar. MVAR limits may also be entered to give permissible range in Q. Voltage control is abandoned when Q limit is reached.

```
        BUSBAR CONTROL DATA MENU
        ========================
--------------------------------+-----
  OPTION                         ENTRY
--------------------------------+-----
READ CONTROL DATA FROM FILE........[R]
EDIT CONTROL DATA .................[E]
LIST CONTROL DATA .................[L]
SAVE CONTROL DATA .................[S]
--------------------------------+-----

ENTER OPTION >
```

Figure 11: Load-flow V and Q Control Data Menu

2. Remote Voltage Control : To impose remote voltage control on a PQ busbar also specify a controlling busbar name. Voltage control is achieved by varying Q on the controlling busbar, which must therefore be a PV busbar. The reactive power of the controlling busbar can be kept within limits by making a separate entry of Q limits for this busbar. Voltage control is abandoned when a Q limit is reached.

3. Reactive Power Control : MVAR limits can be entered to limit the Q on a PV busbar.

6.4 Display

This option allows the User to display the Load-flow results on the screen or write to a file. The screen display works in the same way as the LIST option in that the results are split up into pages and windows. The user can go forward and backward through the pages and windows. A user can return to the main menu and then re-enter the load-flow menu and display the previous Load-flow results. Any over-loaded lines or transformers will be displayed in a table of over-loaded circuits.

6.5 Up-date

IMPORTANT, PLEASE NOTE

For the load-flow results to be transferred to the main data base this option must be run. Otherwise the load-flow results are not accessible by the other algorithms and not stored in the data files by the SAVE command.

6.6 Motor-Starting Module

LFH is fitted with a motor starting module for looking at the voltage dips due to induction motor starting. This involves two solutions of the Load-flow, the first gives the conditions immediately prior to switching in the induction motor. This, coupled with the generator parameters allows the internal

EMF to be generated. Then a fictitious busbar is created for the internal EMF of each generator and set to be a PV busbar. The load-flow is then solves with the induction motor switched on and the extra busbars present. The basis for this is that the generator AVR's cannot respond to maintain the generator terminal voltage in the time-frame of the motor starting study hence it is the internal EMF that remains constant.

7 Fault

7.1 Introduction

This uses the Standard fault analysis technique of forming and solving the system admittance matrix. The details of the fault algorithm used in the LFH are presented in Chapter 8 of Ref. [2].

On entering the fault menu (Fig. 12) the user will be faced with four options.

```
   F A U L T   A N A L Y S I S   M E N U
   ========================================
-------------------------------------+------
     DESCRIPTION                      ENTRY
-------------------------------------+------
CHANGE FAULT CONTROL DATA..............[CHA]
PRINT LOG OF INPUT DATA................[PLI]
RUN FAULT ANALYSIS.....................[RUN]
EXIT TO MAIN MENU......................[EXI]
-------------------------------------+------

Command >
```

Figure 12: Fault Menu

7.2 Control Menu

The options available are; choice of starting conditions, and the percentage load and percentage generation, as shown in Fig. 13. The two options available for initial conditions. One is to use the classical textbook approach (sometimes referred to as flat start), where all busbar voltages are assumed to be (1.0 + j 0.0)p.u. The second option is to use the load-flow results as the starting condition. Another parameter available to be varied is the percentage load and generation. Please refer to load-flow section for comments on percentage load and generation. Finally a diagnosic indicator can be set. This shows the results at various stages of the calculation and is for the program developers use, not the User. If the diagnostic indicator is set, the results should be sent to a file (otherwise LFH will try writing to Logical Unit 2 without Opening it first).

7.3 Log of Input Data

When activated the Menu shown in Fig. 13 will appear. This menu controls what input data is included in the output file.

```
  F A U L T   A N A L Y S I S   C O N T R O L   D A T A
==========================================================

----------------------------------------------------------
    VARIABLE                                  VALUE  ENTRY
---------------------------------------------------+------
CLASSIC OR LOAD-FLOW START..................LF........[S]
DIAGNOSTIC INDICATOR........................ 0........[D]
PERCENTAGE LOAD.............................100.0.....[L]
PERCENTAGE GENERATION.......................100.0.....[G]
WHICH X VALUE (R:SYN,S:SUB-TRAN,T:TRAN)......S.........[X]
RETURN TO FAULT ANALYSIS MENU.........................[E]
---------------------------------------------------+------

Change What? >
```

Figure 13: Fault Analysis Control Menu

```
  L O G   O F   I N P U T   D A T A   M E N U
  ===============================================

----------------------------------------+-----------
    VARIABLE                PRESENT VALUE  ENTRY TO ALTER
----------------------------------------+-----------
PRINT BUSBAR  INFORMATION...............F...[PBUS]
PRINT BRANCH  INFORMATION...............F...[PBRN]
PRINT MACHINE INFORMATION...............F...[PMCN]
RETURN TO PREVIOUS MENU.....................[EXIT]
----------------------------------------+-----------

Change What? >
```

Figure 14: Print Log of Input Menu

```
Exit from Fault Analysis...............[EXIT]
1 Phase to Ground Fault................[L-G]
Phase to Phase Fault...................[L-L]
2 Phases to Ground fault...............[LL-G]
3 Phase Fault..........................[LL-L]
1 Phase Open Circuit...................[1-OC]
2 Phases Open Circuit..................[2-OC]
ENTER FAULT TYPE? >  LL-L
```

Figure 15: Fault Type Menu

```
Enter Fault Location (or HELP) > AVIEMORE-220

Non-zero impedances? (Y/N) [N] >  Y

Positive seq fault resistance (p.u.) ?  > 0.001

Pos seq fault reactance (p.u.) ?  >  .005

Zero seq fault resistance (p.u.) ? > .001

Zero seq fault reactance (p.u.) ?  > 0.005
```

Figure 16: Entering Fault Parameters

.

8 Harmonic and Audio Frequency Analysis

8.1 Introduction

This is a multi-frequency, multi-injection point analysis. The frequency under consideration need not be a pure harmonic. For instance, 675Hz can be analysed. LFH uses a direct method to solve for the harmonic voltages and currents throughout the system, given the system parameters and the current injections. In the case of AC/DC convertors, the University of Canterbury has other programs for the harmonic currents injected by a convertor.

For the background into harmonics please see Ref. [3].

From the *Harmonics and Audio Frequency Analysis Menu* (shown in Fig. 17) two other menu's are accessible. They are :-

- Control
- Component Models

This are dealt with in the subsequent sections.

```
 H A R M O N I C   &   A U D I O   F R E Q U E N C Y
            A N A L Y S I S   M E N U
 ===================================================

----------------------------------------------+------
    DESCRIPTION                                ENTRY
----------------------------------------------+------
CHANGE CONTROL DATA...........................[CHA]
PRINT LOG OF INPUT DATA.......................[PLI]
RUN AUDIO FREQUENCY ANALYSIS..................[RUN]
SET COMPONENT MODELS..........................[MOD]
EXIT TO MAIN MENU.............................[EXI]
----------------------------------------------+------

Command >
```

Figure 17: Main Harmonic & Audio Frequency Analysis Menu

```
 H A R M O N I C   &   A U D I O   F R E Q U E N C Y
               A N A L Y S I S
      C O N T R O L    D A T A   M E N U
 ===================================================

--------------------------------------------------------+----
    DESCRIPTION                                  VALUE  ENTRY
--------------------------------------------------------+----
CONVERT P+jQ LOAD USING LOAD-FLOW VOLTAGE.......F....[L]
PERCENTAGE LOAD............................100.0....[P]
THRESHOLD VALUE..........................0.1E-06....[T]
WHICH X VALUE (R:SYN,S:SUB-TRAN,T:TRAN).........S....[X]
--------------------------------------------------------+----

Command >
```

Figure 18: Control Menu for Harmonic & Audio Frequency Analysis

8.2 Control Menu

The effect of using the load-flow results to calculate the equivalent current injections of the P+jQ loads rather than assuming a flat Vm=1.0 Vang=0.0 can be quite considerable. Therefore this menu allows the User to choose between flat and load-flow conversion.

8.3 Component Models

The various component models that are active, are displayed as part of the Component Model Menu, when it is selected from the Harmonic & Audio Frequency Analysis Menu. Fig. 19 displays this menu. Note the various models are identified by the author of the papers who proposed and used the models. To change the component type is then selected and the valid models are shown and the user selects the model. Figs. 20 to 23 display the options for each component and Figs. 24 to 27 show a diagram of each model.

8.4 Verification

Much work has been done in this area over the last few years. This harmonic analysis has been tested against 3-phase algorithms [4]. In turn, the 3-phase algorithm has been verified against measured test results (see Ref. [5]).

```
 H A R M O N I C   &   A U D I O   F R E Q U E N C Y
                A N A L Y S I S
 C O M P O N E N T     M O D E L     M E N U
 ===================================================

----------------------------------------------+------
    DESCRIPTION                      DEFAULT   ENTRY
----------------------------------------------+------
Load Model...............................B......[LD]
Transformer Model........................B......[TR]
Generator Model..........................B......[GN]
Transmission Line Model..................B......[TL]
----------------------------------------------+------

Command >
```

Figure 19: Component Model Menu

```
A {(R//jX) Rbf,hXbf}.....................[A]
B {(R//jX) Rbf,Xbf}......................[B]
C {(R//jX) Rbf/k,Xbf/k : k=(0.1h+0.9)}....[C]
Enter Load Model >
```

Figure 20: Load Model Options

```
A {(R+jX)     Rbf,hXbf}................[A]
B {(R+jX)  k1hXbf,hXbf}................[B]
C {(R+jX)  k2hXbf,hXbf}................[C]
D {(R//jX) 180Xbf,hXbf}................[D]
Enter Transformer Model >
```

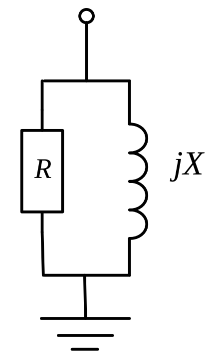
Figure 21: Transformer Model Options

```
A {(R+jX) k1hXbf,hXbf}... (100% X, PF=0.2)........[A]
B {(R+jX) k1hXbf,0.8hXbf} ( 80% X, PF=0.2)........[B]
C {(R+jX) Rbf,hXbf}.......(100% X)................[C]
D {(R+jX) Rbf,0.8hXbf}....( 80% X)................[D]
Enter Generator Model >
```

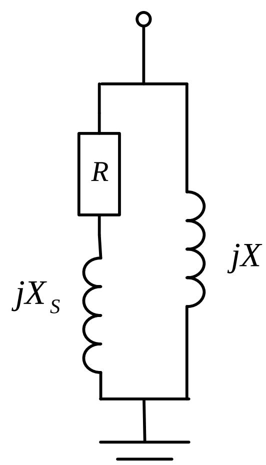
Figure 22: Generator Model Options

```
A {Rbf,hXbf, No Skin Effect}.................[A]
B {k1f**1.5Rbf,hXbf, Baird Model}............[B]
C {k2fRbf,hXbf,     Densem Model}............[C]
Enter Transmission Line Model >
```

Figure 23: Line Model Options



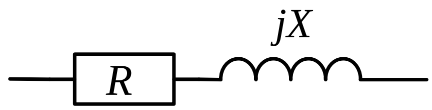
(a) Load Models A,B and C



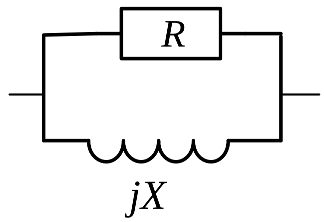
(b) Load Model D

Figure 24: Load Model for Harmonic Analysis

Model A $R = V^2/P_{bf}$, $X = hV^2/Q_{bf}$
Model B $R = V^2/P_{bf}$, $X = V^2/Q_{bf}$
Model C $R = V^2/kP_{bf}$, $X = hV^2/kQ_{bf}$
Model D $R = V^2/P_{bf}$, $X_s = 0.073hV^2/P_{bf}$,$X = hV^2/(6.7Q_{bf} - 0.74P_{bf})$
Note $k = (0.1h + 0.9)$



(a) Transformer Models A,B and C



(b) Transformer Model D

Figure 25: Transformer Model's

Model A $R = R_{bf}$, $X = hX_{bf}$
Model B $R = 0.1026hX_{bf}\frac{j+h}{J+1}$,, $X = hX_{bf}$
Model C $R = R = 0.1026hX_{bf}$ $X = hX_{bf}$
Model D $R = 180X_{bf}$, $X = hX_{bf}$
Note J=ratio of hysteresis to eddy current losses= 3 for silicon steels

9 Limitations and Improvements

9.1 Program Dimensions

The usual number of components accommodated by the real mode version of LFH is:

- 100 busbars
- 100 transmission lines
- 100 transformers
- 200 total branches
- 20 generators
- 100 loads
- 20 filters

9.2 AC/DC Convertors

On the network summary, it can be seen that AC/DC convertors are listed. All three algorithms have the ability to model AC/DC convertors and controllers used for hvdc transmission. However,

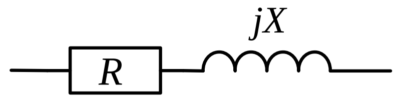


Figure 26: Generator Model's

Model A $R = hX_{bf}/4.899$, $X = hX_{bf}$
Model B $R = 0.8hX_{bf}/4.899$,, $X = 0.8hX_{bf}$
Model C $R = R_{bf}$ $X = hX_{bf}$
Model D $R = R_{bf}$, $X = 0.8hX_{bf}$
Note $tan^{-1}(cos(0.2)) = 4.899$

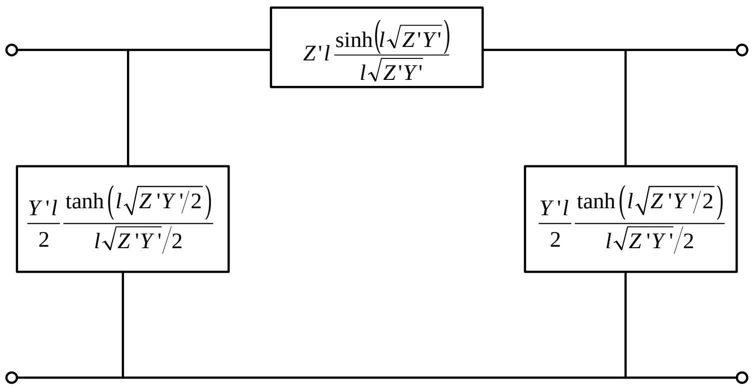


Figure 27: Line Model's

due to the very limited appeal of this feature, it has been disabled in this version and input routines for the model have not been supplied.

10 Other PC Programs

10.1 Utility Programs

A group of utility programs have been developed to aid in developing and using LFH. Table 3 displays the various programs.

Table 3: PC Programs

Program Name	Description
I6PSW	Current Waveform and harmonics for a 6-pulse converter
I12PSW	Current Waveform and harmonics for a 12-pulse converter

Flow as shown below:

```
                                   ---------------
                                   |    User's   |
                                   | Interactive |
                                   |     Input   |
                                   ---------------
                                          |
                                          |
                                          V
 ----------------                      -------       ----------------
 |I6PSW /I12PSW | -----------------> | LFH | <---- | NETWORK DATA |
 ----------------                      -------       ----------------
                                          |
                                          |
                                          V
                                      -----------
                                      | Results |
                                      -----------
```

10.2 Stand-alone Programs

All the analysis programs were developed as stand-alone programs, and are available for PC operation as stand-alone programs. The are many different versions of load-flow available each with its special features. The stand-alone packages can model far bigger systems because there is more memory available. For instance, the standard system size for harmonics is 1805 branches, 850 busbars with the possibility of increasing even further if needed.

References

[1] Keyhani A., Abur A. and Hao S., *Evaluation of Power Flow Techniques for Personal Computers*, IEEE Trans. on Power Systems, Vol. 4, No. 2, May 1989, pp 817-826.

[2] Arrillaga J. and Watson N.R., *Computer Modelling of Electrical Power Systems (2nd Edition)*, Wiley, 2001.

[3] Arrillaga J., Bradley D.A. and Bodger P.S., *Power Systems Harmonics*, Wiley, 1985.

[4] Private communication between N.R. Watson and TRANSPOWER section of the ELECTRICITY CORPORATION OF NEW ZEALAND.

[5] Densem T.J., Bodger P.S. and Arrillaga J., *Three Phase Transmission System Modelling for Harmonic Penetration Studies*, IEEE/PES Summer Meeting, 1983, paper 444-7.

[6] Arrillaga J., Densem T.J. and Harker B.J., *Zero Sequence Harmonic Current Generation in Transmission Lines Connected to Large Convertor Plant*, IEEE/PES Winter Meeting 1983, paper 168-2.

[7] *Westinghouse Electrical Transmission and Distribution Reference Book*, Fourth Edition, 1950.

11 Appendix 1 : Response File

```
  Contents                Comment
=================+==============================================
 READ ALL                 ----- Try to read all components
                          ----- Enter Directory. Data in this directory
 LIST BUS                 --|
 S                          |-- List busbar data to the screen
                            |
                          --|
 LOAD                     ----- Enter Load-flow
 CHA                      --|   Inspect control parameters
 MAXIT                      |-- and change the maximum number
 20                         |   of iterations
 EXIT                     --|
 RUN                      ----- Run Load-flow
 DISP                     --|
 S                          |
                            |-- Display load-flow results
                            |   on the screen
 W 2                      --|
 Q                        ----- Quit displaying Load-flow results
 DIS                      --|   File the load-flow results
 F                          |-- in the file LF.OUT
 LF.OUT                   --|
 EXIT                     ----- Exit load-flow option
 EDIT                     ----- Enter Edit option
 GEN                      ----- Edit generator
 C MANAPOUR1014 1         ----- Change MANAPOUR1014 generator data
 4                        --|-- Change Active power output
 520.                     --|   to 520. MW
                          ----- Exit edit MANAPOUR1014
                          ----- Exit Generator edit
 EXIT                     ----- Exit EDIT Option
 LOAD                     ----- Run Load-flow
 RUN                      ----- Run Load-flow
 DIS                      --|   File the load-flow results
 F                          |-- in the file LF.OUT
 LF2.OUT                  --|
 EXIT                     ----- Exit load-flow
 EXIT                     ----- Exit LFH program
```

12 Appendix 2 : Sample of Program Operation

```
        LL         FFFFFFFF   HH    HH
        LL         FF         HH    HH
        LL         FFFFFF     HHHHHHHH
        LL         FF         HH    HH
        LL         FF         HH    HH
        LLLLLLLL   FF         HH    HH

       Version : 5.1  (8086/8088 Instructions)

       Licensed to : Neville R. Watson
                    by
       System Software & Instrumentation Ltd.
                    and
     Electrical & Electronic Engineering Dept.
         University of Canterbury,
               Christchurch (N.Z.).
                    on
               26 th July 1989




              M A I N   M E N U
              ===================
----------------------------------------+------
     DESCRIPTION                         ENTRY
----------------------------------------+------
READ NETWORK FROM DATABASE...............[READ]
ENTER SYSTEM TITLE.......................[TITL]
LIST NETWORK.............................[LIST]
EDIT NETWORK.............................[EDIT]
SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
LOAD-FLOW ANALYSIS.......................[LOAD]
FAULT ANALYSIS...........................[FAUL]
HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
CHANGE DATABASE..........................[CHAN]
SUMMARY OF NETWORK.......................[SUMM]
SET BASE POWER...........................[POWR]
HELP FACILITY............................[HELP]
TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
```

```
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
@MAN.RFL
 READ ALL

   ENTER DIRECTORY >
 [WATSON.LFH.DATA]

 FILE NAME =[WATSON.LFH.DATA]BUS.DAT
 READING BUSBAR DATA
 NUMBER OF BUSBARS READ IN :   24

 FILE NAME = [WATSON.LFH.DATA]SYSP.DAT
 READING SYSTEM TITLE & PARAMETERS
 SYSTEM TITLE & PARAMETERS HAVE BEEN READ IN

 FILE NAME =[WATSON.LFH.DATA]LOAD.DAT
 READING LOAD DATA
 NUMBER OF LOADS READ IN :   10

 FILE NAME =[WATSON.LFH.DATA]GENR.DAT
 READING GENERATOR DATA
 NUMBER OF GENERATORS READ IN :    7

 FILE NAME =[WATSON.LFH.DATA]SHUN.DAT
 *** NO SHUNT DATA FILE FOUND ***

 FILE NAME =[WATSON.LFH.DATA]LIND.DAT
 READING LINE DATA
 NUMBER OF LINES READ IN :   34

 FILE NAME =[WATSON.LFH.DATA]XFR2.DAT
 READING 2-WINDING TRANSFORMERS DATA
 NUMBER OF 2-WINDING TRANSFORMERS READ IN :    6

 FILE NAME =[WATSON.LFH.DATA]INDM.DAT
 *** NO INDUCTION MOTOR DATA FILE FOUND ***

 FILE NAME =[WATSON.LFH.DATA]FILT.DAT
 *** NO FILTER FILE FOUND ***


                M A I N   M E N U
                ===================
   ----------------------------------------+------
        DESCRIPTION                          ENTRY
```

```
   ----------------------------------------+------
   READ NETWORK FROM DATABASE...............[READ]
   ENTER SYSTEM TITLE.......................[TITL]
   LIST NETWORK.............................[LIST]
   EDIT NETWORK.............................[EDIT]
   SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
   CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
   LOAD-FLOW ANALYSIS.......................[LOAD]
   FAULT ANALYSIS...........................[FAUL]
   HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
   CHANGE DATABASE..........................[CHAN]
   SUMMARY OF NETWORK.......................[SUMM]
   SET BASE POWER...........................[POWR]
   HELP FACILITY............................[HELP]
   TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
LIST BUS

OUTPUT TO:
   SCREEN...........[S]
   FILE.............[F]
   Enter Choice >
S



        B U S B A R     D A T A
NO BUSNAME    AREA S VOLTAGE  MAGN   ANGLE
 1 AVIEMORE-220  8 1  220.0 1.000000       0.
 2 AVIEMORE-011  8 1   11.0 1.045000       0.
 3 BENMORE--220  8 1  220.0 1.000000       0.
 4 BENMORE-1016  8 1  220.0 1.060000       0.
 5 BROMLEY--220  6 1  220.0 1.000000       0.
 6 CROMWELL-220  8 1  220.0 1.000000       0.
 7 INVERCARG220  8 1  220.0 1.000000       0.
 8 ISLINGTON220  6 1  220.0 1.000000       0.
 9 LIVINGSTN220  8 1  220.0 1.000000       0.
10 LOWBURN--220  8 1  220.0 1.000000       0.
11 MANAPOURI220  8 1  220.0 1.000000       0.
12 MANAPOUR1014  8 1   13.8 1.045000       0.
13 NTHMAKARE220  8 1  220.0 1.000000       0.
14 OHAU-S--1011  8 1   11.0 1.050000       0.
15 OHAU-S---220  8 1  220.0 1.050000       0.
16 ROXBURGH-220  8 1  220.0 1.000000       0.
17 ROXBURGH1011  8 1   11.0 1.050000       0.
18 TEKAPO-B-220  8 1  220.0 1.000000       0.
```

```
 19 TEKAPO-B-011  8 1   11.0 1.050000       0.
 20 TWIZEL---220  8 1  220.0 1.000000       0.
(Page   1/  2)    (Window 1/1)  Enter <Rtn>,B,Q,S,W >



        B U S B A R     D A T A
 NO BUSNAME    AREA S VOLTAGE  MAGN   ANGLE
 21 NASBY----220  8 1  220.0 1.000000       0.
 22 THREEMILE220  8 1  220.0 1.000000       0.
 23 TIMARU---220  8 1  220.0 1.000000       0.
 24 TIWAI----220  8 1  220.0 1.000000       0.
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
  .
(Page   2/  2)    (Window 1/1)  Enter <Rtn>,B,Q,S,W >


                    M A I N   M E N U
                    ===================
    ----------------------------------------+------
         DESCRIPTION                         ENTRY
    ----------------------------------------+------
    READ NETWORK FROM DATABASE...............[READ]
    ENTER SYSTEM TITLE.......................[TITL]
    LIST NETWORK.............................[LIST]
    EDIT NETWORK.............................[EDIT]
    SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
    CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
    LOAD-FLOW ANALYSIS.......................[LOAD]
    FAULT ANALYSIS...........................[FAUL]
    HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
    CHANGE DATABASE..........................[CHAN]
    SUMMARY OF NETWORK.......................[SUMM]
    SET BASE POWER...........................[POWR]
```

```
   HELP FACILITY............................[HELP]
   TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
LOAD
```

```
           L O A D - F L O W    M E N U
           =============================

   -------------------------------------+------
        DESCRIPTION                       ENTRY
   -------------------------------------+------
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------

   Command >
CHA
```

```
    L O A D - F L O W   C O N T R O L   D A T A
    ==============================================

 ----------------------------------------+-----------
     VARIABLE               PRESENT VALUE  ENTRY TO ALTER
 ----------------------------------------+-----------
 SLACK BUSBAR..................BENMORE-1016..[SLKBS]
 CONVERGENCE TOLERANCE (MVA)........0.100000..[CONVT]
 MAXIMUM NUMBER OF ITERATIONS............ 40..[MAXIT]
 PERCENTAGE LOAD......................100.0..[LOAD]
 PERCENTAGE GENERATION................100.0..[GENR]
 RETURN TO LOAD-FLOW MENU....................[EXIT]
 ----------------------------------------+-----------

 Change What? >
MAXIT

Maximum Number of Iterations >
20
```

```
    L O A D - F L O W   C O N T R O L   D A T A
    ==============================================

 ----------------------------------------+-----------
     VARIABLE               PRESENT VALUE  ENTRY TO ALTER
 ----------------------------------------+-----------
 SLACK BUSBAR..................BENMORE-1016..[SLKBS]
 CONVERGENCE TOLERANCE (MVA)........0.100000..[CONVT]
 MAXIMUM NUMBER OF ITERATIONS............ 20..[MAXIT]
 PERCENTAGE LOAD......................100.0..[LOAD]
 PERCENTAGE GENERATION................100.0..[GENR]
 RETURN TO LOAD-FLOW MENU....................[EXIT]
```

```
   ----------------------------------------+-----------

   Change What? >
EXIT
```

```
           L O A D - F L O W    M E N U
           =============================

   -------------------------------------+------
       DESCRIPTION                       ENTRY
   -------------------------------------+------
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------

   Command >
RUN
```

```
N U M B E R   I N   D A T A   B A S E
Number of busbars =  24
Number of transmission lines =  34
Number of two winding transformers =   6
N U M B E R   L O A D F L O W   S E E S
Number of busbars =  24
Number of transmission lines =  34
Number of two winding transformers =   6
Total number of branches =  40
ITERATION= 1   PMIS=    7.127481
ITERATION= 1   PMIS=   49.948887
```

```
ITERATION= 2   PMIS=    6.542038
ITERATION= 2   PMIS=    1.231986
ITERATION= 3   PMIS=    0.130109
ITERATION= 3   PMIS=    0.044116
ITERATION= 4   PMIS=    0.007382
ITERATION= 4   PMIS=    0.005879
ITERATION= 5   PMIS=    0.001041
ITERATION= 5   PMIS=    0.000837


+++++++++++++++++++++++++++++++++
+ CONVERGED IN    6. ITERATIONS +
+++++++++++++++++++++++++++++++++
```

```
            L O A D - F L O W    M E N U
            =============================

    -------------------------------------+------
        DESCRIPTION                        ENTRY
    -------------------------------------+------
    CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
    CONTROL V OR Q.........................[CON]
    PRINT LOG OF INPUT DATA................[PLI]
    RUN LOAD-FLOW..........................[RUN]
    DISPLAY LOADFLOW RESULTS...............[DIS]
    UP-DATE DATABASE.......................[UPD]
    EXIT TO MAIN MENU......................[EXI]
    -------------------------------------+------

    Command >
 DISP

 OUTPUT TO:
    SCREEN...........[S]
    FILE.............[F]
    Enter Choice >
```

```
 S

*************************************************************************
*                                                                       *
*                       L F H     P R O G R A M                         *
*                       ------------------------                        *
*                                                                       *
*                     L O A D - F L O W    A N A L Y S I S                       *
*                                                                       *
*************************************************************************

*****************************************************************************
*  THIS IS A TEST TO SEE IF THE SYSTEM TITLE AND PARAMETERS CAN             *
*  BE PICKED UP FROM A DATA FILE CORRECTLY.                                 *
*  HELLO                                                                    *
*****************************************************************************
         DATE :-  0 JANUARY,      0               TIME :- 12:00 PM
=============================================================================
         LOAD      =  100.0 %        BASE POWER    =  100.00 MVA
         GENERATION=  100.0 %        BASE FREQUENCY=    50.0 Hz
=============================================================================

FAST DECOUPLED LOAD FLOW          OUTPUT OF RESULTS
------------------------          -----------------

SOLUTION CONVERGED IN   6 ITERATIONS







Press <RETURN> to continue or Q to Quit >


LINE --------BUSBARS---------   -------SENDING END-------
 NO. FROM         TO                MW      MVAR     MVA
   1 INVERCARG220 MANAPOURI220  -147.809  -38.368  152.707
   2 INVERCARG220 NTHMAKARE220  -173.422  -25.811  175.332
   3 INVERCARG220 ROXBURGH-220    13.766  -26.719   30.057
   4 INVERCARG220 ROXBURGH-220    13.678  -27.018   30.283
   5 INVERCARG220 TIWAI----220   103.808   44.798  113.062
   6 INVERCARG220 TIWAI----220   103.808   44.798  113.062
   7 ISLINGTON220 LIVINGSTN220   -55.571   -0.618   55.574
   8 ISLINGTON220 TEKAPO-B-220  -182.918   29.361  185.260
   9 ISLINGTON220 TIMARU---220   -47.449    1.656   47.478
  10 ISLINGTON220 TWIZEL---220  -182.567   21.283  183.804
  11 ISLINGTON220 BROMLEY--220   -31.510   38.072   49.420
```

```
 12 TWIZEL---220 BROMLEY--220   180.158  -13.699  180.678
 13 NTHMAKARE220 TIWAI----220   119.992   36.686  125.475
 14 NTHMAKARE220 TIWAI----220   119.992   36.686  125.475
 15 NTHMAKARE220 MANAPOURI220  -142.040  -37.572  146.925
 16 NTHMAKARE220 MANAPOURI220  -142.040  -37.572  146.925
 17 NTHMAKARE220 MANAPOURI220  -145.758  -37.964  150.621
 18 LIVINGSTN220 TIMARU---220   105.152  -20.807  107.191
 19 LIVINGSTN220 NASBY----220  -142.805   -4.226  142.867
 20 ROXBURGH-220 NASBY----220   148.276   11.134  148.694
(Page   1/  3)    (Window 1/2)  Enter <Rtn>,B,Q,S,W >


LINE --------BUSBARS---------   -------SENDING END-------
 NO. FROM          TO              MW      MVAR     MVA
 21 AVIEMORE-220 BENMORE--220    23.932   53.628   58.725
 22 AVIEMORE-220 BENMORE--220    23.932   53.628   58.725
 23 AVIEMORE-220 LIVINGSTN220   171.205   10.528  171.529
 24 BENMORE--220 TWIZEL---220  -320.209   35.966  322.222
 25 LOWBURN--220 TWIZEL---220    19.625   20.478   28.363
 26 LOWBURN--220 TWIZEL---220    19.625   20.478   28.363
 27 TEKAPO-B-220 TWIZEL---220   -30.477   -5.203   30.918
 28 ROXBURGH-220 THREEMILE220    77.535   -0.794   77.539
 29 ROXBURGH-220 THREEMILE220    77.535   -0.794   77.539
 30 LOWBURN--220 CROMWELL-220   -19.863  -18.903   27.421
 31 LOWBURN--220 CROMWELL-220   -19.387  -22.052   29.362
 32 CROMWELL-220 ROXBURGH-220   -19.623  -18.720   27.120
 33 CROMWELL-220 ROXBURGH-220   -19.640  -19.861   27.932
 34 TWIZEL---220 OHAU-S---220  -684.516  113.405  693.847
 35 MANAPOURI220 MANAPOUR1014  -587.936 -113.432  598.779
 36 ROXBURGH-220 ROXBURGH1011  -317.977  -51.824  322.172
 37 AVIEMORE-220 AVIEMORE-011  -219.068 -117.784  248.725
 38 BENMORE--220 BENMORE-1016  -232.162 -175.131  290.809
 39 TEKAPO-B-220 TEKAPO-B-011  -159.554   25.363  161.557
 40 OHAU-S---220 OHAU-S--1011  -685.234  108.141  693.714
(Page   2/  3)    (Window 1/2)  Enter <Rtn>,B,Q,S,W >
 W 2

LINE --------BUSBARS---------   ------RECEIVING END------   ----LINE LOSS----
 NO. FROM          TO              MW      MVAR     MVA         MW      MVAR
 20 ROXBURGH-220 NASBY----220   144.664    6.793  144.823     3.612    4.341
 21 AVIEMORE-220 BENMORE--220    23.817   55.417   60.319     0.115   -1.790
 22 AVIEMORE-220 BENMORE--220    23.817   55.417   60.319     0.115   -1.790
 23 AVIEMORE-220 LIVINGSTN220   169.054    5.467  169.142     2.152    5.062
 24 BENMORE--220 TWIZEL---220  -324.689   13.549  324.971     4.480   22.417
 25 LOWBURN--220 TWIZEL---220    19.544   35.980   40.945     0.081  -15.503
 26 LOWBURN--220 TWIZEL---220    19.544   35.980   40.945     0.081  -15.503
 27 TEKAPO-B-220 TWIZEL---220   -30.498   -0.820   30.509     0.021   -4.383
 28 ROXBURGH-220 THREEMILE220    77.126   15.660   78.700     0.409  -16.454
 29 ROXBURGH-220 THREEMILE220    77.126   15.660   78.700     0.409  -16.454
```

```
 30 LOWBURN--220 CROMWELL-220   -19.872  -17.751   26.645     0.008   -1.153
 31 LOWBURN--220 CROMWELL-220   -19.391  -20.830   28.459     0.004   -1.221
 32 CROMWELL-220 ROXBURGH-220   -19.667  -11.087   22.577     0.044   -7.633
 33 CROMWELL-220 ROXBURGH-220   -19.676  -12.054   23.075     0.036   -7.807
 34 TWIZEL---220 OHAU-S---220  -685.231  108.141  693.712     0.715    5.264
 35 MANAPOURI220 MANAPOUR1014  -590.005 -168.600  613.622     2.069   55.168
 36 ROXBURGH-220 ROXBURGH1011  -320.002  -90.075  332.438     2.025   38.252
 37 AVIEMORE-220 AVIEMORE-011  -220.000 -144.307  263.105     0.932   26.523
 38 BENMORE--220 BENMORE-1016  -233.179 -202.268  308.683     1.018   27.137
 39 TEKAPO-B-220 TEKAPO-B-011  -160.000   17.119  160.913     0.446    8.244
(Page   2/  3)    (Window 2/2)  Enter <Rtn>,B,Q,S,W >
 Q
```

```
           L O A D - F L O W     M E N U
           =============================

    -------------------------------------+------
         DESCRIPTION                       ENTRY
    -------------------------------------+------
    CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
    CONTROL V OR Q.........................[CON]
    PRINT LOG OF INPUT DATA................[PLI]
    RUN LOAD-FLOW..........................[RUN]
    DISPLAY LOADFLOW RESULTS...............[DIS]
    UP-DATE DATABASE.......................[UPD]
    EXIT TO MAIN MENU......................[EXI]
    -------------------------------------+------

    Command >
 DIS

 OUTPUT TO:
    SCREEN...........[S]
    FILE.............[F]
    Enter Choice >
 F
```

```
Enter Filename >
LF.OUT




          L O A D - F L O W     M E N U
          =============================

   -------------------------------------+------
        DESCRIPTION                       ENTRY
   -------------------------------------+------
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------

   Command >
EXIT


                 M A I N    M E N U
                 ===================
   ----------------------------------------+------
        DESCRIPTION                          ENTRY
   ----------------------------------------+------
   READ NETWORK FROM DATABASE...............[READ]
   ENTER SYSTEM TITLE.......................[TITL]
   LIST NETWORK.............................[LIST]
   EDIT NETWORK.............................[EDIT]
   SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
   CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
   LOAD-FLOW ANALYSIS.......................[LOAD]
   FAULT ANALYSIS...........................[FAUL]
```

```
   HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
   CHANGE DATABASE..........................[CHAN]
   SUMMARY OF NETWORK.......................[SUMM]
   SET BASE POWER...........................[POWR]
   HELP FACILITY............................[HELP]
   TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
EDIT


       E D I T    M E N U
       -------------------
   BUSBAR.................[BUS]
   TRANSMISSION LINE......[LIN]
   2-WINDING TRANSFORMER..[TR2]
   SHUNT ELEMENT..........[SHU]
   LOAD...................[LOA]
   GENERATOR..............[GEN]
   INDUCTION MOTOR........[IND]
   FILTER.................[FIL]
   EXIT FROM EDIT.........[EXI]
   EDIT WHAT >
GEN

ENTER: A/R/C, NAME, No.
EDIT GENERATOR >
C MANAPOUR1014 1
Busbar Name................................MANAPOUR1014 .................[.1]
Unit Number...................................... 1 .................[.2]
Status........................................... 1 .................[.3]
Active Power Output........................... 590.0000 .................[.4]
Reactive Power Output.........................       0. .................[.5]
Mininum Reactive Power Output.................       0. .................[.6]
Maximum Reactive Power Output.................       0. .................[.7]
Positive Sequence Resistance.................. 0.000430 .................[.8]
Synchronous Reactance......................... 0.151300 .................[.9]
Transient Reactance........................... 0.039300 .................[10]
Sub-Transient Reactance....................... 0.024700 .................[11]
Zero Sequence Resistance......................       0. .................[12]
Zero Sequence Reactance....................... 0.013140 .................[13]
Negative Sequence Resistance..................       0. .................[14]
Negative Sequence Reactance................... 0.026270 .................[15]
Alter all the above...................... ........... .................[16]
Enter Choice >
4
```

```
( DEFAULT = 590.0000 )
 ACTIVE POWER GENERATION (MW) ? >
 520.

 Busbar Name.................................MANAPOUR1014 .................[.1]
 Unit Number................................... 1 .................[.2]
 Status......................................... 1 .................[.3]
 Active Power Output.......................... 520.0000 .................[.4]
 Reactive Power Output.........................       0. .................[.5]
 Mininum Reactive Power Output.................       0. .................[.6]
 Maximum Reactive Power Output.................       0. .................[.7]
 Positive Sequence Resistance.................. 0.000430 .................[.8]
 Synchronous Reactance......................... 0.151300 .................[.9]
 Transient Reactance........................... 0.039300 .................[10]
 Sub-Transient Reactance....................... 0.024700 .................[11]
 Zero Sequence Resistance......................       0. .................[12]
 Zero Sequence Reactance....................... 0.013140 .................[13]
 Negative Sequence Resistance..................       0. .................[14]
 Negative Sequence Reactance................... 0.026270 .................[15]
 Alter all the above..................... ........... .................[16]
 Enter Choice >


 ENTER: A/R/C, NAME, No.
 EDIT GENERATOR >



        E D I T    M E N U
        -------------------
    BUSBAR.................[BUS]
    TRANSMISSION LINE......[LIN]
    2-WINDING TRANSFORMER..[TR2]
    SHUNT ELEMENT..........[SHU]
    LOAD...................[LOA]
    GENERATOR..............[GEN]
    INDUCTION MOTOR........[IND]
    FILTER.................[FIL]
    EXIT FROM EDIT.........[EXI]
    EDIT WHAT >
 EXIT


                   M A I N    M E N U
                   ===================
    ----------------------------------------+------
         DESCRIPTION                          ENTRY
    ----------------------------------------+------
```

```
   READ NETWORK FROM DATABASE...............[READ]
   ENTER SYSTEM TITLE.......................[TITL]
   LIST NETWORK.............................[LIST]
   EDIT NETWORK.............................[EDIT]
   SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
   CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
   LOAD-FLOW ANALYSIS.......................[LOAD]
   FAULT ANALYSIS...........................[FAUL]
   HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
   CHANGE DATABASE..........................[CHAN]
   SUMMARY OF NETWORK.......................[SUMM]
   SET BASE POWER...........................[POWR]
   HELP FACILITY............................[HELP]
   TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
LOAD
```

```
           L O A D - F L O W    M E N U
           =============================

   -------------------------------------+------
        DESCRIPTION                       ENTRY
   -------------------------------------+------
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------
```

```
   Command >
 RUN



 N U M B E R   I N   D A T A   B A S E
 Number of busbars =  24
 Number of transmission lines =  34
 Number of two winding transformers =   6
 N U M B E R  L O A D F L O W  S E E S
 Number of busbars =  24
 Number of transmission lines =  34
 Number of two winding transformers =   6
 Total number of branches =  40
ITERATION= 1   PMIS=    7.127481
ITERATION= 1   PMIS=   49.948887
ITERATION= 2   PMIS=    6.546604
ITERATION= 2   PMIS=    1.229639
ITERATION= 3   PMIS=    0.132772
ITERATION= 3   PMIS=    0.045464
ITERATION= 4   PMIS=    0.006829
ITERATION= 4   PMIS=    0.005683
ITERATION= 5   PMIS=    0.000916
ITERATION= 5   PMIS=    0.000762


+++++++++++++++++++++++++++++++++
+ CONVERGED IN    5. ITERATIONS +
+++++++++++++++++++++++++++++++++
```

```
           L O A D - F L O W    M E N U
           =============================

   -------------------------------------+------
        DESCRIPTION                       ENTRY
   -------------------------------------+------
```

```
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------

   Command >
DIS

OUTPUT TO:
   SCREEN...........[S]
   FILE.............[F]
   Enter Choice >
F

Enter Filename >
LF2.OUT
```

```
           L O A D - F L O W    M E N U
           =============================

   -------------------------------------+------
        DESCRIPTION                       ENTRY
   -------------------------------------+------
   CHANGE LOAD-FLOW CONTROL DATA..........[CHA]
   CONTROL V OR Q.........................[CON]
   PRINT LOG OF INPUT DATA................[PLI]
   RUN LOAD-FLOW..........................[RUN]
   DISPLAY LOADFLOW RESULTS...............[DIS]
   UP-DATE DATABASE.......................[UPD]
   EXIT TO MAIN MENU......................[EXI]
   -------------------------------------+------
```

```
   Command >
EXIT


               M A I N   M E N U
               ===================
   ----------------------------------------+------
        DESCRIPTION                         ENTRY
   ----------------------------------------+------
   READ NETWORK FROM DATABASE...............[READ]
   ENTER SYSTEM TITLE.......................[TITL]
   LIST NETWORK.............................[LIST]
   EDIT NETWORK.............................[EDIT]
   SAVE NETWORK BY WRITING TO DATABASE......[SAVE]
   CHECK TO SEE IF THE NETWORK IS SPLIT.....[CHEC]
   LOAD-FLOW ANALYSIS.......................[LOAD]
   FAULT ANALYSIS...........................[FAUL]
   HARMONIC & AUDIO FREQUENCY ANALYSIS......[HARM]
   CHANGE DATABASE..........................[CHAN]
   SUMMARY OF NETWORK.......................[SUMM]
   SET BASE POWER...........................[POWR]
   HELP FACILITY............................[HELP]
   TO ENTER A DOS COMMAND (E.G. DIR)........[EDOS]
   TERMINATE EXECUTION (RETURN TO DOS)......[EXIT]
   ----------------------------------------+------

   Command >
EXIT


        ### THANK-YOU FOR YOUR TIME ###
```

13 Appendix 3 : Transmission Line Modelling

Transmission lines are represented by an equivalent PI wich is computed for each frequency. Skin effect is taken into account when the line length is known. To gain an understanding of transmission line modelling the paper by Arrillaga *et al.* [6] should be consulted, however, this paper delves into more depth than needed here as it describes three phase modelling of transmission lines at harmonic frequencies.

Model B

Based on the data from Ref. [7]

The resistance at a given frequency f (Hz) is given by:-

$$R_f = K_1 R_d c = K R_{bf} \tag{1}$$

where K_1 *and* K are constants. For transmission line cables, to a first approximation $K_1 = K$.

An equation defining K can be obtained by fitting a curve to the data given the table 5 (Skin Effect Table) of Westinghouse's reference book. Fitting a curve gives:-

$$K = 1 + (0.218M)^3 \tag{2}$$

where the constant M is given by:-

$$M = 0.050132\sqrt{\frac{\mu f}{R_{km}}} \tag{3}$$

where:-

R_{km}	=	Resistance per unit length (Ω/km)
μ	=	permeability = 1.0 for non-magnetic materials

As the resistance/unit length is lower on the larger ASCR type conductors the K factor is larger. However the average resistivity of a ASCR conductor is lower than the steel core, the K factor is reduced from that of a solid conductor. Using a factor of 0.3 to model ASCR conductors gives:-

$$M = 0.050132\sqrt{\frac{0.3f}{R_{km}}} \tag{4}$$

Substituting equation 4 into equation 2 and then substituting this into equation 1 and simplifying gives :-

$$R_f = R_{bf}(1.0 + 2.0 \times 10^{-7}(f/R_{km})^{1.5}) \tag{5}$$