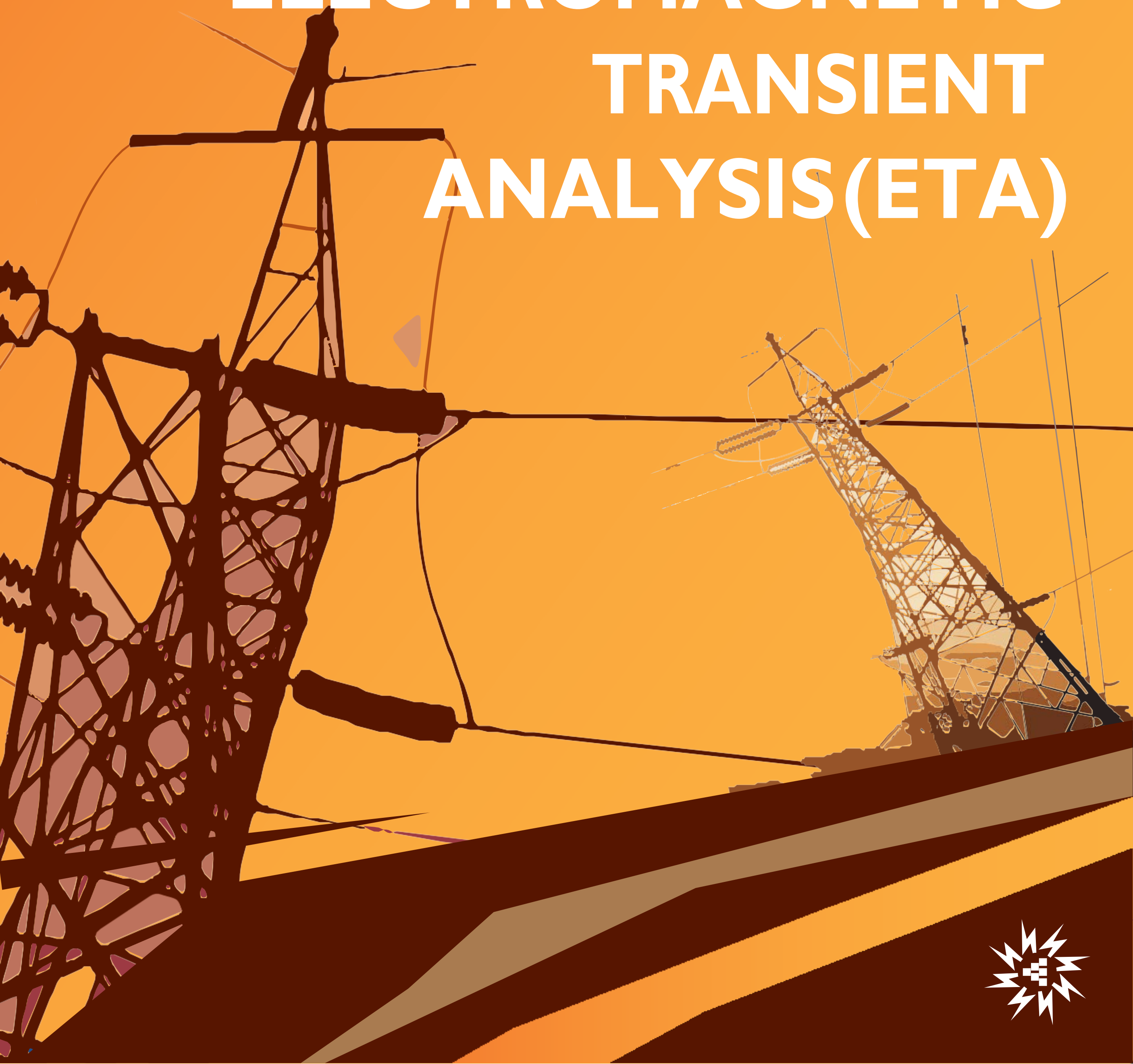
User Manual

PSCT | *Protection Analytic tool*

ELECTROMAGNETIC TRANSIENT ANALYSIS(ETA)



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1. INTRODUCTION

POWERETA module is designed to perform the overvoltage studies for the given system. Using **POWERETA**, it is possible to study the overvoltages arising out of –

- Switching operations
- Different types of faults
- Lightning surges

Power systems may be subjected to overvoltages that may be of transient or of persistent nature. Normally power systems are subjected to two types of overvoltages:

- Overvoltages having atmospheric origin and,
- Overvoltages generated due to internal causes within the power system.

The overvoltages of atmospheric or external origin are called as 'Impulse overvoltages' and those of internal origin are called 'Switching overvoltages' or 'Temporary overvoltages'. Overvoltages stress the insulation of the power system equipment beyond safe limits, leading to equipment failure. Hence it is essential to study overvoltage phenomenon in the power system and their effects on the system.

The transient phenomena occur on a scale of microseconds (e.g., initial transient recovery voltage), milliseconds (e.g., switching surges), or cycles (e.g., Ferro-resonance). The system must be designed to withstand these overvoltages with a certain probability, or their effects must be reduced and limited with protective devices. The simulation of transient phenomena is therefore important for proper insulation co-ordination, as well as for the proper design of protection schemes. Simulation studies are needed to investigate interference in neighbouring communication lines, or hazardous coupling effect to personnel, livestock, and equipment.

POWERETA program input data is through an ASCII file, the format of which is described in Chapter 2. In Chapter 3, the various output files and the error messages generated by POWERETA are listed. Finally in Chapter 4, case studies are given, wherein the data file preparation for typical overvoltage study are discussed along with the analysis of the results.

2. INPUT FORMAT

Input data to **POWERETA** is through an ASCII file. The Input file name is "**ETAIN**". Results are written to output file "**ETAOUT**".

The input data is read in free format. Input data is divided into different heads called *streams* for explanation purposes, `*int*' is used to indicate that the data type is an integer. `*float*' is used to reference the floating point (real) variable. Character streams (string) are indicated by `*char*' type. All the data under different stream are in per unit (pu) on common MVA base (given in *stream 3*), unless the units are specifically mentioned.

Stream 1 : System Description

This consists of 3 lines of data for the description of the power system for which the study is to be done. Each line data is of char type, and maximum number of alphanumeric characters (including blanks) in a line (terminated by a carriage return or line feed) should not exceed 80. Any useful information, which has to appear in the report file ("**ETAOUT**") can be given in this stream.

The comment lines can be given in the data file by entering '%' sign in the first column. Comment line is not written in the output file. These lines are simply read and skipped. However, if the comment line has to appear in the output file also, then one more '%' sign should appear in the second column. In the two statements appearing below, the first line does not appear in the output file, while the second line appears in the output file.

% This comment line does not appear in the output file.
% This comment line appears in the output file.

Stream 2 : System Specification

This consists of one line of data which specifies the system size. Data appearing in different columns are separated by blanks. Since the data is read in free format, data appearing in a line can be given in successive lines also. Table 2.1 gives the data appearing under different columns of this stream.

Table 2.1 : System Specification				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Maximum bus number	int	1	2000
2.	Actual number of buses	int	1	40
3.	Number of user defined filters	int	0	20
4.	Number of series elements	int	0	100
5.	Number of generators	int	0	20
6.	Number of instantaneous sources	int	0	1
7.	Number of RMS sources	int	0	1
8.	Impulse source status	int	0	1
9.	Number of loads	int	0	20
10.	Number of shunt resistors	int	0	20
11.	Number of shunt reactors	int	0	20
12.	Number of magnetizing components	int	0	20
13.	Number of shunt capacitors	int	0	20
14.	Number of shunt capacitors with R_g	int	0	20
15.	Number of delta connected R-L loads	int	0	20
16.	Number of delta connected Capacitors	int	0	20
17.	Number of Static Var Compensators	int	0	10
18.	Number of lightning arresters	int	0	10
19.	Number of non-linear shunt resistors (with V-I characteristics)	int	0	10
20.	Number of delta connected MOV	int	0	10
21.	Number of induction motors	int	0	1
22.	Number of arc furnaces	int	0	1

Explanation for the entries in Table 2.1 are as follows -

- In **POWERETA** bus numbers need not be assigned continuously and there can be cases wherein some buses are deleted. Maximum bus number is equal to the largest bus number of all the buses. The entry in column 1 is equal to the bus number of the last bus (having maximum bus number).
- Actual number of buses refer to total buses that are physically present in the system.
- An unique feature of specifying the user defined filter is provided in **POWERETA**.
- Number of series elements (except VCB) correspond to transformers, switches, series resistors, series capacitors and short and long transmission lines connected between two buses.
- Number of generators, modelled as constant voltage behind the source impedance.
- Instantaneous sources arise due to the modeling of the HVDC converters, rolling mills, arc

furnaces etc. They can be either voltage sources or current sources.

- RMS sources arise due to HVDC converters, rolling mills, arc furnaces etc. In this case RMS value of different harmonic components are given.
- Impulse source, used for modeling of lightning & switching impulses.
- Number of loads, given in terms of MW & Mvar in bus data stream.
- Number of shunt resistors.
- Number of shunt reactors.
- Magnetizing components arise due to the modeling of the transformers.
- Shunt capacitors with solidly grounded neutral.
- Shunt capacitors with resistance ground to represent unbalanced & isolated neutral system.
- Delta connected resistive (R) and inductive (L) loads.
- Delta connected capacitor banks.
- Number of Static Var Compensators (SVC) to improve the voltage profile.
- Lightning/Surge arresters modelled in the form of characteristic equation.
- The non-linear shunt resistors /arresters can be modelled by giving the V-I characteristic.
- Delta connected arresters/Metal Oxide Varisters
- Number of induction motor loads, to study the motor starting behaviour.
- Number of arc furnace loads to study the flickering phenomena.

Stream 3: Base Quantities

This stream consists of system base values as given in Table 2.2.

Table 2.2 : Base Quantities

Col.No.	Description	Type	Min	Max
1.	System frequency in Hzs.	float	1.0	100.0
2.	Base MVA	float	1.0e-6	1.0e+6

Explanation for the entries in Table 2.2 are as follows –

- System frequency is normally 50 Hzs. or 60 Hzs.
- Base MVA is the common base at which per unit values of all the elements are given. It should be selected depending on the system rating. 100 MVA is the base value normally selected.

Stream 4 : Simulation Timings

In this stream simulation timings are given, which consists of 3 fields as given in Table 2.3.

Table 2.3 : Simulation Timings				
Col.No	**Description**	**Type**	**Min**	**Max**
1.	Time step for simulation in seconds	float	1.0e-9	1.0e-4
2.	Maximum simulation time in Seconds	float	1.0e-9	20.0
3.	Screen printing time in seconds	float	1.0e-9	20.0

Explanation for the entries in Table 2.3 are as follows -

- The simulation time step is important which depends on the type of study. Usually it will be in terms of micro seconds. Typical values are 1μ sec, 10 μ sec and 50 μ secs.
- Maximum duration of simulation, normally 1 to 2 seconds will be enough to study the transient behaviour.
- This option is provided to the user to know the program execution status, wherein the current execution time is displayed on the screen at every user given time interval.

Stream 5: Graph Plot Control Option

In this stream plot control options are given, which are essential to control the generation of graph files as per user requirements. Data appearing in different columns of this stream are given in Table 2.4.

Table 2.4 : Graph Control Options				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Phase plot option	int	0	6
2.	Branch current plot option	int	0	1
3.	Shunt component plot option	int	0	1
4.	Number of plot zone/interval	int	0	10
5.	For each zones			
	• starting time in seconds	float	0.0	20.0
	• ending time in seconds	float	0.0	20.0
	• plot steps	int	0	1e+5
6.	Number of plot buses	int	0	40
7.	Plot bus numbers	int	0	2000

Explanation for the entries in Table 2.4 are as follows -

- Phase plot option is interpreted as -

Option	Plot Control
1	Phase A
2	Phase B
3	Phase C
6 (1+2+3)	All phases

Depending on the selected option the graph file generation for the required phase can be controlled.

- Series element current plot status is interpreted as -

Option	Plot Control
0	No plot
1	Plot.

- Shunt component plot status is interpreted as -

Option	Plot Control
0	No plot
1	Plot.

- This option is to visualize a given graph in different time zones/intervals. User can give up to maximum of 10 zones.
- For each plot zone starting & ending time in seconds with the number of plot steps.
- Enter the total number of buses to be plotted. A maximum of 40 buses can be plotted
- Enter the actual bus numbers which are to be plotted

Stream 6: Program Control Indices

Different control indices are read by **POWERETA** to control the program flow. These inputs are specified under this stream. Data appearing in different columns of this stream are given in Table 2.5.

Table 2.5 : Control Option Index

Col.No.	Description	Type	Min	Max

1.	Switching index	int	0	1
2.	Fault index	int	0	1
3.	Report Print index	int	1	4
4.	Peak Print index	int	0	1

Explanation to entries given in Table 2.5 are as follows –

- Switching index is interpreted as -

Index	Program Control
0	No switching operation is considered
1	Switching operation is considered

- Fault index is interpreted as -

Index	Program Control
0	No fault is considered
1	Fault is considered

- Report Print index is interpreted as -

Index	Program Control
1	Standard report generation
4	Detailed report generation

- Peak print index is interpreted as -

Index	Program Control
0	No peak voltage file generation.
1	Peak voltage file generation, it will generate a file named "PEAKOUT", which gives the peak values of voltage at selected buses and tabulated case wise as per the user given time interval in *stream 33*.

Stream 7: Switch Data

This stream will come into picture only when the switching index in *stream 6* is 1. In this stream, all the data related to switch are given as tabulated in Table 2.6.

Table 2.6 : Switch Data

Col.No.	Description	Type	Min	Max
A. Conductance values corresponding to switch status				
1.	Initial conductance value when closed	float	500.0	5000.0
2.	Pre-insertion conductance	float	1.0e-9	1.0e-9
3.	Conductance value when open	float	1.0e-9	1.0e-9
4.	Conductance value when closed	float	1.0e-9	1.0e-9
B. Switch closing timings				
5.	Phase A closing with resistor	float	0.0	10.0
6.	Phase B closing with resistor	float	0.0	10.0
7.	Phase C closing with resistor	float	0.0	10.0
8.	Phase A pre-insertion resistor shorting	float	0.0	10.0
9.	Phase B pre-insertion resistor shorting	float	0.0	10.0
10.	Phase C pre-insertion resistor shorting	float	0.0	10.0

Explanation to entries given in Table 2.6 are as follows –

- When the switch is closed, the resistance across the switch is negligible. Hence, conductance value is given very high say, 5000 pu.
- In EHV systems (400 kV and above), the transmission line circuit breakers are closed with pre-insertion resistors to minimize the switching surges. Pre-insertion conductance value of 4 pu implies 400 ohms on 100 MVA base for 400 kV voltage level.
- When the switch is opened, the resistance value across it is very high. Hence the conductance value is very small, say 1.0e-9 PU.
- A high value is given for conductance in closed position, say 1.0e9 PU.
- Initially the circuit breaker is in open position, which is equivalent to having a high resistor connected between the two ends of each pole. When the switching is

initiated (switching start time is explained under series element data stream), this column gives the time at which pole A should close with resistor after zero crossing of the voltage. This time is usually 0.0 seconds.

- This column gives the time in seconds at which pole B should close with pre-insertion resistor, from the start of closing operation. This time is usually 2 milli seconds.
- This column gives the time in seconds at which pole C should close with pre-insertion resistor, from the start of closing operation. This time is usually 4 milli seconds.
- This column gives the time in seconds at which pole A pre-insertion should be shorted. This is usually 8 milli seconds from the start of closing operation.
- These columns give the time in seconds at which pole B and C pre-insertion resistor should be shorted. These times are usually 10 and 12 milli seconds respectively.

Note : {2} : If no pre-insertion resistors are present, then this value should be given same as conductance value when closed {4}.
{5} to {10} : These timings refer to the moment, at which the switching operation is initiated and not from the beginning of the simulation. For example, simulation starts from 0.0 sec., however switching may be initiated after 0.5 second. Under this condition {5} is 0.002 second, means (0.5+0.002) seconds is the phase A closing time. These timings should be given in sequence and in increasing order.

Stream 8: Fault Data

This stream will come into picture only when the fault index in *stream 6* is 1. In this stream, all the data related to fault are given as tabulated in Table 2.7.

Table 2.7 : Fault Data

Col.No.	Description	Type	Min	Max
A. Fault bus no. and type				
1.	Fault bus number	int	0	2000
2.	Fault type	int	0	8
B. Fault timings				
3.	Fault occurring time	float	0.0	20.0
4.	Fault clearing time	float	0.0	20.0
C. Fault resistance data				
5.	Fault resistance from neutral to	float	0.0	1.0e+

	ground			9
6.	Fault resistance from phase to neutral	float	0.0	1.0e+9
D. Fault tolerance values				
7.	Tolerance for phase A opening	float	0.0	1.0
8.	Tolerance for phase B opening	float	0.0	1.0
9.	Tolerance for phase C opening	float	0.0	1.0
10.	Fault initiation voltage at phase A	float	0.0	1.0
11.	Fault initiation voltage at phase B	float	0.0	1.0
12.	Fault initiation voltage at phase C	float	0.0	1.0

Explanation to entries given in Table 2.7 are as follows -

- Enter the node number at which the fault is created.
- Fault type is interpreted as -

Fault Option	**Fault Type**
1	No fault
2	Line A to ground fault
3	Line B to ground fault
4	Line C to ground fault
5	Line A and B fault
6	Line B and C fault
7	Line C and A fault
8	Line A, B and C fault

Figure 2.1 shows the representation of fault. Depending on the values of fault resistance from neutral to ground, R_{ng} and fault resistance from phase to neutral, R_{pn} fault option is controlled.

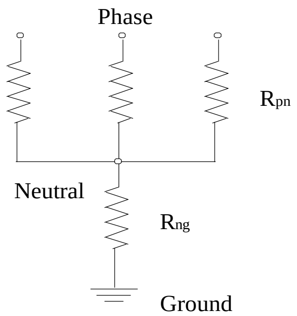

Figure 2.1: Representation of fault.

- Fault initiation time is measured from the beginning of the simulation i.e., t = 0.0 seconds. It is the time at which fault is applied.
- Fault clearing time is measured from the beginning of the simulation i.e., t = 0.0 seconds. It is the time at which fault is cleared.
- Fault resistance from neutral to ground $\mathbf{R_{ng}}$ is 0.0 for earth faults. For line to line fault without involving the ground, this value should be very high say 1.0e+9 pu.
- Fault resistance from phase to neutral $\mathbf{R_{pn}}$ is usually 0.001 pu. Different value can be considered depending on the severity of fault.
- Tolerance values for pole opening during fault clearing are given. Tolerance value is in pu, which is used to detect the zero crossing or maximum voltage. When the absolute value of instantaneous voltage is less than or equal to the tolerance, the opening in each pole is initiated. This is to detect zero crossing. The values are usually 0.02 pu.
- Fault initiation voltage is the magnitude of the voltage at the instant of fault. To initiate the fault at different voltage magnitudes, this value is used. The values for all phases are usually same and equal to 0.005 pu.

Stream 9: Bus data

In this stream, bus details are given. Total number of lines of data are equal to actual number of buses as given under system size specification. Data appearing in different columns of this stream are as given in Table 2.8.

Table 2.8 : Bus Data				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Bus number	int	1	2000
2.	Bus status	int	0	1
3.	Zone number	int	1	1
4.	Bus voltage in KV	float	0.001	1.0e5
5.	Bus name	char	1	8
6.	Bus voltage magnitude	float	0.0	2.0
7.	Bus voltage angle	float	-360.0	360.0
8.	Real power generation in MW	float	-1.0e6	1.0e6
9.	Reactive power generation in MVAR	float	-1.0e6	1.0e6
10.	Real power load in MW	float	-1.0e6	1.0e6
11.	Reactive power load in MVAR	float	-1.0e6	1.0e6
12.	Compensation in MVAR	float	-1.0e6	1.0e6

Explanations to entries given in Table 2.8 are as follows –

- Bus number refers to the number by which the buses are identified. When "**ETAIN**" file is created through integrated environment, the buses are numbered automatically and the numbers are transparent to the user.
- Status field is interpreted as -

Status	**Description**
0	Bus does not exit.
1	Bus exists.

- Zone field refers to the zone number to which the bus belongs.
- Bus voltage is in kilovolts, which is the base voltage for that bus.
- Buses are more commonly referred by names rather than numbers. Bus name is a string of maximum 8 characters. Any alphanumeric characters can constitute the bus name. Bus name should be unique.
- Bus voltage magnitude in pu, voltage angle in degrees, power generation at the bus (MW & Mvar), load at the bus (MW, Mvar and Compensation in Mvar) are obtained from the initial load flow run for the system under consideration. Establishment of proper initial condition is very important in overvoltage study. When **POWERETA** is executed from integrated environment after executing the POWERLFA program (program for load flow analysis), columns 6 to 12 are automatically generated.

Stream 10 : Filter data

In this stream, filter details are given. For each filter, the bus number to which the filter is connected and the number of branch elements (Resistor, Inductor, and Capacitor) that constitute the filter are given. This is followed by the filter data for each branch. The data that appears in different columns for a filter branch is given in Table 2.9.

Table 2.9 : Filter data

Col.No.	Description	Type	Min	Max
1.	Filter branch number	int	0	20
2.	From node	int	0	10
3.	To node	int	0	10
4.	Filter element type	int	1	3
5.	Element value	float	0.0	1.0e4

Explanation to entries in the Table 2.9 are as follows -

- Branch number is the serial number of the filter branch. Total number of branches per filter should be less than 20.
- Filter nodes are numbered in order considering the reference node (ground) as 0 and the bus to which the filter is connected as 1. From and to filter nodes refer to the node numbers of the filter between which the basic filter element is connected.
- Filter element type is interpreted as -

Identification	Filter element
1	Resistor - in□ohm □
2	Inductor - in Henry
3	Capacitor - in □F

In the overvoltage study, each filter component is treated as separate branch, and hence the number of additional nodes added to the original nodes should not exceed 20. If a filter at bus say 8, consists of resistor, inductor and capacitor connected as shown in Figure 2.2, then the data appearing for the filter is as follows-

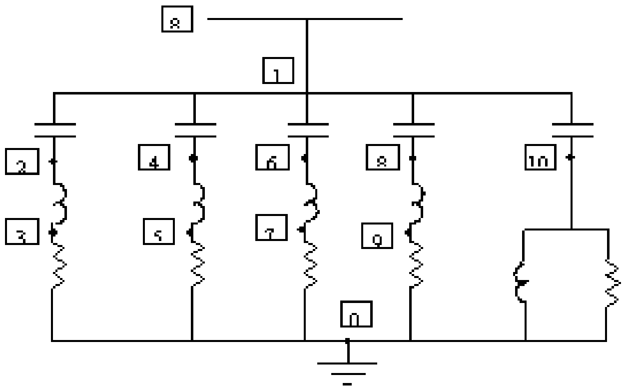

Figure 2.2 : Example for a filter data

Bus No = 8

No. of Branches = 15

Branch	**From node**	**To node**	**Branch element type**	**Actual value**
1	1	2	3	000.417e-6
2	2	3	2	000.974
3	3	0	1	037.000
4	1	4	3	000.417e-6
5	4	5	2	000.497
6	5	0	1	026.600
7	1	6	3	000.417e-6
8	6	7	2	000.201
9	7	0	1	016.900
10	1	8	3	000.417e-6
11	8	9	2	000.145
12	9	0	1	014.400
13	1	10	3	000.417e-6
14	10	0	2	0.085

15	10	0	1	452.000

Stream 11: Branch Data

In this stream, the branch/series element information are given. Values appearing under different columns are given in Table 2.10.

Table 2.10 : Branch information

Col.No	Description	Type	Min	Max
1.	Serial number of the branch	int	1	100
2.	From node number	int	1	2000
3.	To node number	int	1	2000
4.	Type of branch	int	1	8
5.	Positive sequence resistance $\mathbf{R}_p$	float	0.0	1.0e6
6.	Positive sequence reactance $\mathbf{X}_p$	float	-1.0e6	1.0e6
7.	Positive sequence susceptance $\mathbf{B}_p$	float	0.0	10.0
8.	Tap ratio /Line length	float	0.8/1	1.2/1000.0
9.	Zero sequence resistance $\mathbf{R}_z$	float	0.0	1.0e6
10.	Zero sequence reactance $\mathbf{X}_z$ /t_close	float	-1.0e6/1.0e-5	1.0e6/20.0
11.	Zero sequence susceptance $\mathbf{B}_z$ /t_open	float	0.0/1.0e-5	1.0e6/20.0

Explanation to entries given in Table 2.10 are as follows –

- Serial number of the branch is used for information purpose only.
- From and to node numbers between which the branch element is connected.
- Branch type is interpreted as -

Option	Description of Line Type
1	Resistor connected between two nodes. Only fields {5} and {9} values are of interest. However, other fields should be present, but values are ignored.
2	Resistance in series with an inductor to model the transformer and series reactor (inductor). For transformer, tap value is given in tap field. For inductor, resistance value is 0.0. For transformer, resistance value depends on R/X ratio, which is usually 0.05.
3	Series capacitor is considered between the buses. In this case, resistance value is 0.0 and reactance value is negative. Only $\mathbf{X_p}$ and $\mathbf{X_z}$ fields are of interest. Other fields should be present, but the values are ignored.
4	This corresponds to long transmission line. Line charging susceptance is for the complete unit of length. Line is modelled with distributed inductor and capacitor. The positive and zero sequence parameter are for the unit length of the line. The length of the line in unit should be given in the tap ratio/line length field {8}.
5	Switch in closed position. This is used for opening the line to simulate the line tripping or load rejection.
6	Switch in open position. This is used to simulate the charging of a line. Positive sequence resistance, reactance and susceptance fields give the trapped charge in the switch for phase A, phase B and phases C respectively.
7	Time varying resistance. In this case, variation of phase A, B and C resistances with time are specified at discrete time intervals.
8	Double circuit line. For each section considered data is separately given as 6x6 resistance, reactance and susceptance matrices respectively.
9	Frequency dependent line.
10	Vaccum Circuit Breaker (VCB).

- Positive sequence parameters. For switch these fields refer to the trapped charges.
- Tap ratio should be given here for line type 2. For line type 4, it refers to the line length.

Zero sequence parameters. {10} is the closing time in seconds & {11} is the opening time in seconds for switch i.e., for line type 5 & 6 respectively. If the line is to be closed permanently, the opening time should be given more than the maximum simulation time & vice-versa.

Stream 12: Time varying Resistance Data

This stream will come into picture only when the line type in *stream 11* is 7. The time varying resistance is modelled as a combination of linear resistances varying with time as shown in Figure 2.3. The data appearing under different columns are given in Table 2.11.

Table 2.11 : Non-linear resistance data

Col.No.	Description	Type	Min	Max
1.	Number of discrete point	int	0	10
2.	For each point			
	a). Time in seconds	Float	0.0	16.0
	b). Phase A resistance	Float	0.0	1.0e05
	c). Phase B resistance	Float	0.0	1.0e05
	d). Phase C resistance	Float	0.0	1.0e05

Explanations for the entries in Table 2.11 are as follows -

- Number of discrete points to be given here.
- For each point the following data should be given-
  {a} Time in seconds
  {b,c,d} Each phase resistances.

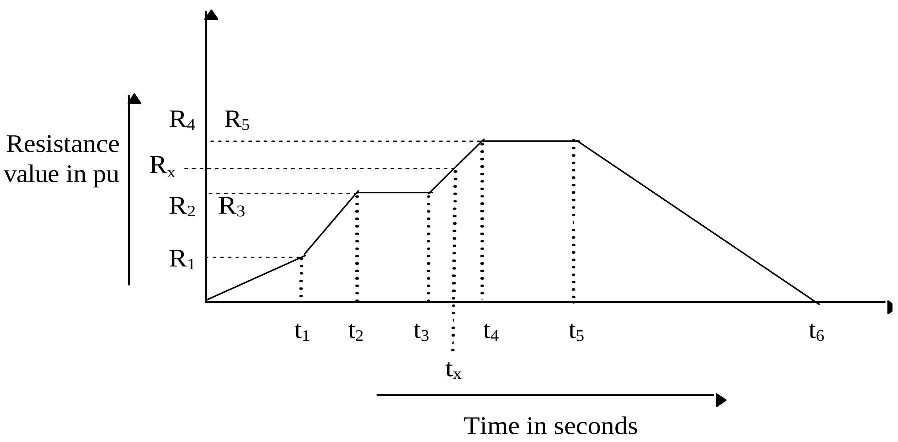

Figure 2.3: Example of a time varying resistance characteristics

In between two discrete time intervals the resistance is determined from the slope as-

$$R_x = \frac{R_4 - R_3}{t_4 - t_3} \times (t_x - t_3) + R_3$$

Note: If the simulation time is less than the minimum time specified, resistance value considered is the one given at the first location. If the simulation time is greater than the maximum time specified resistance value considered is the one given at the last location. Time specified is always in the increasing order. For any other simulation time, resistance value is computed using straight line relation between the two successive points.

Stream 13: Double Circuit Line Data

This stream will come into picture only when the line type in *stream 11* is 8. In this stream, double circuit line details are given. The data appearing under different columns are given in Table 2.12.

Table 2.12 : Double Circuit Line Data

Col.No.	Description	Type	Min	Max
1.	Number of π sections	int	0	10
2.	Length of each π section	float	0.0	100.0
3.	For both circuit and for each π section			
	a). From end bus number	int	0	20
	b). To end bus number	int	0	20
4.	Series resistance in ohm	float	0.0	100.0
5.	Series reactance in ohm	float	0.0	100.0
6.	Line susceptance in mho	float	0.0	10.0
7.	For each circuit and each section initial capacitor current			
	a). Sending end capacitor current magnitude	float	0.0	10.0
	b). Sending end capacitor current angle	float	-90.0	90.0
	c). Receiving end capacitor current magnitude	float	0.0	10.0
	d). Receiving end capacitor current angle	float	-90.0	90.0

Explanations for the entries in Table 2.12 are as follows -

- Total number of π sections to be considered, each π section is considered symmetrical having same length & parameter.
- Length of each π section in Kms.
- For both the circuit and each line section from bus and to bus numbers are given. Bus numbers of the first circuit is given first followed by the second circuit.
- All the π sections are assumed to be symmetrical. π section bus numbers are followed by 6X6 resistance (in ohm per Km), reactance (in ohm per Km) and total line charging susceptance (in mho per Km) respectively. The impedance matrix for the line parameters are represented as -

$Z_{I.I}$(3x3)	$Z_{I.II}$(3x3)
$Z_{II.I}$(3x3)	$Z_{II.II}$(3x3)

(6x6)

Here $Z_{I.I}$ & $Z_{II.II}$ represents the self-impedance matrices for circuit I & II respectively. $Z_{I.II}$ & $Z_{II.I}$ are mutual coupling impedance matrices between circuit I & II respectively.

- {7} Initial capacitor current (magnitude in pu and angle in degree) for each section at the sending end and the receiving end are given.

Stream 14: Vacuum Circuit Breaker Data

This stream will come into picture only when the line type in *stream 11* is 10. This stream consists of the vacuum circuit breaker data connected between two nodes. The data appearing under different columns of each line are given in Table 2.13.

Table 2.13 : VCB data

Col.No.	Description	Type	Min	Max
1.	From end bus number	int	0	2000
2.	To end bus number	int	0	2000
3.	Gap between the two poles in m	float	0.0	10.0
4.	Rate of opening in m/s	float	0.0	10.0
5.	Transient recovery voltage in kV/m	float	0.0	10000.0
6.	Rate of rise of recovery voltage in kV/s	float	0.0	10.0
7.	Chopping current in A	float	0.0	10.0

8.	Arc voltage in volt	float	0.0	100.0
9.	Time of opening in seconds	float	0.0	20.0

Explanations for the entries in Table 2.13 are as follows –

- From & To end node numbers between which the VCB is connected.
- Gap between the two poles, when fully opened.
- Rate of opening of the breaker poles in m/s.
- TRV & RRRV to be specified to check the restricting phenomena.
- Maximum chopping current of the breaker, which is normally 4 to 5 A to be given as specified by the manufacturer.
- Arc voltage in volts, which determines the resistance of the arc during arc creation.
- Time in seconds at which the breaker opening process to be started.

Note : Here, the VCB is modelled to simulate the circuit breaking conditions only.

Stream 15: Frequency Dependent Line Data

This stream will come into picture only when the line type in *stream 11* is 9. This stream consists of the frequency dependent line data connected between two nodes. The data appearing under different columns of each line are given in Table 2.14.

Table 2.14 : Frequency Dependent Line Data

Col.No.	Description	Type	Min	Max
1	Frequency dependent line index	int	1	10
2	Number of samples	int	1	100
3	Frequency count	int	100	2000
4	Number of time step	int	100	1000
5	Damping	Float	1.0	1000
6	For each sample:			
a)	Frequency in Logarithm scale	Float	1.0	100
b)	Zero sequence resistance R_0	Float	10E-4	10E+4
c)	Zero sequence inductance L_0	Float	10E-4	10E+4

d)	Positive sequence resistance R_1	Float	10E-4	10E+4
e)	Positive sequence inductance L_1	Float	10E-4	10E+4

Explanations for the entries in Table 2.14 are as follows –

- Enter index for the frequency dependent line. This index for the frequency dependent lines should appear in the same order as the lines in the branch.
- For all the frequency dependent lines enter parameters of the line (R and L) corresponding to the frequency.
- Damping factor for the line.
- {a} Enter frequency in Log. scale.
- {b,c,d,e} Enter zero sequence and positive sequence line parameters (R & L) in actual per unit length of the line.

Stream 16 : Generator Data

In this stream generator details are given. It is assumed that for the simulation duration, generator internal voltage remains constant. The data appearing in the different columns are given in the Table 2.15.

Table 2.15 : Source (generator) data

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	Positive sequence resistance	float	0.0	10.0
3.	Positive sequence reactance	float	1.0e-4	10.0
4.	Zero sequence resistance	float	0.0	10.0
5.	Zero sequence reactance	float	1.0e-4	10.0

Explanation to entries given in Table 2.15 are as follows –

- Node number is the bus number to which the generator is connected.
- Positive & zero sequence resistances and reactances to be given here.

Stream 17 : Instantaneous Source Data

In this stream, data for instantaneous voltage/current sources are given. Instantaneous current sources are those for which the instantaneous values of injected current at the bus are available. Usually the current is measured using digital instruments, by sampling at discrete intervals. Positive convention is used for the current injected to the bus. It is assumed that the current/voltage sources are ideal. An ideal current source is modelled with a high impedance path in parallel with the current source and an ideal voltage source is modelled with a low impedance path in series with the voltage source. The data appearing in different columns are given in Table 2.16.

Table 2.16 : Instantaneous current source details

Col.No.	Description	Type	Min	Max
1.	Serial number	int	0	1
2.	Bus number	int	0	2000
3.	Voltage/Current index	int	0	1
4.	Number of samples	int	0	1000
5.	For each sample			
	a) Sample count	int	0	1000
	b) Instantaneous current in phase A	float	-1.0e-5	1.0e5
	c) Instantaneous current in phase B	float	-1.0e-5	1.0e5
	d) Instantaneous current in phase C	float	-1.0e5	1.0e5

Explanations for the entries in Table 2.16 are as follows –

- Each instantaneous current source is identified by a serial number. In this field serial number of instantaneous current source is to be entered.
- Node number to which the instantaneous source is connected.
- Voltage/Current source index is interpreted as -

Status	Description
0	Voltage source
1	Current source

- The number of samples to be considered.
- For each samples the following information should be given-
  {a} Sample count is the serial number varying from 1 to number of samples. This field is used for information purpose only. Samples should be present at each simulation time step, for complete simulation interval. In the subsequent lines, instantaneous current values are given.
  {b,c,d} Instantaneous values of current in amperes or voltages in pu for all the 3 phases to be given in these fields.

Stream 18 : RMS Voltage/Current Source

In this stream, rms current/voltage source data is given. The data appearing in different columns are given in Table 2.17.

Table 2.17 : RMS Current/Voltage source details

Col.No.	Description	Type	Min	Max
1.	Node number	int	0	2000
2.	V/I source index	int	0	1
3.	Harmonic count	int	0	20
4.	For each order of harmonics			
	a) Harmonic order	int	1	50
	b) Phase A voltage magnitude	float	0.0	1000.0
	c) Phase A angle in degrees	float	0.0	360.0
	d) Phase B voltage magnitude	float	0.0	1000.0
	e) Phase B angle in degrees	float	0.0	360.0
	f) Phase C voltage in magnitude	float	0.0	1000.0
	g) Phase C angle in degrees	float	0.0	360.0

Explanations for the entries in Table 2.17 are as follows -

- Node number to which the RMS Current/Voltage source is connected.
- Voltage/Current source index is interpreted as-

Status	Description
0	Voltage source
1	Current source

- Harmonic count stands for the total number of different order of harmonics.
- For each order of harmonics the data given is as follows-

{a} Order of harmonics
{b-g} Voltage/Current magnitude and phase angles of all the 3 phases. Voltage magnitude is in pu and current magnitude in ampere.

Stream 19 : Impulse Source Data

In this stream, impulse current/voltage source data is given. The data appearing in different columns are given in Table 2.18.

Table 2.18 : Impulse current/voltage source details

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	V/I source index	int	0	1
3.	Starting time	float	0.0	20.0
4.	Stopping time	float	0.0	20.0
5.	Peak of wave	float	0.0	10.0
6.	Front time in s	float	0.0	100.0
7.	Tail time in s	float	0.0	200.0

Explanation to entries given in Table 2.18 are as follows –

- Node number at which impulse source is connected. Here the impulse is assumed to be applied at phase A only.
- Voltage/Current source index field is interpreted as-

Status	Description
0	Voltage source
1	Current source

- Starting and ending time of the impulse to be applied to the system.
- Peak value of voltage or current impulse wave in pu. For voltage impulse it is in the range of 1 to 2 pu & for current impulse it is in the range of 1 to 10 pu.
- The front time & tail time of the impulse wave in seconds should be given here. Usually for voltage impulse it is 1.2/50 μs & for current impulse it is 8/20 μs. The impulse wave shape is shown in Figure 2.4.

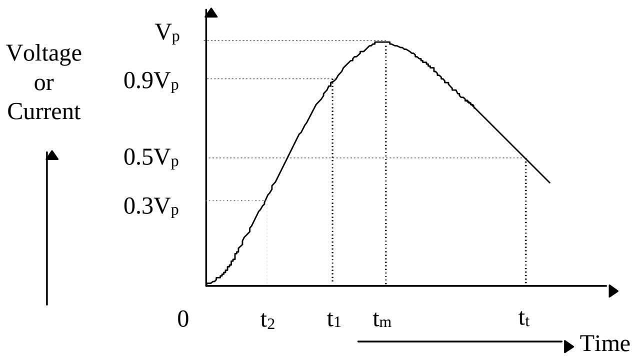

Figure 2.4 : Impulse wave shape

t_f = front time = $(t_2 - t_f)/0.6$ and t_t = tail time

Here, the impulse source is modelled as a double exponential curve as given by equation -

$$I(t) = E\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where E, α and β are constants & I(t) is the impulse voltage or current.

Stream 20 : Load Data

In this stream, load data is given. For each load, one integer field giving actual load bus number is read. The load values are obtained from the bus data stream.

Stream 21 : Shunt Resistor Data

In this stream, data for shunt resistance are given. The model of shunt resistance is shown in Figure 2.5. The data appearing in different columns of each line are given in Table 2.19.

Table 2.19 : Shunt Resistor Details

Col.No.	Description	Type	Min	Max
1.	Bus number	int	0	2000
2.	Phase A resistance	float	0.0	1.0e9
3.	Phase B resistance	float	0.0	1.0e9
4.	Phase C resistance	float	0.0	1.0e9

Explanations for the entries in Table 2.19 are as follows –

- Node number to which the shunt resistance is connected.
- Resistance values in all the 3 phases in pu.

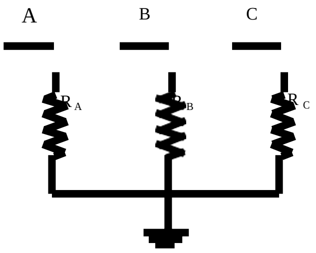

Figure 2.5 : Representation of Shunt Resistor

Stream 22 : Shunt Reactor Data

In this stream, shunt reactors data is read. The model of shunt reactor is shown in Figure 2.6. The data appearing in different columns are given in Table 2.20.

Table 2.20 : Shunt reactor data

Col.No.	Description	Type	Min	Max
1.	Bus number	int	1	2000
2.	Resistance at pre-saturation	float	0.0	1.0e6
3.	Reactance at pre-saturation	float	0.0	1.0e6
4.	Resistance at saturation	float	0.0	1.0e6
5.	Reactance at saturation	float	0.0	1.0e6
6.	Neutral resistance	float	0.0	1.0e6
7.	Neutral reactance	float	0.0	1.0e6
8.	Saturation (Knee point) flux	float	0.0	1.0

Explanations to entries given in the Table 2.20 are as follows -

- Bus number at which the shunt reactor is connected.
- The resistance (R) & reactance(X) values before saturation.
- The resistance (R) & reactance (X) values after saturation.
- Neutral resistance (R_n) and reactance (X_n) values. These values are normally zero for solidly grounded system.
- Saturation flux is in pu (volt/radians/sec). Thus if 1.2 is the pu voltage at which the saturation knee point lies, then flux is given by dividing the knee point voltage by the system base frequency in radians/sec.

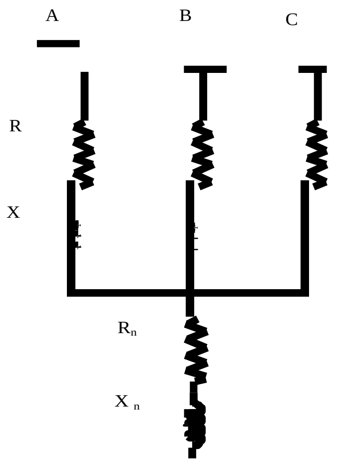

Figure 2.6 : Representation of Shunt Reactor

Stream 23 : Magnetising Component Data

In this stream, magnetizing component data is given. Magnetizing component arises because of the transformers. It is considered usually at primary side of the transformer. Here all the 3 phases are assumed to be balanced. For each phase the magnetising component is modelled as shown in Figure 2.7. The data appearing for each magnetizing component is given in Table 2.21.

Table 2.21 : Magnetizing component data

Col.No.	Description	Type	Min	Max
1.	Bus number	int	1	2000
2.	Resistance at pre-saturation	float	0.0	1.0e6
3.	Reactance at pre-saturation	float	0.0	1.0e6
4.	Resistance at saturation	float	0.0	1.0e6
5.	Reactance at saturation	float	0.0	1.0e6
6.	Saturation (Knee point) flux	float	0.0	1.0
7.	X/R ratio of inductance branch	float	0.0	1000.0

8.	Remnant flux in phase A	float	0.0	1.0
9.	Remnant flux in phase B	float	0.0	1.0
10.	Remnant flux in phase C	float	0.0	1.0

Explanations to entries given in the Table 2.21 are as follows –

- Node number refers to the bus number at which the magnetizing component is considered.
- These fields indicate the resistance & reactance values at pre-saturation.
- These fields indicate the resistance & reactance values at saturation.
- Saturation flux is in pu (volt/radians/sec). Thus if 1.2 is the pu voltage at which the saturation knee point lies, then flux is given by dividing the knee point voltage by the system base frequency in radians/sec.
- Reactance by resistance ratio of the parallel inductance branch. it is usually taken around 500, depending on the transformer rating.
- Usually transformer cores have residual flux. When it is required to charge a transformer, these flux values can be given to find the inrush current and the overvoltage. Flux value is in pu (volts/radians/sec).

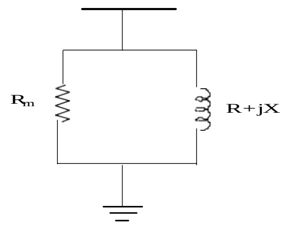

Figure 2.7: Representation of magnetising component

Stream 24 : Shunt Capacitor Data (Balanced)

In this stream, shunt capacitor data is read. The shunt capacitor is modelled as given in Figure 2.8. The data appearing in different columns are given in Table 2.22.

Table 2.22 : Shunt capacitor data

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000

2.	Positive sequence susceptance	float	0.0	10.0
3.	Zero sequence susceptance	float	0.0	10.0

Explanations to entries given in the Table 2.22 are as follows –

- Node number refers to the bus number at which the shunt capacitor is connected.
- Positive & zero sequence susceptance of the capacitor.

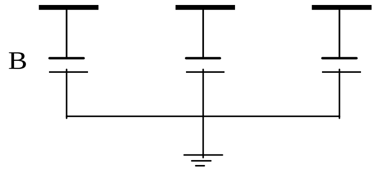

Figure 2.8 : Representation of Shunt Capacitor

Stream 25 : Shunt Capacitor with Resistance Ground *(unbalanced)*

In this stream, shunt capacitor with neutral resistance data is read. The shunt capacitor with resistance ground is modelled as given in Figure 2.9. The data appearing under different coloumns are given in Table 2.23.

Table 2.23 : Shunt capacitor data

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	Phase A susceptance	float	0.0	10.0
3.	Phase B susceptance	float	0.0	10.0
4.	Phase C susceptance	float	0.0	10.0
5.	Neutral to ground resistance	float	0.0	10e+6

Explanations to entries given in the Table 2.23 are as follows –

- Node number refers to the bus number at which the shunt capacitor is connected.
- Susceptance of the capacitor in A, B & C phases.

- Neutral to ground resistance (R_n). This is useful to represent both solidly grounded & resistive grounded neutral.

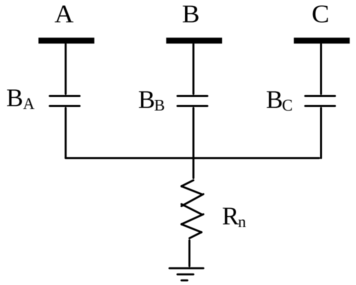

Figure 2.9: Representation of shunt capacitor with resistance ground

Stream 26 : Delta Connected Resistor - Reactor

In this stream, delta connected RL load is read. The delta connected resistor-reactor is modelled as given in Figure 2.10. The data appearing under different columns is given in Table 2.24.

Table 2.24 : Delta RL data				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Node number	int	1	2000
2.	Resistance between phase A & B	float	0.0	10e+6
3.	Resistance between phase B & C	float	0.0	10e+6
4.	Resistance between phase C & A	float	0.0	10e+6
5.	Reactance between phase A & B	float	0.0	10e+6
6.	Reactance between phase B & C	float	0.0	10e+6
7.	Reactance between phase C & A	float	0.0	10e+6

Explanations to entries given in the Table 2.24 are as follows –

- Node number refers to the bus number at which the delta RL load is connected.
- Resistance between the phases.
- Reactance between the phases.

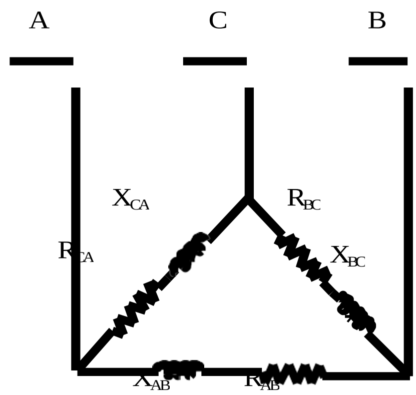

Figure 2.10 : Representation of Delta connected RL

Stream 27 : Delta Connected Capacitor

In this stream, delta capacitance load is read. The delta connected capacitor is modelled as given in Figure 2.11. The data appearing under different columns are given in Table 2.25.

Table 2.25 : Delta Capacitance data

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	Susceptance between phase A & B	float	0.0	10.0
3.	Susceptance between phase B & C	float	0.0	10.0
4.	Susceptance between phase C & A	float	0.0	10.0

Explanations for the entries in Table 2.25 are as follows –

- Node number at which the delta capacitor load is connected.
- Susceptance of the capacitor between the phases.

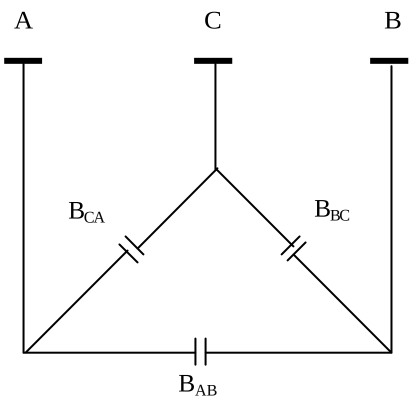

Figure 2.11 : Representation of delta capacitance

Stream 28 : Static Var Compensator Data

In this stream, SVC details is read. The SVC is modelled as a combination of a shunt capacitor and a variable reactor as given in Figure 2.12. Figure 2.13 gives the characteristics of voltage control. The reactance value of the reactor varies within the specified limits depending on the voltage at that particular bus. The data appearing under different columns is given in Table 2.26.

Table 2.26 : SVC Data

Col.No.	Description	Type	Min	Max
1.	Bus number	int	1	2000
2.	Susceptance	float	0.0	10e+6
3.	Minimum reactance (Xmin)	float	0.0	10e+6
4.	Maximum reactance (Xmax)	float	0.0	10e+6
5.	Minimum voltage (Vmin)	float	0.0	10.0
6.	Maximum voltage (Vmax)	float	0.0	10.0
7.	Number of samples	float	0.0	100.0
8.	Number of cycles	float	0.0	100.0

Explanations for the entries in Table 2.26 are as follows –

- Node number refers to the bus number at which the SVC is connected.
- Susceptance of the shunt compensator.
- Minimum & maximum limit of the variable shunt reactor.
- Minimum & maximum limit of the voltage.
- Number of samples per cycle. This field is required to compute the RMS value of voltage in each cycle. Usually it will be around 100.
- Number of start cycle. This field is used to establish the initial conditions. After this specified period the dynamic function of SVC will come into action, i.e., the reactor value will change depending on the voltage level. Usually it is around 5 cycles.

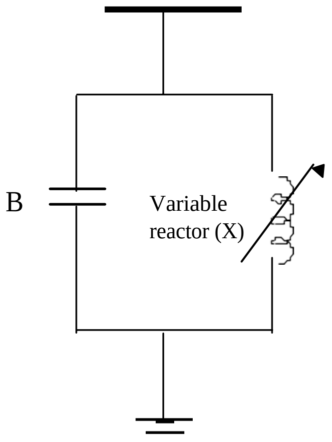

Figure 2.12 : Representation of SVC

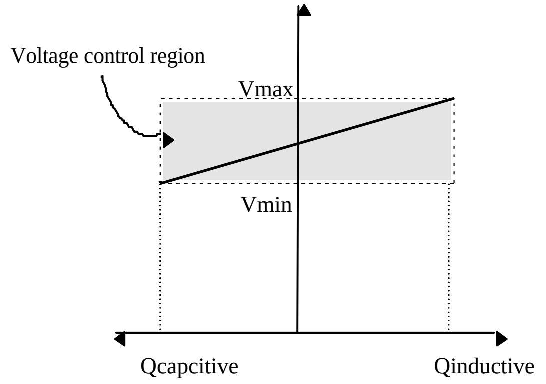

Figure 2.13 : SVC voltage control

Here the capacitance is fixed, the effective compensation is provided by the combination of inductive and capacitive element, by varying the reactor value. The reactance value is changed depending on the voltage level of that particular bus. If the voltage is less than Vmin, inductor is completely cut out and only the capacitor will be in operation. If the voltage is greater than Vmax, inductor is completely in and both inductor and capacitor will be in operation.

For a 50 Mvar SVC,

- with Q_C = 50 and Q_L = 0 Mvar; no voltage control is possible.
- with Q_C = 50 and Q_L = 50 Mvar; voltage control is possible to increase the voltage.
- with Q_C = 50 and Q_L = 100 Mvar; voltage control is possible to reduce the voltage also.

Stream 29: Lightning Arrestor Data

In this stream, lightning arrester data is provided. Lightning arrestor characteristic is non-linear in nature, which is modelled as a combination of 3 curves as shown in Figure 2.14. The data appearing under different columns are given in Table 2.27.

Table 2.27 : Lightning arrester details

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	Multiplication factor for region 1	float	-1.0e4	1.0e4
3.	Power factor for region 1	float	-1.0e4	1.0e4
4.	Voltage magnitude for region 1	float	0.0	10.0
5.	Multiplication factor for region 2	float	-1.0e4	1.0e4
6.	Power factor for region 2	float	-1.0e4	1.0e4
7.	Voltage magnitude for region 2	float	0.0	10.0
8	Multiplication factor for region 3	float	-1.0e4	1.0e4
9.	Power factor for region 3	float	-1.0e4	1.0e4
10.	Voltage magnitude for region 3	float	0.0	10.0

Explanation to entries given in Table 2.27 are as follows –

- Node number at which the lightning arrester is connected.

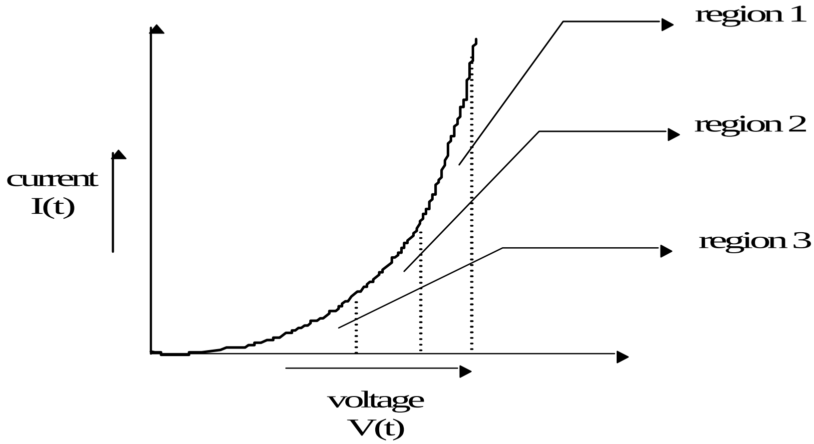

Figure 2.14 : Representation of LA characteristics

Here the Lightning arrester characteristic is modelled as a combination of 3 discrete interval. Each discrete interval is represented in terms of the following expression -

$$I(t) = aV(t)^b$$

where,

I(t) is the current drawn by the lightning arrestor.
V(t) is the voltage at the bus.
a is the multiplication constant.
b is the power constant.

- Represent the constants in all the 3 regions with the voltage limit. Depending on the voltage, characteristic region is selected.

Stream 30 : Arrester with v-i characteristics

This stream contains the arrester/non-linear shunt resistor data which is modelled in terms of V-I characteristics as given in Table 2.28.

Table 2.28 : Arrester with v-i characteristics				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Node number	int	1	2000
2.	Number of points	int	1	20
3.	For each point			
	a). Voltage	float	0.0	1.0e+6
	b). Current	float	0.0	1.0e+6

Explanations for the entries in Table 2.28 are as follows -

- Node number at which the arrester is connected.
- Number of points (voltage, current) in the characteristic.
- For each point the voltage and current values in pu.

Stream 31 : Delta Connected Metal Oxide Varistor (MOV)

This stream contains the delta connected metal oxide varistor (delta arrester) data, which is modelled in terms of V-I characteristics as shown in Figure 2.15. The data appearing under different columns are given in Table 2.29.

Table 2.29 : Delta MOV				
Col.No.	**Description**	**Type**	**Min**	**Max**
1.	Node number	int	1	2000
2.	Number of points	int	1	20
3.	For each point			
	a). Voltage	float	0.0	1.0e+6
	b). Current	float	0.0	1.0e+6

Explanations for the entries in Table 2.29 are as follows -

- Node number at which the delta connected MOV is present.
- Number of points (voltage, current) in the characteristic.
- For each point the voltage and current values in pu.

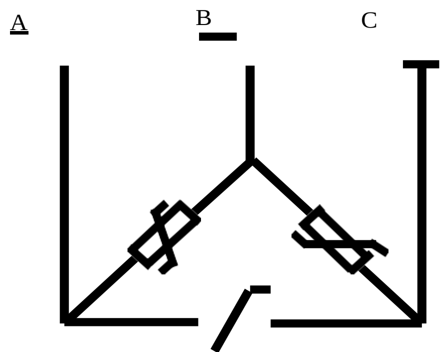

Figure 2.15 : Representation of Delta connected MOV

Stream 32: Induction Motor Data

In this stream, data for induction motor is given. The equivalent circuit representation for each phase is given in Figure 2.16. The data appearing in different columns of each line are given in Table 2.30.

Table 2.30 : Induction Motor details

Col.No.	Description	Type	Min	Max
1.	Bus number	int	0	2000
2.	Stator resistance (R_s)	float	0.0	1.0e5
3.	Stator reactance (X_s)	float	0.0	1.0e5
4.	Rotor resistance referred to stator (R_r)	float	0.0	1.0e5
5.	Rotor reactance referred to stator (X_r)	float	0.0	1.0e5
6.	Magnetising reactance (X_m)	float	0.0	1.0e5
7.	Slip	float	0.0	1.0
8.	Inertia Constant (H)	float	0.0	1.0
9.	Load torque	float	0.0	1.0e5
10.	Torque Constant (phase A)	float	0.0	1.0
11.	Torque Constant (phase B)	float	0.0	1.0
12.	Torque Constant (phase C)	float	0.0	1.0
13.	Starting or running status	int	0	1

Explanations for the entries in Table 2.30 are as follows –

- Bus number is the node number to which the motor is connected
- Stator resistance & reactance values.

- Rotor resistance & reactance values referred to stator side.
- Magnetising reactance.

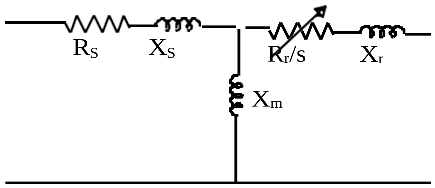

Figure 2.16 : Equivalent circuit of Induction Motor

- Slip of the motor. it is 1 for motor starting.
- Inertia constant (H) is defined as -

$$H = \frac{\frac{1}{2}\left(\frac{2}{P}\right)^2 J \varpi_s^2}{\text{Machine Rating}}$$

where, P is number of poles, J is the moment of inertia in kg-m^2 and ω_S is the angular velocity in revolutions per second (rps).

- Load torque T_{load}.
- Torque constants. The mechanical torque characteristics of the induction motor is represented in terms of equation as-

$$T_m = T_{load}\left(A + B\omega + C\omega^2\right)$$

Where T_{load} is the constant load torque and A, B & C are the proportionality constants.

- Motor running or starting status is interpreted as-

Status	Description
0	Motor starting condition

1	Motor running condition

Note *:* At present the motor is modelled for starting condition only.

Stream 33 : Arc Furnace Load Data

The arc furnaces used in iron and steel industry are the main source of voltage fluctuations in electrical networks, which lead to flicker effect. The arc furnace is modelled as given in Figure 2.17. This stream consists of arc furnace data as given in Table 2.31.

Table 2.31 : Arc Furnace Load data

Col.No.	Description	Type	Min	Max
1.	Node number	int	1	2000
2.	Arc frequency in Hz.	float	0.0	1.0e+6
3.	Maximum arc length in cms	float	0.0	1.0e+6
4.	Lead resistance in ohm	float	0.0	1.0e+6
5.	Lead reactance in ohm	float	0.0	1.0e+6
6.	Number of non-linear arc resistances at different time intervals	int	0	10
7.	For each time interval			
	a). Arc resistance in ohm	float	0.0	1.0e+6
	b). Time in seconds	float	0.0	1.0e+6
	c). Change in arc length in cm	float	0.0	10.0

Explanations for the entries in Table 2.31 are as follows –

- Bus number at which the arc furnace is connected.
- The voltage fluctuations due to random arc length variations leads to a frequency range of 0.5 to 25 Hz.
- Maximum arc length in cms. Usually the anode to cathode voltage drop is around 40 V and voltage drop per unit arc length is around 10 V/cm, which implies an arc length of 4 cm.
- Lead resistance and reactance in ohms. Lead resistance is usually in the order of

3.0e-4 ohm and lead reactance is in the order of 3.0e-3 ohm.

- In a single execution of the simulation, it is possible to specify different arc resistance values at different time intervals to simulate open circuit, short circuit and melt down process. In this field number of such intervals are specified.
- For each time interval-
  {a} Arc resistance in ohm, which is very high for open circuit and very low for short circuit. Intermittent values are considered during melt down process.
  {b} Time in seconds - this field refers to the end point of the interval.
  {c} Change in arc length in cm (Dl) is explained below.

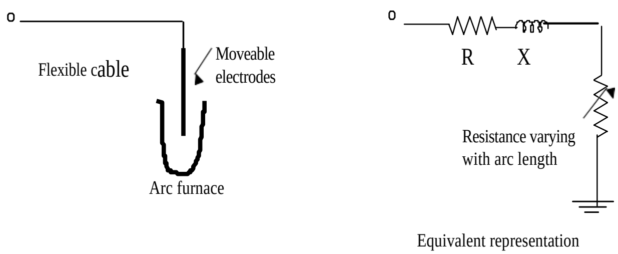

Figure 2.17 : Representation of Arc Furnace Load

In literature various models are reported to represent the arc furnace. In MiP-PSCT a simple time varying resistance model is considered. The resistance is varied as a sinusoidal function as the arc length varies. To incorporate the flicker effect in the model, the voltage-current characteristics must undergo time variations, which corresponds to a time dependence of the arc length. This can be expressed as-

$$V_a = K\, V_{a0}\,(I_a)$$

where V_{a0} is the arc voltage corresponding to the reference arc length l_0
The arc length in sinusoidal time variation law can be expressed as-

$$l_t = l_0 - \frac{Dl}{2}\left(1 + \sin \omega t\right)$$

where, Dl is the maximum variation of arc length, l_0 is the maximum arc length.

Stream 34 : PeakVoltage Print Data

This stream will come into picture only when the **peak print index** in *stream 6* is 1. This contains the options to tabulate the peak voltage. This summarises the peak voltage occurring in all the buses and all the phases in a tabular form in PEAKOUT file. The data appearing under different columns are tabulated in Table 2.32.

Table 2.32 : Peak voltage print data

Col.No.	Description	Type	Min	Max
1.	Number of cases	int	1	2000
2.	For each case			
	a). Case no.	int	0	10
	b). Starting time in sec	float	0.0	10e+6
	c). Ending time in sec	float	0.0	10e+6
3.	Number of peak buses	int	0	10
4.	Bus numbers	int	0	2000

Explanations for the entries in Table 2.32 are as follows –

- Number of cases to print the peak voltage.
- For each case the case id number, starting & ending time.
- Number of buses where the peak values are required.
- Actual bus numbers where the peak values are required.

3. INPUT/OUTPUT FILES

Table 3.1 gives names of different input and output files of **POWERETA** by defaults.

Table 3.1 : Input and Output Files of POWERETA			
Sl.No.	**File Name**	**Mode**	**Description**
1.	"**ETAIN**"	input	Program input file
2.	"**ETAOUT**"	output	Program output (general report) file
3.	**"ETABIN"**	output	Binary file will be generated by passing +b or +B options in the arguments, which contains the graph file informations.
4.	**"PEAKOUT"**	output	Generated, if peak voltage print option is 1.

"ETAIN" file contains -The user defined input data.

"**ETAOUT**" file contains **-** Input data to the program, in the same order as data is read, phase and sequence values of voltage and energy absorbed by the lightning arrestor.

"**ETABIN**" file contains **-** All the graph file informations in binary mode.

The file names in Table 3.1 are the default. For viewing the results by graph, graph module -Migraph has to be invoked. While importing the file, the binary file can be selected at a time. The variables list will be displayed in the screen which user can select according to the requirement.

Error Messages

If any error is traced by the program while execution, an error message is written to the report file and further execution of the program is terminated. The error messages which are traced by the program are printed in the following format -

Error Number ***Error Message Error Description***

Error number is a number by which the error is identified. The nature of error is given in the error message. An error description specific to an user/application is also given.

The errors identified by the program are -

[Error no 0] *Parameter passing error* : If there is an error in passing parameters to the program, then an error is reported. In the description, the missing parameter is named.

[Error no 1] *Input file opening error* : If the input data file name specified by the user is not found or if an error occurs while the input file is opened, this message is generated. If there are more than one input file for the program then, the description specifies missing input file.

[Error no 2] *Output file opening error* : If an error occurs while opening the output file, this message is generated.

[Error no 3] *Too less parameters to read* : If the data provided is insufficient then, this error is displayed. The input data ''stream' for which data is insufficient is also described in the error message.

[Error no 4] *Memory allocation error* : If memory is not allocated for a variable for which dynamic memory allocation is done, this error message is given. The variable for which memory allocation is not successfully done is mentioned in the error description.

[Error no 5] *Invalid character* : If an invalid character data is present in the input data file then this message is generated. The data item for which invalid character is entered is also mentioned in the error message.

[Error no 6] *Invalid number* : If an invalid integer data is present in the input data file then this message is displayed. The data item for which invalid integer data is given is also mentioned in the error message.

[Error no 7] *Invalid value* : If the data given exceeds the limits mentioned for each item mentioned under different streams, an error message is given along with a description of the data item.

[Error no 8] *Division by zero* : During a mathematical operation, if division by zero occurs, then this error is generated. The variables which may have caused this condition is mentioned in the error description.

[Error no 9] *Diverging error* : This message is generated if no convergence is observed after a specified number of iterations.

[Error no 10] *Error in data, Results not okay* : If an erroneous input data is present which doesn't come under any of the above mentioned categories as a result of which wrong results are obtained, then this message is generated.

These errors are displayed in the output file mentioned by the user. Some of the common error messages and their probable reason for occurrence are -

For example:

if etain is the input file and ***etaout*** is output (report) file, then if input file is not found in the current working directory, or error while opening the file, message-

ERROR [1] : *Input file opening error* - Input file not opened for reading is written to the report file. If the program expects data to be read from input file, but the user has not provided data and end of file is reached, then the error message.

ERROR [3] : *Too less parameters to read* - Insufficient data provided for Stream is written to the report file. If the from/to bus of a transformer specified by the user doesn't exist in the bus data stream, then an error message

ERROR [6] : *Invalid number* - Invalid bus id specified is written to the report file.

4. CASE STUDY

In this chapter, a typical power systems is considered with most of the data and element types to explain the execution and analysis of results of **POWERETA**. A three phase fault study for a sample system is considered to highlight the capability of POWERETA.

The sample power system considered for the analysis consists of 7 buses at same voltage level, two generators at buses 6 & 7 and a lightning arrestor at bus 5. Figure 4.1 shows the single line diagram of the sample system. Initial condition is first established in the circuit by closing the switches SW1 & SW2 at 0.02 second. A three phase fault is applied at bus 3 at 0.06 second and again the fault is cleared at 0.12 second. Tables 4.1 and 4.2 lists "**ETAIN**" and "**ETAOUT**" files respectively. Figure 4.1(a) & 4.1(b) shows the plot of voltages for phases A, B and C at bus 5 & 3 respectively.

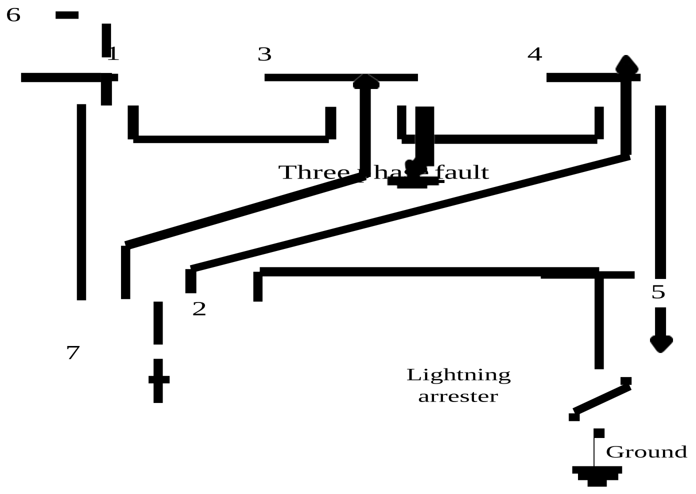

Figure 4.1 : A sample test system

Table 4.1 : Input File(ETAIN)

```
%======STREAM 1 : System Description
% First 3 line will appear on the output file as it is. The first character
% of the string should not be '%' character, if its so it will be treated as
% a comment line.
%
Input format for the Overvoltage Study
3 phase fault study
Sample 7 bus system with Lightning arrester
%
%====STREAM 2 : SYSTEM SPECIFICATION
%
%1. number(id) of bus (highest bus no.)
%2. actual number of bus present in the system          ( S-BUS    )
%3. no. of Filter                                ( S-FILT   )
%4. no. of Line (all series elements except VCB)        ( S-BRANCH )
%7. no. of Generator                              ( S-GEN    )
%8. no. of Instantaneous source                      ( S-INST   )
%9. no. of RMS source                             ( S-RMS    )
%10.no. of Impulse Source                           ( S-IMPL   )
%11.no. of Load                                  ( S-LOAD   )
%12.no. of Shunt Resistor                          ( S-RES    )
%13.no. of Shunt Reactor (R&L)                       ( S-REA    )
%14.no. of Maganetizing Branch                        ( S-MAG    )
%15.no. of Shunt Capacitance (solidely grounded)        ( S-CAP    )
%16.no. of Shunt Capacitance with Resistance Ground     ( S-CAPRG  )
%17.no. of DELTA RL                               ( S-DELTRL )
%18.no. of DELTA C                                ( S-DELTC  )
%19.no. of Static Var System                         ( S-SVC    )
%20.no. of Lightning Arrrester                       ( S-LIGHT  )
%21.no. of Arrester characteristics
%      ( by giving points on V-I characteristics)       ( S-ARSTVI )
%22.no. of Delta Metal Oxide Varistor                 ( S-MOV    )
%22.no. of Induction Motor (starting)                 ( S-MOT    )
%23.no. of Arc Furnace                            ( S-ARC    )
%
% SYSTEM SPECIFICATION
%  1.nbus      2.actual_bus  3.nFilt    4.nLine
       7         7            0          9
%  7.nGen      8.nInst       9.nRms    10.nImpl
       2           0            0          0
% 11.nLoad    12.nRes        13.nRea    14.nMagz    15.nCap   16.nsRgc
      4           0            0          0          0          0
% 17.nDelt-RL  18.nDelt-C     19.nSvc
```

```
      0            0             0
% 20.nLar      21.nArst-VI    22.n_dMOV  23.Motor     24.nArc furnace
      1           0              0          0          0
%
%====STREAM 3 : BASE QUANTITIES
%Base_freq
%Base_MVA
% (S-BASE)
50.0 100.0
%===STREAM 4 : SIMULATATION TIMINGS
%1.time step(dt)  ( < 50 micro sec)
%2.maximum simulation time
% (S-TIME)
  0.000050  0.2
%
%=====STREAM 5 : GRAPH PLOT CONTROL OPTION
% (S-PLOT)
% 1 = phase A, 2 = phase B, 3= phase C, 6 = all three phases
  6
% 2. index for volt plot (0=no plot, 1=plot in pu, 2=plot in kv, 3=both)
  1
% 3. index for series element current plot (0=no plot, 1=plot)
  0
% 3. index for shunt element current plot (0=no plot/ 1=plot)
  1
% 4.No. of plot interval Regions
  2
% 5.For each plot interval min & max time & no. of plot steps
% i.starting time ii.ending time iii.no. of plot steps
  0.0     0.08     10
  0.08    0.2      5
%
% 6. No. Plot buses
  2
%7. plot bus nos
 3 5
%
%======STREAM 6 : PROGRAM CONTROL INPUTS
%1.Switch Index (1=switch is present)
%2.Fault_index (0 or 1)
%3.report print index ( 1 or 4)
%4.peak voltage printing index  (0 or 1)
%(S-INDEX)
%  1    2   3  4
   1    1   1  1
```

```
%
%=======STREAM 7 : SWITCH DATA
%(S-SWITCH)
%A. conductance values corresponding to SWITCH
%
%1.initial conductance value when closed
%2.preinsertion conductance 1
%3.conductance value when open
%4.conductance value when closed
   10e+9   10e+9  10e-9  10e+9
%  500.0   4.0    10e-9  10e+9
%
%B.closing time sequences
%
%1.phase A closing with resistor
%2.phase B closing with resistor
%3.phase C closing with resistor
%4.phase A preinsertion resistor shorting
%5.phase B preinsertion resistor shorting
%6.phase C preinsertion resistor shorting
%


%Note : the time field 1 to 6 should be in ascending order
%
 .00000  .0020000  .0040000  .008000  .01000 .01200
%
%======STREAM 8 : FAULT DATA
%(S-FAULT)
%A.
%1.fault bus no
%2.fault type
%3.fault occuring time
%4.fault clearing time
%
3  8  0.06 0.12
%B : fault resistance data
%1.fault resistance from neutral to ground
%2.fault resistance from phase to neutral
%
0.0  0.001
%C : fault tolerance values
%1.tolerance for phase A opening
%2.tolerance for phase B opening
%3.tolerance for phase C opening
%4.Fault intiation voltage at phase A
```

```
%5.Fault intiation voltage at phase B
%6.Fault intiation voltage at phase C
%
0.002 0.002 0.002 0.005 0.005 0.005
%=====STREAM 9 : BUS DATA
%1.bus no. 2.status 3.zone_no. 4.bus_base_voltage in kV 5.bus_name
%6.Vin (mag) 7.Vain(angle in degree) 8.Pgen 9.Qgen 10.Pload 11.Qload 12.Qcomp
%
%1  2 3   4      5       6        7     8       9     10    11   12
% (S-BUS)
 1  1 1  132.00 BUS1     0.0      0.0    130.0   -7.5   0.0  0.0 0.0
 2  1 1  132.00 BUS2     0.0      0.0     40.0   30.0  20.0 10.0 0.0
 3  1 1  132.00 BUS3     0.0      0.0      0.0    0.0  45.0 15.0 0.0
 4  1 1  132.00 BUS4     0.0      0.0      0.0    0.0  40.0  5.0 0.0
 5  1 1  132.00 BUS5     0.0      0.0      0.0    0.0  60.0 10.0 0.0
 6  1 1  132.00 BUS6     1.0      0.0      0.0    0.0   0.0  0.0 0.0
 7  1 1  132.00 BUS7     1.0      0.0      0.0    0.0   0.0  0.0 0.0
%
%======STREAM 10 : FILTER DATA
%1.bus_no.
%2.no. of branch_element
%For each branch
%i.sl.no. of flt_branch
%ii.from_node
%iii.to_node
%iv.flt_element_type
%v.element_value
%(S-FILT)
%


%======STREAM 11 : BRANCH DATA  (series elements)
%1.sl no.
%2.from_node
%3.to_node
%4.branch_type
%5.positive sequence resistance Rp
%6.positive sequence reactance Xp
%7.positive sequence susceptance Bp /2
%8.tap_ratio / line length
%9.zero sequence resistance Ro
%10.zero sequence reactance Xo / Closing time
%11.zero sequence suceptance Bo/2 / Opening time
%(S-BRANCH)
% 1   2  3    4  5         6         7         8    9        10       11
%
  1   1   2   4  2.009e-2  5.997e-2  6.001e-2  1.0  4.02e-2  1.20e-2 4.80e-2
  2   1   3   4  8.000e-2  2.400e-1  4.997e-2  1.0  1.60e-1  4.80e-1 4.00e-2
```

```
 3   2   3   4  5.997e-2  1.800e-1  4.008e-2  1.0  1.20e-1  3.60e-1 3.20e-2
 4   2   4   4  5.997e-2  1.800e-1  4.008e-2  1.0  1.20e-1  3.60e-1 3.20e-2
 5   3   4   4  9.990e-3  2.996e-2  2.000e-2  1.0  2.00e-2  6.00e-2 1.60e-2
 6   4   5   4  8.000e-2  2.400e-1  4.997e-2  1.0  1.60e-1  4.80e-1 4.00e-2
 7   2   5   4  3.994e-2  1.200e-1  3.000e-2  1.0  8.00e-2  2.40e-1 2.40e-2
 8   6   1   6  0.0       0.0       0.0       1.0 0.0      0.02     10.01
 9   7   2   6  0.0       0.0       0.0       1.0 0.0      0.02     10.01
%
%Note : The opening & closing time should be given for Switch. If the switch
%       is to be done only open or close then give a high value ( more than
%       the total simulation time) in the other field.
%
%=====STREAM 12 : NON_LINEAR RESISTANCE DATA
%1.no. of discrete points
% for each point
%i.time in sec ii.phase A resistance  iii.phase B res  iv.phase C res
%
%======STREAM 13 : DOUBLE CIRCUIT LINE DATA
%(S-DCL)
%1.Number of pi section 2.Length of each pi section
%3.For Circuit I & II and for each pi section (first I then II)
% a).from end b) to end
%4.Circuit resistance in ohm (6x6)
%5.Circuit reactance in ohm (6x6)
%6.Circuit suceptance in mho (6x6)
%7.For Circuit I & II and for each pi section (first I then II) intial cap
% current (a & b). sending end cap i and angle
% (c & d).receiving end cap i and angle
%
%======STREAM 14 : Vacuum Circuit Breaker DATA
%initially vcb is in closed position
%1.from_end  2.to_end  3.dist_VCB (mts)    4.rate_open (mts/sec) 5.trv(kv/mm)
%6.rrrv(kv/sec)  7.chop_I(4 to 5 amp) 8.arc_voltage 9.time_open(sec)
% (S-VCB)
%


%======STREAM 15 : GENERATOR DATA (infinite gen modeling)
%1.bus_no.
%2.positive sequence source resistance Rp
%3.positive sequence source reactance Xp
%4.zero sequence source resistance Ro
%5.zero sequence source reactance Xo
%(S-GEN)
 6  0.0   0.25   0.0  0.25
 7  0.0   1.5    0.0  1.5
%
```

```
%====STREAM 16 : INSTANTANEOUS SOURCE DATA
%1.serial no.  2.bus_no.    3.V/I_index (0=voltage, 1=current)
%4.no._of_samples
%5.For each sample
%i.sample_count
%ii.instantaneous current in phase-A  I_A
%iii.instantaneous current in phase-B I_B
%iv.instantaneous current in phase-C  I_C
%(S-INST)
%
%====STREAM 17 : RMS VOLTAGE\CURRENT SOURCE
%1.bus_no.
%2.source_type( whether voltage or current source)
%           0 - voltage
%           1 - current
%3.harmcount -total order of harmonics
%4.For each order of harmonics
%i.harm order
%ii.magnitude of phA (amp/pu)
%iii.angle phA(degree)
%iv.magnitude of phB
%v.angle phB
%vi.magnitude of phC
%vii.angle phC
%(S-RMS)
%
%=====STREAM 18 : IMPULSE SOURCE DATA
%1.bus_no. 2.Voltage or Current source index (1= current, 0 =voltage)
%3.starting time 4.stopping time
%5.Peak value 6.front time 7.tail time
%(5.constant E   6.constant alpha  7.constant betta )
%(S-IMPL)
%
%=====STREAM 19 : LOAD DATA
%1.bus numbers(give all the node no's where load is present)
%(S-LOAD)
%
4  5  2 3
%====STREAM 20 : SHUNT RESISTANCE DATA
%1.bus_no.
%2.phase A resistance in pu
%3.phase B resistance in pu
%4.phase C resistance in pu
%(S-RES)
%


%======STREAM 21 : SHUNT REACTOR DATA
```

```
%1.bus_no.
%2.resistance at pre-saturation Rpre   3.reactance at pre-saturation Xpre
%4.resistance at saturation     Rsat   5.reactance at saturation      Xsat
%6.neutral resistance          Rneu   7.neutral reactance           Xneu
%8.Knee_flux
%(S-REA)
%
%=====STREAM 22 : MAGNETISING COMPONENT DATA
%1.bus no.
%2.resistance at pre-saturation Rpre   3.reactance at pre-saturation Xpre
%4.resistance at saturation     Rsat   5.reactance at saturation      Xsat
%6.Knee point flux 7. X/R ratio of the inductance branch
%8.Remnant flux phA 9.Remnant flux phB 10.Remnant flux  phC
%(S-MAG)
%
%=====STREAM 23 : SHUNT CAPACITOR DATA (solidly grounded)
%1.bus no.
%2.+ve seq susceptance       3.zero seq susceptance
%(S-CAP)
%
%=====STREAM 24 : STAR CAPACITANCE RESISTANCE GROUND(unbalanced)
%1.bus no.
%2.phase A Suspetance
%3.phase B Suspetance
%4.phase C Suspetance
%5.Resistance from neutral to ground
%(S-CAPRG)
%
%=====STREAM 25 : DELTA Resistance-Reactance LOAD(balanced/unbalanced)
%1.bus no.
%2.Resistance between phase A & B
%3.Reactance between phase A & B
%4.Resistance between phase B & C
%5.Reactance between phase B & C
%6.Resistance between phase A & C
%7.Reactance between phase A & C
%(S-DELTR)
%

%=====STREAM 26 : DELTA CAPACITANCE LOAD
%1.bus no.
%2.Suspetance between A & B
%3.Suspetance between B & C
%4.Suspetance between C & A
%(S-DELTC)
%
%====STREAM 27 : Static Var Compensator Data
%1.bus no. 2.Susceptance Bc   3.Initial reactance Xci
```

```
%4.Maximum Reactance Xcm  5.Vmin   6.  Vmax
%7.No. of samples  8.No. of cycles
% (S-SVC)
%

%====STREAM 28 : LIGHTNING ARRESRER DATA
%1.bus no.
%2.multiplication constant for region-1 a_1
%3.power constant for region-1 b_1
%4.voltage magnitude for region-1 V_1
%5.multiplication constant for region-2 a_2
%6.power constant for region-2 b_2
%7.voltage magnitude for region-2 V_2
%8.multiplication constant for region-3 a_3
%9.power constant for region-3 b_3
%10.voltage magnitude for region-3 V_3
%(S-LIGHT)
    5 0.00001 10.0 1.2 0.0000015   31.42 1.56 0.0041908  8.50833 1.8
%   5 0.0     1.0  0.5 0.0000002  23.08 1.14 0.0002071 13.8     1.25
%

%====STREAM 29 : No of nonlinear shunt resistor (v-i characteristic)
%1.bus no.
%2.no of points on the v-i characteristics
%3. for each point voltage and current in pu
%example of a 10kA arrester
%(S-ARSTVI)
%
%======STREAM 30 : DELTA METAL OXIDE VARISTOR DATA
%
%1.bus no.
%2.no of points on the v-i characteristics
%3. for each point i.voltage and ii.current in pu
%example of a 10kA arrester
%(S-DELTMOV)
%
%======STREAM 31 : INDUCTION MOTOR DATA
%1.bus_no.  2.stator resistance  3.stator reactance
%4.rotor R refer to stator side 5.rotor X  refer to stator side
%6.magnetising reactance 7.slip    8.inertia constant(H)   9.load torque
%10.torque constant(t1)  11.torque constant(t2)  12.torque constant(t3)
%13.tolerance 14.no. of iteration
%15.status of the motor i.e., starting or running condition
%                        (0=starting,1=running)
%the following options are to be given if it's in running conditions
%16.intial stator I_mag 17.stator I_angle 18.rotor I_mag 19.rotor I_angle
%(S-MOT)
%
```

```
%====STREAM 32 : Arc furnace data
%1.busno.
%2.Arc_frequency_Hz 3.Max_arc_length_cms 4.Arc_change_cms
%5.tolerance       6.max_iter          7.Arc_R_ohm  8.Arc_x_ohm
%9.ca              10.cb               11.da        12.db       13.a    14.b
%15.model_type - no. of non linear resistance section
%16. for each section
%  i.resistance in ohm   ii.time in sec  iii.Arc_changes
%(S-ARC)
%

%=====STREAM 33 : PEAK VOLTAGE PRINT DATA
%1.no of cases to find the peak voltage
2
%2.for each case
% i.  case no. ii. minimum time iii.maximum time
%
1   0.0  0.04
2   0.04 2.0
%3.number of peak Bus
5
%4.peak bus numbers :
%     Give the important bus numbers where peak values are required
1  2   3 4 5
%
%Relay test data
0
```

Table 4.2: Output file(ETAOUT)

```
==========================================================================
             Date and Time : Fri Dec 18 13:28:19 1998

                  Powereta
===========================================================================

Input format for the Overvoltage Study
3 phase fault study
Sample 7 bus system with Lightning arrester

------------------------------------------------------------------------------
SYSTEM SPECIFICATION
========================
LARGEST BUS NUMBER USED                    :   7
ACTUAL NUMBER OF BUSES                     :   7
NUMBER OF USER DEFINED FILTERS             :   0
NUMBER OF SERIES ELEMENTS                  :   9
NUMBER OF GENERATORS                       :   2
INSTANTANEOUS VOLTAGE/CURRENT SOURCES      :   0
RMS VOLTAGE/CURRENT SOURCES                :   0
IMPULSE CURRENT STATUS                     :   0
NUMBER OF LOADS                            :   4
NUMBER OF SHUNT RESISTORS                  :   0
NUMBER OF SHUNT REACTORS                   :   0
NUMBER OF MAGNETIZING COMPONENTS           :   0
NUMBER OF SHUNT CAPACITORS                 :   0
NUMBER OF SHUNT CAPACITORS(Resistance Ground): 0
NUMBER OF DELTA_R-L                        :   0
NUMBER OF DELTA CAPACITANCE                :   0
NUMBER OF STATIC VAR SYSTEMS               :   0
NUMBER OF LIGHTNING ARRESTERS              :   1
NUMBER OF Arrester Non linear resistor(shunt)

(by giving points on V-I characteristics) : 0
NUMBER OF DELTA MOV                        :   0
NUMBER OF MOTORS                           :   0
NUMBER OF ARC FURNACE                      :   0
------------------------------------------------------------------------------
SYSTEM FREQUENCY                           :  50 Hzs.
BASE MVA                                   :  100
------------------------------------------------------------------------------
SIMULATION TIMINGS
===================
TIME STEP FOR SIMULATION  (in micro sec)   :  50
```

MAXIMUM SIMULATION TIME (in sec) : 0.2

GRAPH PLOT CONTROL OPTION

==============================

Plot phase option(6=all,1=A,2=B,3=C) : 6
Plot volt opt(0=no print,1=pu,2=volt,3=both) : 1
Plot line I option(1=print,0=not print) : 0
Plot shunt I option(1=print,0=not print) : 1

Number of PLOT INTERVAL : 2
For Each INTERVAL :

sl. no.	Start time	End time	plotting steps
1	0.000000	0.080000	10
2	0.080000	0.200000	5

No. of PLOT BUSES : 2

PLOT BUSES No's : 3 5

Different INDEX options

========================

SWITCHING INDEX : 1
FAULT INDEX : 1
Report PRINT INDEX : 1
Peak Print INDEX : 1

SWITCH DATA

====================

INITIAL CONDUCTANCE VALUE WHEN CLOSED : 1e+010
PRE-INSERTION CONDUCTACE 1 : 1e+010
CONDUCTANCE VALUE WHEN OPEN : 1e-008
CONDUCTANCE VALUE WHEN CLOSED : 1e+010

switching and pre-insertion timings

==================================

PHASE A CLOSING WITH RESISTOR : 0.00000
PHASE B CLOSING WITH RESISTOR : 0.00200
PHASE C CLOSING WITH RESISTOR : 0.00400
PHASE A PRE INSERTION RESISTOR SHORTING : 0.00800
PHASE B PRE INSERTION RESISTOR SHORTING : 0.01000
PHASE C PRE INSERTION RESISTOR SHORTING : 0.01200

FAULT BUS : 3 TYPE : 8 LINE A, B and C FAULT

Fault Timings

```
===================
FALT INITIATION TIME                          : 0.06
FAULT CLEARING TIME                            : 0.12
FAULT RESISTANCE (Rg) FROM NEUTRAL TO GROUND : 0
FAULT RESISTANCE (Rp) FROM PHASE TO NEUTRAL     : 0.001
TOLERANCE FOR PHASE A POLE OPENING             : 0.002
TOLERANCE FOR PHASE B POLE OPENING             : 0.002
TOLERANCE FOR PHASE C POLE OPENING             : 0.002
FAULT INITIATION VOLTAGE AT PHASE A           : 0.005
FAULT INITIATION VOLTAGE AT PHASE B           : 0.005
FAULT INITIATION VOLTAGE AT PHASE C           : 0.005

-------------------------------------------------------------------------------
BUS DATA
==============
 NO. STATUS ZONE VOLT-KV NAME VOLTGW-M VOLT-ANG PGEN-MW QGEN-MVAR PL-
                             MW          QL-MVAR    QCOMP-MVAR
----- ------ ----- -------- ----- -------- ---------- ------------ ------------
   1     1    1    132.000     BUS1  0.00000  0.000  130.00000   -7.50000
                                   0.00000 0.00000     0.00000
   2     1    1    132.000     BUS2  0.00000 0.000    40.00000   30.00000
                                   20.0000 10.00000     0.00000
   3     1    1    132.000     BUS3  0.00000 0.000     0.00000    0.00000
                                   45.0000 15.00000     0.00000
   4     1    1    132.000     BUS4  0.00000 0.000     0.00000    0.00000
                                   40.00000 5.00000     0.00000
   5     1    1    132.000     BUS5  0.00000 0.000     0.00000    0.00000
                                   60.00000 10.0000     0.00000
   6     1    1    132.000     BUS6  1.00000 0.000     0.00000    0.00000
                                   0.0000  0.00000     0.00000
   7     1    1    132.000     BUS7  1.00000 0.000     0.00000    0.00000
                                   0.0000   0.00000   0.00000
--------------------------------------------------------------------------------
BRANCH INFORMATION
===================
 SLNO  FROM   NAME    TO    NAME   TYPE   Status  RP        XP        BP
                          TAP       RZ      XZ       BZ
---- ---- -------- ---- -------- ---- -------- -------- -------- -------
   1    1    BUS1    2    BUS2    4    0    0.02009   0.059970   0.060010
                             1.000 0.04020    0.01200   0.04800
   2    1    BUS1    3    BUS3    4    0    0.08000    0.24000  0.049970
                             1.00  0.16000    0.48000   0.04000
   3    2    BUS2    3    BUS3    4    0    0.05997    0.18000  0.040080
                             1.00  0.12000    0.36000   0.03200
   4    2    BUS2    4    BUS4    4    0    0.05997    0.18000  0.040080
                             1.00  0.12000    0.36000   0.03200
   5    3    BUS3    4    BUS4    4    0    0.00999   0.029960   0.020000
                             1.00  0.02000    0.06000   0.01600
```

```
  6   4    BUS4   5    BUS5   4   0   0.08000   0.24000  0.049970
                          1.00  0.16000   0.48000  0.04000
  7   2    BUS2   5    BUS5   4   0   0.03994   0.12000  0.030000
                          1.00  0.08000   0.24000  0.02400
  8   6    BUS6   1    BUS1   6   0   0.00000   0.00000   0.00000
                     1.000    0.00  0.02000  10.01000


  9   7    BUS7   2    BUS2   6   0   0.00000   0.00000   0.00000
                     1.000    0.00  0.02000  10.01000
-----------------------------------------------------------------------------
GENERATOR DATA
====================
BUS    NAME     RP       XP       R0       X0
----- --------  --------- ----------- --------- ---------
  6    BUS6   0.000000   0.250000   0.000000   0.250000
  7    BUS7   0.000000   1.500000   0.000000   1.500000
-----------------------------------------------------------------------------
LOAD DATA
====================
 BUS NAME
 ---- --------
  4    BUS4
  5    BUS5
  2    BUS2
  3    BUS3
----------------------------------------------------------------------------------

LIGHTNING ARRESTOR DATA
=========================
BUS  NAME     C1-V     C1E-V V-MAG C2-V    C2E-V V-MAG C3-V   C3E-V V-MAG
---- -------- -------- ----- ----- ----- ----- ----- -------- ----- -----
  5    BUS5 0.000010 10.00  1.20 0.000002 31.42  1.56 0.004191  8.51  1.80
--------------------------------------------------------------------------------
Peak Voltage Print Data
==============================
No. of case   : 2

For Each case ::
case no.    tmin  tmax
------ ------- --------
  1 0.00000 0.04000
  2 0.04000 2.00000

No. of peakBus     :  5

Peak Buses Numbers :    1   2   3   4  5
```

```
==============================================================================
        RESULTS
==============================================================================
-----------------------------------------------------------------------------
BUS  NAME     VA-PEAK  A-PEAK-T VB-PEAK  B-PEAK-T VC-PEAK  C-PEAK-T
                PU    mili Sec   PU     mili Sec    PU    mili Sec
---- -------- -------- -------- -------- -------- -------- --------
 CASE-1  : tmin =  0.00000, tmax = 0.04000
==================================================
   1    BUS1  0.92389 25.45000 -0.93066 23.65000 -0.93414 29.25000
         99.57484          -100.30452          -100.67921
   2    BUS2  0.89314 25.65000  0.90251 32.75000 -0.91421 29.75000
         96.26028            97.27043          -98.53091
   3    BUS3  0.89157 25.70000 -0.88520 23.85000 -0.91866 29.50000
         96.09141           -95.40440          -99.01044
   4    BUS4  0.88285 26.35000  0.88555 32.95000 -0.91145 29.50000
         95.15102            95.44223          -98.23370
   5    BUS5  0.92624 26.20000  0.88827 32.95000 -0.89792 29.95000
         99.82829            95.73505          -96.77509
   6    BUS6  1.00000  5.00000  0.99999 11.65000 -0.99999  8.35000
        107.77755           107.77610          -107.77610
   7    BUS7  1.00000  5.00000  0.99999 11.65000 -0.99999  8.35000
        107.77755           107.77625          -107.77625
 CASE-2  : tmin =  0.04000, tmax = 2.00000
==================================================
   1    BUS1  1.71465 123.80000 -1.13841 122.45000  2.01936 121.40000
        184.80061          -122.69555           217.64192
   2    BUS2 -1.61370 121.50000 -1.12244 123.00000  2.05020 121.50000
       -173.92108          -120.97417           220.96569
   3    BUS3 -1.78849 121.75000 -1.31816 123.10000  2.31362 121.75000
       -192.75855          -142.06835           249.35633
   4    BUS4 -1.92639 121.85000 -1.23799 123.00000  2.50548 121.85000
       -207.62209          -133.42790           270.03493
   5    BUS5 -1.70162 121.35000  1.37685 133.25000  1.88922 122.20000
       -183.39689           148.39385           203.61604
   6    BUS6  1.71465 123.80000 -1.13841 122.45000  2.01936 121.40000
        184.80061          -122.69555           217.64192
   7    BUS7 -1.61370 121.50000 -1.12244 123.00000  2.05020 121.50000
       -173.92108          -120.97417           220.96569
-----------------------------------------------------------------------------
Energy absorbed in Lightning Arrestors Mega-Joules
BUS  NAME     A-ENERGY B-ENERGY C-ENERGY
---- -------- -------- -------- --------
   5    BUS5 0.01615 0.00544 0.04185
-----------------------------------------------------------------------------
Specific Energy absorbed in LA in kJules/kV
BUS  NAME     A-ENERGY B-ENERGY C-ENERGY
---- -------- -------- -------- --------
```

5 BUS5 0.12232 0.04120 0.31702
==
Date and Time : Fri Dec 18 13:28:22 1998

Powereta
==

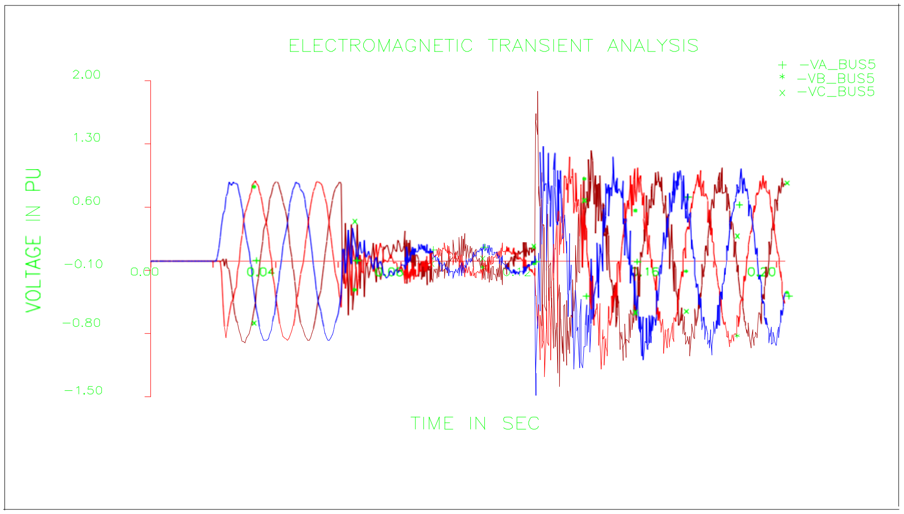

Figure 4.1 (a) : Phase A, B and C Voltages at Bus 5

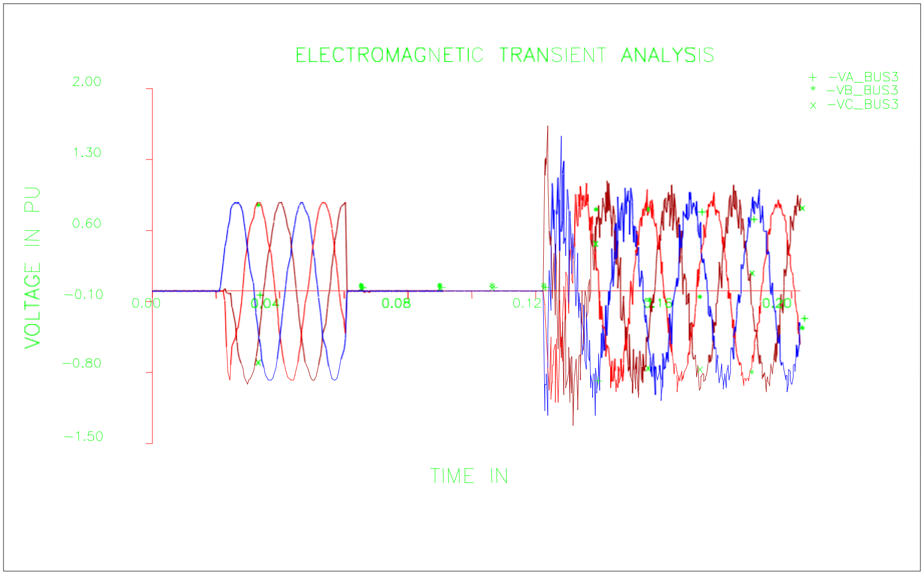

Figure 4.1 (b) : Phase A, B and C Voltages at Bus 3

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