IMPLEMENTATION OF EMTP/ATP SOFTWARE IN THE STUDY OF ELECTROMAGNETIC TRANSIENT PHENOMENON

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ABSTRACT
Electromagnetic Transient Phenomenon deals with the study of high voltage transients in power systems due to lightning, switching and traveling waves. However, it is not easy to visualize the effects of transients in power systems merely from transient analysis equations. Electromagnetic Transient Program/Alternative Transients Program (EMTP/ATP) is a general purpose software for simulating transient phenomena in power systems and for power system analysis. The plotting facility of the program makes it an excellent tool for understanding and visualizing the effects of transients in power systems. However, it is not easy to use EMTP/ATP. The paper explains a method of developing input modules for various components and illustrates the ease and effectiveness of using these modules for power system analysis using EMTP/ATP.

INTRODUCTION
Switching, lightning or faults may cause transients in power systems. To study these transients by using a digital computer necessitates the development of mathematical models that describe the transient behavior of the system. EMTP/ATP is powerful software developed to model and simulate both the steady state and transient behavior of power systems [1-4]. The software incorporates simple equivalent networks for all the components in the power system. The system behavior is simulated through nodal analysis of the system equivalent network. EMTP/ATP is however, not very user-friendly. A full-fledged graphical user interface for the software is yet not available. The rulebook for this software is 800 pages long and a novice user can easily get frustrated using the software. Traditionally, an EMTP/ATP data file has to be structured so that power system data is grouped by classes, e.g. data (cards) for switches, branch impedances and sources. This makes it very difficult to track errors and maintain data for changes in the system. As a result the data file creation and editing becomes very cumbersome.

There are, however, two options[5,6] available to users to overcome the above problem. The first option allows the user to mix the data classes by using the "/" cards, e.g. the /BRANCH, /SWTCH, /SOURCE, etc. Using these cards, the user can group the components of different classes, which are geographically close in the power system. Even though this option helps in the creation and debugging of the data file, the user still has to be well aware of the rules of creating the data file using the element templates for the different elements in a power system. The second option available to the user is the data modularization. This option allows the novice user to start using the software in minimum time and evaluate transient phenomena of a power circuit. Once the input module files for the various components are available, all the user has to do is to learn to incorporate the module punch files for the components in a data file and run the
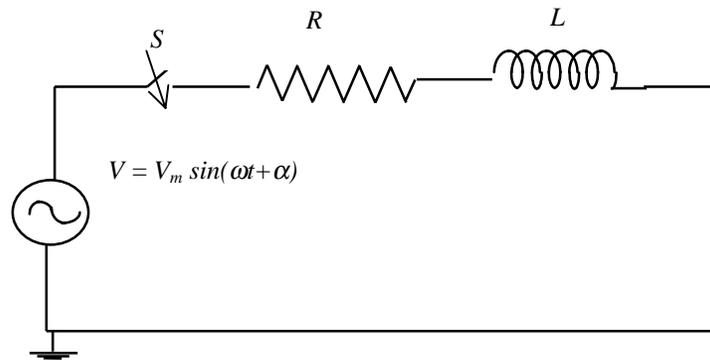
file using EMTP/ATP. The user does not need to study the rule book and know an element's template to create a data file or make changes.

DATA MODULARIZATION

An EMTP/ATP input module can be thought of as a component consisting of one or more elements of the same or different data classes. EMTP/ATP input modules can be created by using the individual element templates and the available supporting subroutine called DATA BASE MODULE[1]. The input modules have arguments just like the subroutines in a FORTRAN program. These module files can be stored as ordinary files and run using the EMTP/ATP program. The resulting module output files are called " punch files " and they are used to create the data file needed for analysis. The punch files have a **.**PCH extension. The punch files for various components of the system are included in a data file by using the $INCLUDE statement followed by the punch file name and a list of arguments that describe the component. The procedure for creating the input module files is given in the Appendix.

VALUER

FRNODE   TONODE

Fig. 1. Schematic diagram for a resistor element

The comment cards in EMTP/ATP start with the letter "C" in the first column with the second column being blank. The input module file (1R.DAT) and the punch file (1R.PCH) for the element in Figure 1 are shown below.

Input module file : 1R.DAT

```
BEGIN NEW DATA CASE            -- NOSORT ---
C Module for a resistor.
C USAGE: INCLUDE, 1R,FRNODE,TONODE,VALUER,H
DATA BASE MODULE
$ERASE
ARG,FRNODE,TONODE,
ARG,VALUER,H
NUM,VALUER,H
DUM,
/BRANCH
C <Bus M<Bus K<Bus 3<Bus 4<----R<----L<----C<--------------------------------->0
  FRNODETONODE            VALUER                                              H
C .....^.....^.....^.....^.....^.....^.....^xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx^
BEGIN NEW DATA CASE
C Just one comment card only, since the KASEND in "startup" file is 1.
$PUNCH
BEGIN NEW DATA CASE
BLANK
```

Punch file : 1R.PCH

```
KARD  3  3  3  3
KARG  1  2  3  4
KBEG  3  9 27 80
KEND  8 14 32 80
KTEX  1  1  0  0
$ERASE
```

```
/BRANCH
C <Bus M<Bus K<Bus 3<Bus 4<----R<----L<----C<-------------------------------->0
  FRNODETONODE          VALUER                                              H
C .....^.....^.....^.....^.....^.....^.....^xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx^
$EOF   User-supplied header cards follow.        27-Aug-97  14.55.19
ARG,FRNODE,TONODE,
ARG,VALUER,H
NUM,VALUER,H
DUM,
```

Table 1 below gives the explanation for each argument of the resistor module along with its allowed length in number of character spaces.

Table 1

Explanation and usage of arguments for a resistor module

RESISTOR MODULE
Usage : $INCLUDE, 1R,FRNODE,TONODE,VALUER,H

ARGUMENT	DESCRIPTION	FORMAT/UNIT	TYPE	NUMBER OF CHARACTER SPACES
FRNODE	FROM NODE NAME	FULL NODE NAME	NAME	6
TONODE	TO NODE NAME	FULL NODE NAME	NAME	6
VALUER	RESISTANCE VALUE	Ω	VALUE IN OHMS	6
H	OUTPUT REQUEST	TYPE OF OUTPUT	0, 1, 2, 3 OR 4	1

The punch files contain the numerical pointers for all arguments (parameters) that should be supplied by the user using the $INCLUDE statement in the power circuit data file. While simulating a power circuit, EMTP/ATP will read the circuit data file and expand the $INCLUDE statements with actual templates of elements using component punch files and the values we supply. The listing of the circuit data with actual templates can be created while running EMTP/ATP. This list file can be used as a debugging tool.

A library of modules has been created for over 40 single and three-phase power system components. The authors will be happy to share the input modules with anyone interested in using these modules.

To enhance the use of EMTP/ATP software in power system courses, the following examples are created to illustrate the use of modules in simulating various transient cases.

1. SWITCHING TRANSIENTS

The study of transients created due to closure of a switch in an R-L circuit can be illustrated by considering the circuit in Figure 2. Assume that the inductance $L = 92.0$ mH, the resistance R = 3.5Ω and the source voltage V=V_m sin(377t+α) where V_m=162.3 volts and $\alpha = 40$ degrees. The power factor angle for the circuit θ = 84.24 degrees. The current flow in the circuit, after the switch is closed at t=0, is given in Eq. (1).[7,8]

Fig. 2. Schematic diagram of an R-L circuit

As can be seen from Eq. (1), the current has two components. The first component varies

$$i = \frac{V_m}{|Z|}[\sin(\omega t + \alpha - \theta) - e^{-Rt/L}\sin(\alpha - \theta)] \qquad (1)$$

sinusoidally with time while the second component is a non-periodic dc component and will not exist if the circuit is closed at a point on the voltage wave such that (α-θ) is either 0 or π. The EMTP/ATP data file RL.DAT for the circuit created using the component punch files is shown below.

Data file : RL.DAT

```
BEGIN NEW DATA CASE
C SIMULATION OF AN RL CIRCUIT
$PREFIX, C:\ATP\PRG\DBMODULE\
$SUFFIX, .PCH
$INCLUDE, SIMULATE,75.E-6,200.E-3,0.0,0.0,1001,3,1,1,0
$INCLUDE, 1SORS_1,#####1,0,14,162.6,60.0,-50.0,-1.0,1.0
$INCLUDE, 1BREAK_1,#####1,#####2,0.0,1.0,0.0,0
$INCLUDE, 1R,#####2,#####3,3.5,1
$INCLUDE, 1L,#####3,######,92.0,0
$INCLUDE, OUTPUT,#####1,######,######
$INCLUDE, END
```

An EMTP/ATP circuit data file begins with "BEGIN NEW DATA CASE" statement. The $PREFIX statement is used to tell EMTP/ATP about the directory that contains the component punch files. The $SUFFIX statement tells EMTP/ATP, the extension of the punch files. The punch files are included in the data file by using the $INCLUDE statement. The sequence of the parameters given in the $INCLUDE statement should be the same as that listed in the input module file. For example, to include a resistor, we include the punch file, 1R.PCH and the required parameters, namely, the node names of the resistor (FRNODE and TONODE), its value (VALUER) and the output request H. As given in Table 1, FRNODE and TONODE can be a maximum of 6 characters long and VALUER can be 6 digits long, including the decimal if any. The output request H can be 0, 1 , 2 3 or 4 where 0 is for no output, 1 for branch current, 2 for branch voltage, 3 to get both branch current and voltage and 4 for branch

power and energy consumption. Similarly, punch files for inductance, source and switch are included as shown in the data file.

The node voltage output requests are given by using the punch file OUTPUT.PCH. Each OUTPUT punch file can request a maximum of 3 node voltages. If less than three node voltages are requested by the user, then each of the remaining node names should be kept blank by using 6 pound signs i.e. ######. The arguments supplied by the user for a particular component should match the number and order of arguments required by its module file. The node names will be left-justified and the numerical values will be right-justified in the fields in the template for the elements while the circuit list file is created. If the actual node name is less than six characters, adjust the name by using the "#" sign. The "#" sign is interpreted as a blank space by EMTP/ATP. A grounded node can be represented by six "#" signs.
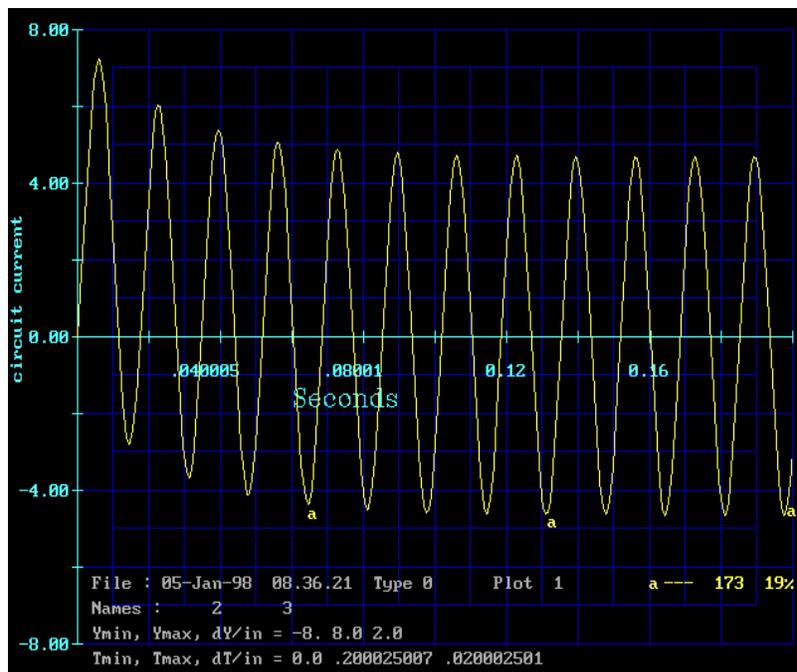
Fig. 3. Plot of the current in the R-L circuit

The EMTP/ATP program creates both list file and plot file from the above data file. The plot shown in Figure 3 shows the initial transient in current waveform for the circuit.

The rest of the paper shows a few more of the case studies used in the EE532 - Transient Phenomenon in Power Engineering course.

2. SWITCHING SURGE ANALYSIS
Single frequency circuit:
This example illustrates the recovery voltage across the oil circuit breaker in a power system when the breaker interrupts a short circuit current. Figure 4 shows a simplified one-line diagram of a three-phase power circuit with a three-phase to ground fault at point F. When the circuit

breaker contacts separate, the arc formed prolongs the flow of current beyond the time of physical separation of contacts. This arc is extinguished at a current zero of the alternating current. After this interruption of the current, the rate at which the recovery voltage across the breaker builds up is important for the design and selection of suitable circuit breaker. The breaker can successfully interrupt the short circuit current only if the rate of dielectric recovery of the space between its rapidly separating contacts is faster than the rate of rise of the transient voltage that the system is building up simultaneously across the same contacts.
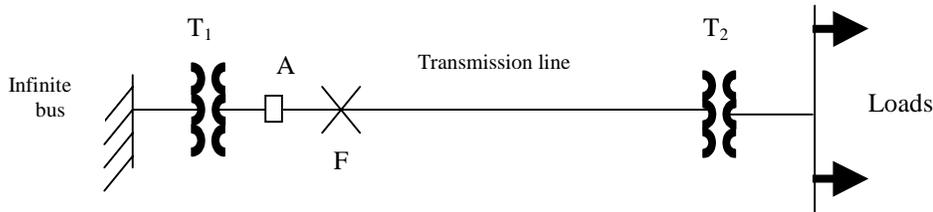
Fig. 4. One-line diagram of a power system (single frequency case)

The simplified equivalent circuit for simulating the recovery voltage across the circuit breaker contacts is shown in Figure 5. The voltage V is the line to neutral voltage at the infinite bus and it
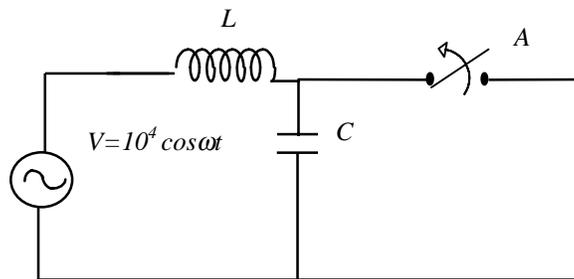
Fig. 5. Single-phase equivalent circuit for the recovery voltage across breaker A

is assumed to be $V=10^4 \cos\omega t$ with a frequency $f = 60$ Hz. In Figure 5, L is the transformer T_1 leakage inductance per phase and C is the combined capacitance to ground of the transformer T_1 terminal bushing, high tension winding and the breaker A pole on the high voltage side of transformer T_1. It is assumed that $L=$ 5mH and $C=0.2$ µF and that the circuit is interrupted exactly when the fault current is zero. The natural frequency of the L-C circuit is given by

$$f_n = \frac{1}{2\pi\sqrt{LC}} = 5032.9 \text{Hz} \tag{2}$$

The EMTP/ATP data file STRV.DAT for the above circuit using the component punch files is given below.

Data file : STRV.DAT

```
BEGIN NEW DATA CASE
C Simulation of single frequency TRV
$PREFIX, C:\ATP\PRG\DBMODULE\
$SUFFIX, .PCH
$INCLUDE, SIMULATE,1.E-7,40.E-3,0.0,0.0,1001,5,1,1,0
$INCLUDE, 1SORS_1,####N1,0,14,10000.0,60.0,-90.0,-1.0,1.0
```

```
$INCLUDE, 1L,####N1,####N2,5.0,1
$INCLUDE, 1C,####N2,######,0.2,0
$INCLUDE, 1BREAK_1,####N2,######,-1.0,0.007,0.0,1
$INCLUDE, OUTPUT,####N1,####N2,######
$INCLUDE, END
```

The voltage across the circuit breaker can be derived as below [7,8] .

$$V_R = E_S(\cos\omega t - \cos\frac{t}{\sqrt{LC}}) \tag{3}$$
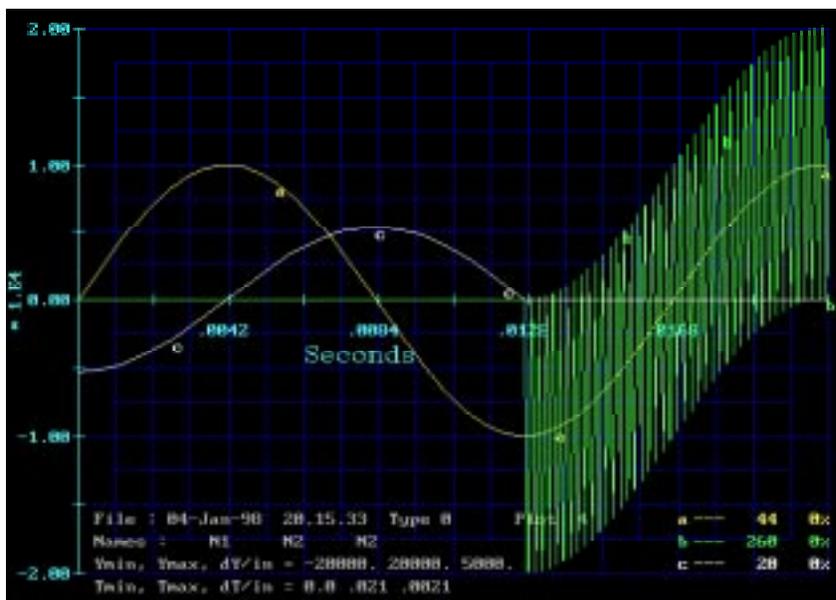
Fig. 6 (a). Fundamental frequency voltage across the open breaker
(b). Recovery voltage across the breaker (c). Fault current

Here, V_R is the recovery voltage across the breaker contacts and E_S is the peak voltage of the fundamental frequency appearing across the switch when it is open. The second term in the above equation varies at a much higher natural frequency. The above system was simulated by EMTP/ATP using the data file STRV.DAT. The variations of the fundamental frequency voltage across the open breaker, the recovery voltage across the breaker contacts and the fault current are shown in Figure 6 as curves a, b and c respectively. EMTP/ATP's TPPLOT program allows the visualization of this recovery voltage across the breaker contacts, which is very difficult to see from Eq. (3). It is evident from curve "b" that the voltage across the breaker contacts reaches twice the fundamental frequency amplitude in one quarter period of natural frequency.

Double frequency case:
Let us consider a similar system as before except that there is a reactor RR to the right of the breaker to limit the fault current. The power system for this case is shown in Figure 7. If a fault occurs to the right of the reactor at point F, the equivalent circuit is represented by Figure 8.
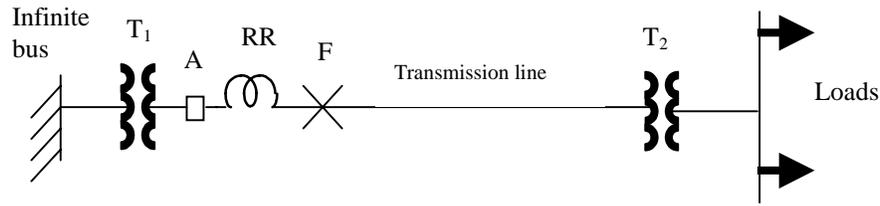
Fig. 7. One–diagram of the power system (double frequency case)
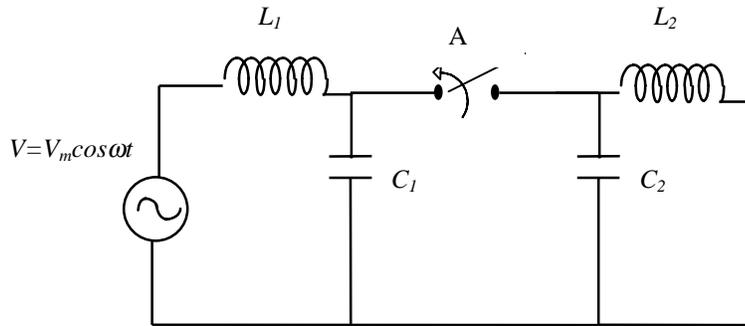
Fig. 8. Single phase equivalent circuit for the recovery voltage across breaker A

In this figure, L_2 is the inductance of the reactor RR and C_2 is the combined capacitance to ground of the breaker pole on the side of the reactor and the capacitance to ground of the reactor RR. It is assumed that $L_1 = 5mH$, $C_1 = 0.2 \mu F$, $L_2 = 20mH$ and $C_2 = 0.1 \mu F$. The circuit interruption is timed so that the interruption is instantaneous when the short circuit current is zero. The natural frequencies of the two L-C circuits are $f_1 = 5032.9$ Hz and $f_2 = 3558.8$ Hz. The EMTP/ATP data file DTRV.DAT for the above circuit using the component punch files is given below.

Data file : DTRV.DAT

```
BEGIN NEW DATA CASE
C Simulation of double frequency TRV
$PREFIX, C:\ATP\PRG\DBMODULE\
$SUFFIX, .PCH
$INCLUDE, SIMULATE,1.E-7,100.E-3,0.0,0.0,1001,10,1,1,0
$INCLUDE, 1SORS_1,####N1,0,14,10000.0,60.0,-90.0,-1.0,1.0
$INCLUDE, 1L,####N1,####N2,5.0,1
$INCLUDE, 1C,####N2,######,0.2,0
$INCLUDE, 1BREAK_1,####N2,####N3,-1.0,0.007,0.0,3
$INCLUDE, 1L,####N3,######,20.0,1
$INCLUDE, 1C,####N3,######,0.1,0
$INCLUDE, OUTPUT,####N1,####N2,####N3
$INCLUDE, END
```

To keep the model simple, circuit resistances are assumed negligible. Before the breaker opening, the source voltage V will divide in direct proportion to the inductance L_1 and L_2 values. The voltage across the capacitor C_2 will be approximately

$$V_{C2} = \frac{L_2}{(L_1 + L_2)} V \tag{4}$$

When the current is interrupted, this voltage will be at its peak. Following the current interruption, C_2 will discharge through L_2 at a frequency f_2. Meanwhile, C_1 will oscillate about the source voltage with a frequency f_1 until the losses in the system damp out the disturbance.
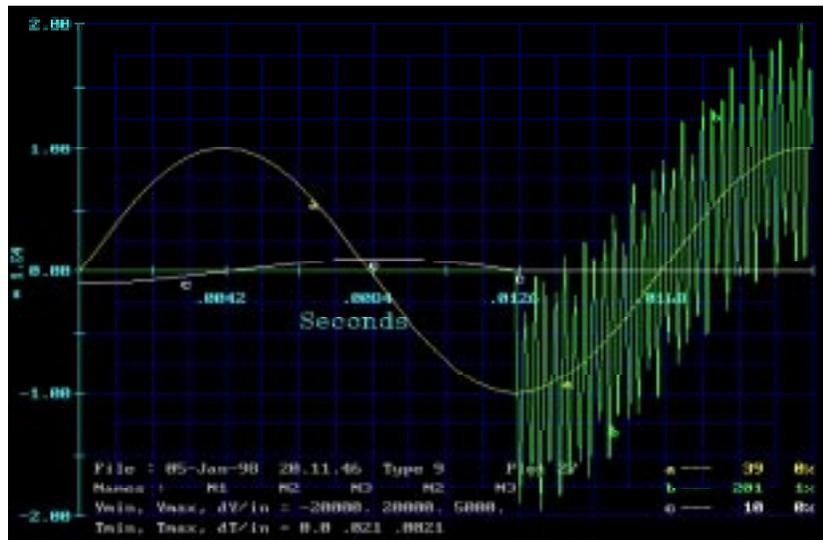
Fig. 9(a) System voltage (b). Recovery voltage across the breaker (c). Fault current

The above system was simulated by EMTP/ATP using the data file DTRV.DAT. The system voltage, the recovery voltage across the breaker and the fault current are shown in Figure 9. Since the resistances in the system were neglected, the recovery voltage oscillations are sustained as seen in the figure. Without the use of EMTP/ATP's TPPLOT program it would be very difficult to visualize the voltage variations across the breaker contacts.

3. LIGHTNING SURGE STUDY
   Stroke to Tower:
This study simulates a lightning stroke to a 230 kV transmission tower and plots the voltage between the tower top and one of the outer phase conductors. This can be very useful for calculating the line outage rates[9] and insulation design of transmission lines. Ground wires on high voltage transmission towers are used to shield the lines from direct lightning strokes. But strokes to the transmission tower or the shield wire can raise the tower top voltage to cause a back flashover to occur from the tower to the phase conductor resulting in line outage.

A stroke current surge terminating on the tower will divide between the tower and the shield wires connected to the tower according to the tower and shield wire surge impedances Z_t and Z_s respectively. Voltage waves equal to the initial tower top voltage will travel along the tower and

along the shield wires at different velocities. The tower top voltage wave will be reflected between the tower footing resistance R_{tf} and the tower top repeatedly. The shield wire voltage waves will be reflected and further transmitted at the adjacent towers. The negative voltage reflections from adjacent towers and the tower footing resistance will reduce the tower top voltage of the struck tower.

If $R_{tf} < Z_t$, then reflections from the tower footing resistance will be negative and this further reduces the tower top voltage V_t of the struck tower. If $R_{tf} > Z_t$, V_t will increase despite negative reflections from adjacent towers as the length of the tower is less than the span length and hence the positive reflection from the tower footing resistance will reach the tower top sooner.
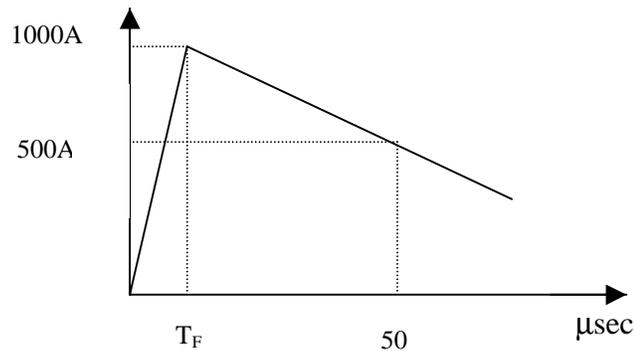
Fig. 10. Input lightning current surge
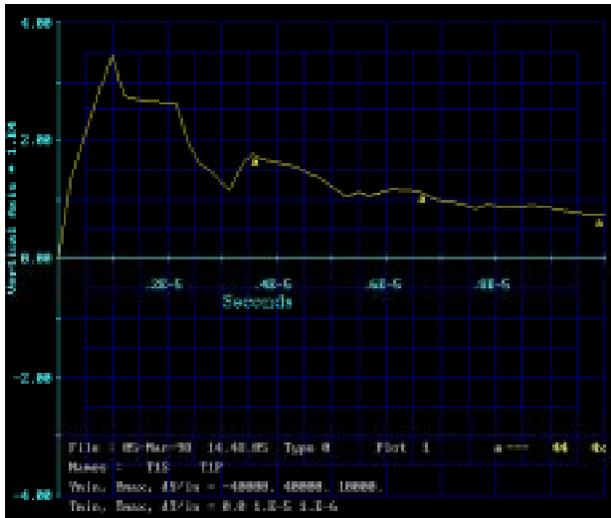
Fig 11. Insulator-string voltage
($R_{tf} =50\Omega, T_F= 1$ μsec)
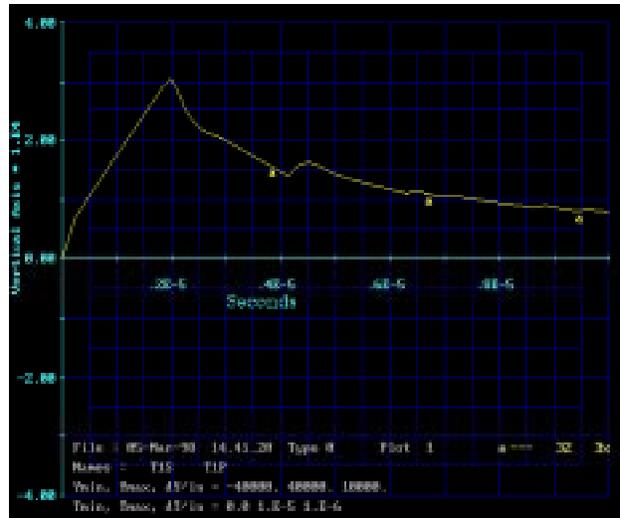
Fig 12. Insulator-string voltage
($R_{tf} =50\Omega, T_F= 2$ μsec)

For the present case, $Z_t =200\ \Omega$ and $Z_s =316.46\ \Omega$ are chosen. The mutual surge impedance between the shield wire and the phase wire Z_m is chosen as $93.6\ \Omega$. The tower height is 100 feet and the tower travel time is assumed to be 0.102 μsec. The towers are modeled as single conductor lines to ground. The phase conductors are at a height of 88 feet above the ground. A

lightning stroke current of 1000 amps crest with a front time of T_F and a tail time of 50 μsec is considered as shown in Figure 10. For the present study, reflections from only two adjacent towers were considered. The EMTP/ATP data file ISV.DAT for this case using the component punch files is shown below.

Data file : ISV.DAT

```
BEGIN NEW DATA CASE
C Simulation of insulation string voltage.
$PREFIX, C:\ATP\PRG\DBMODULE\
$SUFFIX, .PCH
$INCLUDE, SIMULATE,1.0E-8,10.E-6,60.0,0.0,9001,1,1,1,0
C Tower footing resistances
$INCLUDE, 1R,###T1G,######,50.0,0
$INCLUDE, 1R,###T2G,######,25.0,0
$INCLUDE, 1R,###T3G,######,25.0,0
C Terminating surge impedance at the end of the lines
$INCLUDE, 2RLCPI,###T3P,######,###T3S,######,240.40,0.0,0.0, 46.80,0.0,0.0,   $$
                 158.23,0.0,0.0
C Transmission line towers
$INCLUDE, 1LINE,###T1S,###T1G,-1,0.0,200.0,9.8E8,100.0,1,0,0
$INCLUDE, 1LINE,###T2S,###T2G,-1,0.0,100.0,9.8E8,100.0,1,0,0
$INCLUDE, 1LINE,###T3S,###T3G,-1,0.0,100.0,9.8E8,100.0,1,0,0
C Untransposed line models
$INCLUDE, 2LINE,###T1P,###T2P,###T1S,###T2S,0.0,261.59,186280.0,        $$
                 0.0,137.04,186280.0,-0.2,1,0,0, 0.91097,-0.41247,0.0,0.0,   $$
                 0.41247,0.91097,0.0,0.0
$INCLUDE, 2LINE,###T2P,###T3P,###T2S,###T3S,0.0,261.59,186280.0,0.0,     $$
                 137.04,186280.0,-0.2,1,0,0, 0.91097,-0.41247,0.0,0.0,       $$
                 0.41247,0.91097,0.0,0.0
C Switch to get the insulator string voltage
$INCLUDE, 1BREAK_1,###T1S,###T1P,1.0,0.0,0.0,0.0,2
C Lightning current surge
$INCLUDE, 1SORS_4,###T1S,-1,13,1000.0,0.0,2.0E-6,500.0,50E-6,0.0,0.0
C Node voltage outputs
$INCLUDE, OUTPUT,###T1S,###T1P,######
$INCLUDE, END
```

Figures 11 and 12 show the insulator-string voltage for $R_{tf} = 50Ω$ and $T_F = 1$ μsec and 2 μsec respectively. As seen in the above figures, increased front time T_F results in slower rate of rise and decay of insulator-string voltage. This example illustrates the ease with which EMTP/ATP can be used to study the effects of various parameters for designing lightning protection.

CONCLUSION
The paper illustrates the use of input modules of various components in power system analysis using EMTP/ATP. The paper illustrates the simulation of recovery transient across circuit breaker contacts for single frequency and double frequency cases and the insulator string voltage transient when lightning strikes a transmission tower. These were studied in the EE532-

Transient Phenomenon in Power Engineering course. We hope that this paper will generate interest in using EMTP/ATP for power system analysis.

APPENDIX

PROCEDURE FOR CREATING INPUT MODULE FILES

DATA BASE MODULE is an EMTP/ATP supporting subroutine which uses input module files to create templates for various power system components[1]. This helps the user avoid the cumbersome and tedious task of creating template for every power system component. Each input module file for an element or a combination of elements consists of two main parts; an argument declaration list and an EMTP/ATP template. A sample input module file is shown below.

BEGIN NEW DATA CASE -- NOSORT—
DATA BASE MODULE request card.
$ERASE card
argument declaration list (ARG, NUM, DUM)
templates
BEGIN NEW DATA CASE
$PUNCH
BEGIN NEW DATA CASE
BLANK card terminating the case

The first card, BEGIN NEW DATA CASE --NOSORT-- marks the beginning of a new program run and can be thought of as a case separation marker. The DATA BASE MODULE request card transfers the control to the supporting subroutine DATA BASE MODULE. This subroutine searches the input module file for the argument names and establishes numerical pointers for all arguments in the component template. $ERASE command clears the buffer that holds the punched card output.

The argument declaration list defines whether an argument is named or dummy. The declaration for named arguments referring to node names is

ARG,name1,name2,…namen

Here, name1, name2 etc. are the argument node names of the component in the input module file. The declaration for named arguments referring to numerical values is

ARG,value1,value2,…valuen

NUM,value1,value2,…valuen

Here, value1, value2 etc. are the named arguments referring to numerical values supplied via the $INCLUDE statement. The dummy arguments should be given as

DUM,dummy1,dummy2,…dummyn

Here, dummy1, dummy2 etc. are the dummy arguments. The dummy arguments do not appear in the ARG or NUM list, nor do they appear in the $INCLUDE statement. They denote the internal node names of the component(s) in the input module file. The dummy argument allocation is generated automatically by the $DUMMY command.

The templates are the EMT/ATP input representation of the component(s). All the rules applicable for EMTP/ATP input format is applicable here, except that there will be combined use of actual values and arguments names in these templates[1].

The BEGIN DATA CASE card is used as a marker to indicate that the data input for modularization is terminated. The $PUNCH card creates the punch file by flushing out the punch buffer contents. The punch file contains the numerical pointers to all arguments used in the template as well as the template itself.

The BEGIN NEW DATA CASE card is used as a separation marker and the BLANK card terminates all cases.

Once the punch files are created, simulation of any power circuit simplifies to incorporating the $INCLUDE statements for the various components in the circuit and running the data file using EMTP/ATP.

Values are allocated to the named arguments through the $INCLUDE statement in a data file used for the simulation of a power circuit. The general format of an $INCLUDE statement is

$INCLUDE, punch file-name, arg1, arg2,…, argn

where file-name is the name of the component punch file created by DATA BASE MODULE and arg1,… argn are the arguments (actual node names or values in the power circuit) describing the component in the input module file. The order of the arguments in the $INCLUDE statement should correspond to the order of the arguments in the argument declaration list of the input module file. The data continuation line for the $INCLUDE statement is achieved by putting two dollar signs i.e. "$$" in columns 79 and 80 in the data file.

We have modules for about 40 power system components and these will be available to faculty if they need them.

REFERENCES

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