EMTP Tech Notes

for users of the Electromagnetic Transients Program

Issue # 93-1 ***March, 1993*** ***Editor: Thomas Grebe***

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Letter from the Editor:

This is the initial issue of *EMTP Tech Notes*. The technical newsletter provided to members of the EMTP User's Group. The initial plan for the newsletter is a quarterly technical publication highlighting contributions from members of the User's Group.

Contributions in the following areas are welcome:

- Technical articles
- Modifications / enhancements to the code
- Case studies / unique simulations
- Research projects
- EMTP data preparation / model development
- Modules developed for distribution on the BBS
- Letters to the editor / User's Group
- Technical paper abstracts
- Questions for members of the User's Group

I believe that the exchange of technical information is one of the most important functions of the EMTP User's Group and this newsletter, in conjunction with *Transients*, will help to serve the needs of the members. Thanks to Bob Jones, Tom Sims, and Le Tang for helping to get the first issue off the ground. As always, I'm open for suggestions regarding this publication and the User's Group in general.

Thanks for your support

For more information concerning the newsletter or to submit a contribution please contact:

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EMTP Data Modules

What Is EMTP Data Module?

An EMTP data module is another data input format which is accepted by the EMTP preprocessor to form a regular case file automatically. In many cases such input modules can help users to greatly reduce data input work and build cases with better organization and readability. The most important advantage of the input module is that, after the module is built, it can be reused as many times as needed whenever an identical circuit structure is encountered. In such cases, users can simply insert the module with appropriate connection node names and new circuit parameters.

EMTP data modules that have been developed by members of the EMTP User's Group will be available through the bulletin board system.

The goal for writing this article is to familiarize members of the User's Group with the concept of data modules and to provide a reference for module documentation.

How to Create An EMTP Data Module?

To create an input module, a user needs to follow three simple steps.

- Create a *.MOD file
- Create a MAKE.DAT file
- Run MAKE.DAT file as a regular EMTP case

When running of the MAKE.DAT case is completed, the EMTP has automatically made an input module file (*.INC file). This is the file ready to be inserted whenever an identical circuit structure is needed in a case file construction.

The input formats and rules needed to be followed while building a *.MOD file are very similar to those while developing a regular data file. A major difference between a *.mod file and a regular input file is that in the *.mod file general character strings are used to replace all the determined node names and numerical values specified in the regular input file. In addition, all of the used character strings need to be declared as proper types.

The example, illustrated in Figure 1, shows the file "DIOCNVT.MOD" developed for a three-phase diode bridge converter.

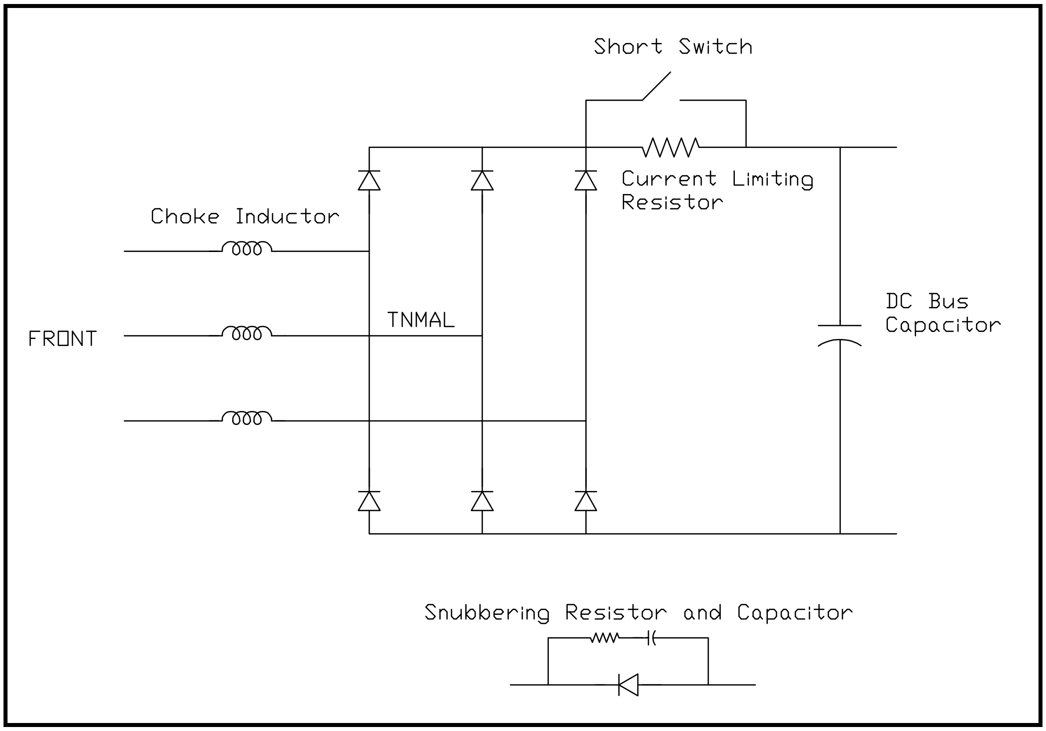

Figure 1 - Three-phase Diode Bridge Converter

Data sorting is made possible through use of the "/" cards. A summary of the "/" cards is provided below (the user is refereed to section 19.1.2 of the Rule Book for additional information):

/REQUEST - special request cards

/TACS - TACS data

/BRANCH - indicate branch data

/SWITCH - indicate switch data

/SOURCE - indicate source data

/OUTPUT - indicate output request

/PLOT - indicate plot request

/LOAD FLOW - EMTP load flow

/STATISTICS - statistics request

/END MODULE - signal end of module

```
C ********************************************************************************
C *
C *                  General Diode Bridge Rectifier Module
C *
C USAGE:
C INCLUDE DIOCNVT FRONT,  TRMNL,  DCPLUS, DCMINU,                         -;
NODES
C                  CHOKEL, SNUBBR, SNUBBC, STARTR, RSHORTIME, DCBUSC, ?, @  ;
PARA.
C ********************************************************************************
ARG                                                                 - ; ARGUMENTS
FRONT,  TRMNL,  DCPLUS, DCMNUS,                                     - ; CON.
NODES
CHOKEL, SNUBBR, SNUBBC, STARTR, RSHORTTIME, DCBUSC,                 - ;
PARAMETERS
?, @                                                                  ; OUTPUT
REQ.
NUM                                                                 - ; NUMERICAL
CHOKEL, SNUBBR, SNUBBC, STARTR,RSHORTTIME,DCBUSC                      ;
PARAMETERS
DUM                                                                 - ; DUM
RECPOS, RECNEG, SHRTBK,                                             - ; DUM1
DIOD1C, DIOD2C, DIOD3C, DIOD4C, DIOD5C, DIOD6C,                     - ; DUM2
DIOD1A, DIOD2A, DIOD3A, DIOD4A, DIOD5A, DIOD6A                        ; DUM2
/BRANCH
C AC Choke Inductance
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                    V
  FRONTATRMNLA            1.0E-4CHOKEL                                          1
  FRONTBTRMNLB            1.0E-4CHOKEL                                          ?
  FRONTCTRMNLC            1.0E-4CHOKEL                                          ?
C Diode Snubber Circuits
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                    V
  TRMNLARECPOS            SNUBBR      SNUBBC
  TRMNLBRECPOS            SNUBBR      SNUBBC
  TRMNLCRECPOS            SNUBBR      SNUBBC
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                    V
  TRMNLARECNEG            SNUBBR      SNUBBC
  TRMNLBRECNEG            SNUBBR      SNUBBC
  TRMNLCRECNEG            SNUBBR      SNUBBC
C <-------- Connection to positive and negative dc bus
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                    V
  DIOD1CRECPOS            0.0010
  DIOD3CRECPOS            0.0010
  DIOD5CRECPOS            0.0010
  DIOD1CRECPOS                  0.0100
  DIOD3CRECPOS                  0.0100
  DIOD5CRECPOS                  0.0100
  RECNEGDIOD4A            0.0010
  RECNEGDIOD6A            0.0010
  RECNEGDIOD2A            0.0010
  RECNEGDIOD4A                  0.0100
  RECNEGDIOD6A                  0.0100
```

```
  RECNEGDIOD2A                  0.0100
C <-------- Connection to power system (diode front-end)
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLADIOD1A            0.0010
  TRMNLBDIOD3A            0.0010
  TRMNLCDIOD5A            0.0010
  TRMNLADIOD1A                  0.0100
  TRMNLBDIOD3A                  0.0100
  TRMNLCDIOD5A                  0.0100
  DIOD4CTRMNLA            0.0010
  DIOD6CTRMNLB            0.0010
  DIOD2CTRMNLC            0.0010
  DIOD4CTRMNLA                  0.0100
  DIOD6CTRMNLB                  0.0100
  DIOD2CTRMNLC                  0.0100
C <-------- Phase-to-Phase Voltage Sampling
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLATRMNLB            1.0E08                                               2
  TRMNLBTRMNLC            1.0E08                                               @
  TRMNLCTRMNLA            1.0E08                                               @
C <-------- Starting Resistor
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  RECPOSSHRTBK            STARTR                                               ?
/SWITCH
C <-------- Starting Resistor Short Switch
C BUS-->BUS--><---TCLOSE<----TOPEN<-------IE<----FLASH<--REQUEST<-----TARGET<--O
  RECPOSSHRTBKRSHORTTIME      9999                                             ?
/BRANCH
C <-------- dc Bus
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  SHRTBKDCPLUS            0.00100.0100                                         ?
  DCMNUSDCPLUS            10000.
  DCPLUSDCMNUS                        DCBUSC                                   2
  RECPOS                              1.0000
  RECNEG                              1.0000
  RECNEGDCMNUS            0.00100.0100
/SWITCH
C <-------- Diodes (front-end)
C BUS-->BUS--><------Vig<----Ihold<-------td<---------CLOSEDSame<Grid<Op/Cl<xxOO
11DIOD1ADIOD1C               0.1                                               ?
11DIOD3ADIOD3C               0.1                                               ?
11DIOD5ADIOD5C               0.1                                               ?
11DIOD4ADIOD4C               0.1                                               @
11DIOD6ADIOD6C               0.1                                               @
11DIOD2ADIOD2C               0.1                                               @
/ENDMODULE
$EOF
```

The first part of this file is argument declarations. All 12 variables used in this module are declared as ARG type. Among them, six arguments requiring numerical value substitution are further declared as NUM type. Notice that some connection nodes in the circuit are declared as DUM variables. This is because that, for this converter, the main interest is the circuit block terminal characteristics. Namely, the ac input voltage and current and the dc output voltage and current. In fact, a proper selection of dummy variables can make a module more generic. It also helps to reduce a number of variables that need to be replaced when the module is called. A summary of variable types and special characters includes:

'ARG'	argument declaring all external variables
'NUM'	subset of type ARG, indicating a numeric value
'DUM'	internal variables of a module
'-'	continuation character for type declaration
';'	indicate that the rest of a line is a comment
'#'	indicate imbedded blanks (i.e. "BUS###" means "BUS ")
'_'	indicate imbedded blanks in a numeric field
'?','@'	change branch output request (one character in column 80)

After the declarations, the connections between the circuit components are made as usual. All the regular EMTP data input rules are applicable. In order to facilitate data input and make a better file organization, a "/" syntax is used to define the type of input cards.

After a *.mod file is made, a user needs to make a MAKE.DAT file. The simple structure of a MAKE.DAT file is shown in the following example:

```
MODULE
C:\ETK\MODULE\MODFILE\DIOCNVT.MOD
C:\ETK\MODULE\INCFILE\DIOCNVT.INC
STOP
```

In general, the second and third lines give the paths leading to the places where *.MOD and *.INC files are stored.

After running the above MAKE.DAT case, the EMTP generates the corresponding DIOCNVT.INC file. This file keeps all the circuit connections as specified in the DIOCNVT.MOD file, and the EMTP also generates connection codes for the EMTP internal matrix. The user does not need to pay attention to such codes (however, do not change anything in the *.INC file, all changes to the module should be made to the *.MOD file and then recompiled).

How to Use a Data Module?

An input module is easily inserted into a data case as an include file. For the previously described DIOCNVT module, the form of usage is given below. A user needs to use an INCLUDE statement with 12 supplied parameters. An example data case illustrating the module usage is provided.

```
USAGE:
$INCLUDE DIOCNVT FRONT,  TRMNL,  DCPLUS, DCMINU,                         -;
NODES
                 CHOKEL, SNUBBR, SNUBBC, STARTR, RSHORTIME, DCBUSC, ?, @  ;
PARA.
FRONT -        Converter ac side connection bus name
TRMNL-         Converter bridge connection point
DCPLUS-        DC positive bus
DCMNUS-        DC negative bus
CHOKEL-        AC choke inductance
SNUBBR-        Diode snubber resistance
SNUBBC-        Diode snubber capacitance
STARTR-        Charging current limiting resistance
RSHORTIME-     Time to short the starting resistor
DCBUSC-        Capacitance connected between dc positive and negative buses
?-             First  output control flag (outputs)
@-             Second output control flag.(more outputs for debugging)
```

```
C ******************************************************************************
C                  EMTP INPUT MODULE USING ILLUSTRATION CASE
BEGIN NEW DATA CASE
C ----Dt<---Tmax<---Xopt<---Copt
 50.E-060.180000
C -Iprnt<--Iplot<-Idoubl<-Kssout<-Maxout<---Ipun<-Memsav<---Icat<-Nenerg
    5001       3       1       3       1       0       0       2       0
$PREFIX C:\ETK\MODULE\INCFILE\
$SUFFIX .INC
C       480 Voltage Source
$INCLUDE 3PHRDS  VS480, 0.0004, 0.0600, 0.0008, 0.04070 20.00, 392.0,      - ;
                 -1.0,  9999                                                 ;
C
C       Switch between Source and Drive
$INCLUDE 3PHBRK   VS480, DRIVE, 0.0, 9999,  0.0, 1, 1                        ;
C
C       Diode Converter
$INCLUDE DIOCNVT DRIVE,  TRMNL,  DCPLUS, DCMNUS,                           - ;
                 0.001,  10.0,   10.0,   0.50,   0.10,  22500., 0, 0         ;
/BRANCH
C <BUS1><BUS2>            <RES ><IND ><CAP >                                   O
  DCPLUSDCMNUS            2.8000
/OUTPUT
  VS480A
/PLOT
$INCLUDE ENDRUN
```

The lines:

$PREFIX C:\ETK\MODULE\INCFILE
$SUFFIX .INC

provide information regarding the path and file extension for the include files. An alternate format would be to include the entire path name in the $INCLUDE statement.

Four input modules are used in the following example. Module 3PHRDS gives a three phase 480 V voltage source with finite source impedance. Module 3PHBRK gives a circuit breaker connected between voltage source bus VS480 and the drive connection bus DRIVE. The switch is closed at t=0 to energize 150 HP dc drive. Module DIOCNVT gives a three-phase full bridge converter. The last module ENDRUN provides all the BLANK cards required by the EMTP rule book. The load of the drive is represented by a 2.8 ohms resistor connected between DCPLUS and DCMNUS.

When running this data case, the EMTP preprocessor first reads in this data file including all the modules. The modules are interpreted and cards of each type are sorted according to the "/" keywords. After this preprocessing, the original input file is actually translated into a regular EMTP input file as illustrated:

```
C ******************************************************************************
C                  EMTP INPUT MODULE USING ILLUSTRATION CASE
BEGIN NEW DATA CASE
C ----Dt<---Tmax<---Xopt<---Copt
 50.E-060.180000
C -Iprnt<--Iplot<-Idoubl<-Kssout<-Maxout<---Ipun<-Memsav<---Icat<-Nenerg
    5001       3       1       3       1       0       0       2       0
C $PREFIX C:\ETK\MODULE\INCFILE\
C $SUFFIX .INC
C ******************************************************************************
C
C       480 Voltage Source
C $INCLUDE 3PHRDS  VS480, 0.0004, 0.0600, 0.0008, 0.04070 20.00, 392.0,      - ;
C                  -1.0,  9999                                                 ;
C $INCLUDE 3PHRDS TERML, R0, L0, R1, L1,DAMPR, VPEAK, TSTART, TSTOP ; COM
C <Bus1><BUS2>            <REST>
  VS480ADUM003             20.00
  VS480BDUM002             20.00
  VS480CDUM001             20.00
C <Bus1><BUS2>            <SEQUENCE VALUES >
51VS480ADUM003            0.0004      0.0600
52VS480BDUM002            0.0008     0.04070
53VS480CDUM001
C AC Choke Inductance
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                  V
```

```
  DRIVEATRMNLA            1.0E-4 0.001                                         1
  DRIVEBTRMNLB            1.0E-4 0.001                                         0
  DRIVECTRMNLC            1.0E-4 0.001                                         0
C Diode Snubber Circuits
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLADUM021              10.0        10.0
  TRMNLBDUM021              10.0        10.0
  TRMNLCDUM021              10.0        10.0
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLADUM020              10.0        10.0
  TRMNLBDUM020              10.0        10.0
  TRMNLCDUM020              10.0        10.0
C <-------- Connection to positive and negative dc bus
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  DUM018DUM021            0.0010
  DUM016DUM021            0.0010
  DUM014DUM021            0.0010
  DUM018DUM021                  0.0100
  DUM016DUM021                  0.0100
  DUM014DUM021                  0.0100
  DUM020DUM009            0.0010
  DUM020DUM007            0.0010
  DUM020DUM011            0.0010
  DUM020DUM009                  0.0100
  DUM020DUM007                  0.0100
  DUM020DUM011                  0.0100
C <-------- Connection to power system (diode front-end)
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLADUM012            0.0010
  TRMNLBDUM010            0.0010
  TRMNLCDUM008            0.0010
  TRMNLADUM012                  0.0100
  TRMNLBDUM010                  0.0100
  TRMNLCDUM008                  0.0100
  DUM015TRMNLA            0.0010
  DUM013TRMNLB            0.0010
  DUM017TRMNLC            0.0010
  DUM015TRMNLA                  0.0100
  DUM013TRMNLB                  0.0100
  DUM017TRMNLC                  0.0100
C <-------- Phase-to-Phase Voltage Sampling
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  TRMNLATRMNLB            1.0E08                                               2
  TRMNLBTRMNLC            1.0E08                                               0
  TRMNLCTRMNLA            1.0E08                                               0
C <-------- Starting Resistor
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  DUM021DUM019              0.50                                               0
C <-------- dc Bus
C <-Bus1<-Bus2<-Bus3<-Bus4<----R<----L<----C                                   V
  DUM019DCPLUS            0.00100.0100                                         0
  DCMNUSDCPLUS            10000.
  DCPLUSDCMNUS                        22500.                                   2
  DUM021                              1.0000
```

```
  DUM020                              1.0000
  DUM020DCMNUS            0.00100.0100
C <BUS1><BUS2>            <RES ><IND ><CAP >                                  O
  DCPLUSDCMNUS            2.8000
BLANK ENDS BRANCH
C
C MODULE 3PHBRK TCLOSING, TOPENING, ISTOP,IOUT
C
C 3456789 123456789 123456789 123456789 123456789 123456789 123456789 1234567890
C <---Nodes-->
C <-Bus1<-Bus2<TCLOSING><TOPENING><I-LIMIT >
  VS480ADRIVEA     0.000      9999       0.0                                  1
  VS480BDRIVEB     0.000      9999       0.0                                  1
  VS480CDRIVEC     0.000      9999       0.0                                  1
C
C <-------- Starting Resistor Short Switch
C BUS-->BUS--><---TCLOSE<----TOPEN<-------IE<----FLASH<--REQUEST<-----TARGET<--O
  DUM021DUM019      0.10      9999                                            0
C <-------- Diodes (front-end)
C BUS-->BUS--><------Vig<----Ihold<-------td<---------CLOSEDSame<Grid<Op/Cl<xxOO
11DUM012DUM018                 0.1                                            0
11DUM010DUM016                 0.1                                            0
11DUM008DUM014                 0.1                                            0
11DUM009DUM015                 0.1                                            0
11DUM007DUM013                 0.1                                            0
11DUM011DUM017                 0.1                                            0
BLANK ENDS SWITCH
C AMPLITUDE=1.414*RMS(l-l)/1.732 VOLTS
C <--Bus<I<-----Ampl<-----Freq<----Phase<-------A1<------T1><---Tstart<----Tstop
14DUM003 1     392.0      60.0      0.0                           -1.0      9999
14DUM002 1     392.0      60.0   -120.0                           -1.0      9999
14DUM001 1     392.0      60.0    120.0                           -1.0      9999
BLANK ENDS SOURCE
  VS480A
BLANK ENDS OUTPUT
BLANK ENDS PLOT
BEGIN NEW DATA CASE
BLANK TERMINATE EMTP RUN
```

Hopefully, this example has provided some useful information regarding EMTP data module usage. The modules illustrates in the article can be downloaded from the EMTP User's Group bulletin board.

Le Tang
Electrotek Concepts, Inc.

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TRV Capability of Circuit Breakers

A transient recovery voltage (TRV) is the voltage which builds up across the contacts of a circuit breaker after the current is extinguished during the opening of the breaker. The dielectric strength of the gap between the contacts of the breaker also builds up after current is extinguished. If the TRV as a function of time always remains less than the capability of the breaker, then current interruption is successful. However, if the TRV exceeds the capability of the breaker, then a reignition or a restrike may occur. This could cause undesirable effects on the power system (and the breaker). According to the ANSI circuit breaker standards, transient recovery voltages (TRV) should be considered whenever a circuit breaker is applied on a power system. ANSI C37.04 and C37.06 give the TRV capability that a breaker must have for a given voltage rating and interrupting rating. EMTP can be used to calculate the TRV as a function of time that a breaker would be subjected to at a given location on the power system. C37.011 gives the details on how to calculate the system TRV. It would be very convenient if EMTP could also be used to calculate the TRV capability of a breaker as a function of time. Then the system TRV could be compared directly to the breaker's capability using EMTPOUT or TOP. This article describes a method for accomplishing this.

The TRV capability for bus faults of a breaker with a voltage rating of 121 kV and above is defined by ANSI standards as an exponential-cosine waveshape. That means it is a combination of a 1-exponential waveshape and a 1-cosine waveshape with the capability being the maximum value of either of the two curves (see Figure 1). The 1-exponential portion of the curve is defined in terms of the parameters E1, R, and T1 where E1 is the asymptotic crest magnitude of the curve, R is the initial rate-of-rise, and T1 is a small time delay at the beginning of the curve. The parameter T1 has only a small effect on the curve defining the breaker capability and can usually be neglected. If it can't be neglected, the 1-exponential curve is described by equations which use hyperbolic sines and cosines (not good!). By neglecting the small time delay, the 1-exponential curve has a simple expression:

$$\mathrm{TRV}(t) = \mathrm{E1} * \; 1 - e^{\mathrm{E1} / \mathrm{R} * t}$$

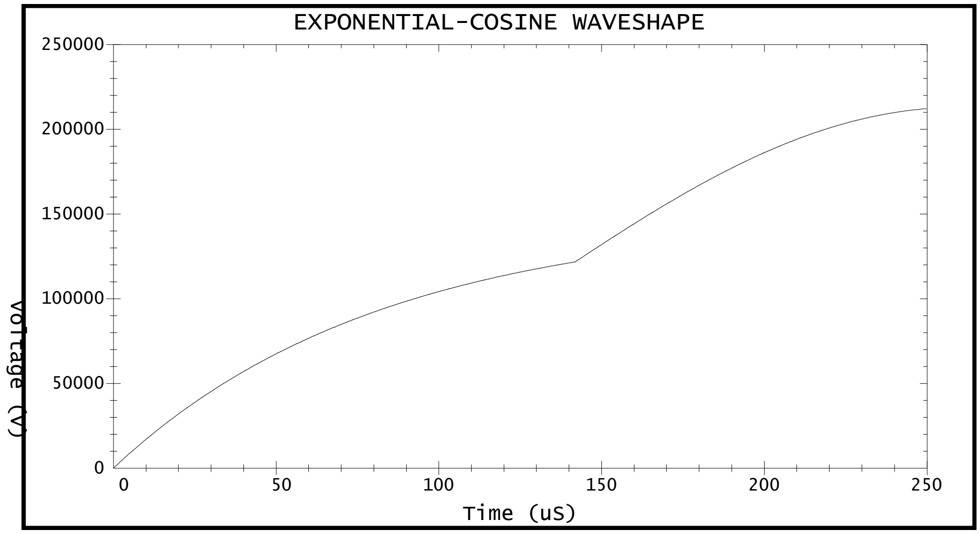

Figure 1

The 1-cosine portion of the curve is defined in terms of the parameters E2 and T2 where E2 is the crest value of the curve and T2 is the time to crest. This curve has the simple expression:

$$TRV(t)=\frac{E2}{2}*\ 1-COS\ {}^{\pi}\!/_{T2*t}$$

For breakers with voltage ratings which are 72 kV or less, the TRV capability is just the 1-cosine curve. It does not include a 1- exponential portion. The parameters E1 and E2 are defined by the breaker standards in terms of the voltage rating of the breaker as follows:

$$E1=\sqrt{\frac{2}{3}}*1.5*Vrat$$
$$E2=1.76*Vrat(Vrat>72.5kV)$$
$$E2=1.88*Vrat(Vrat\le 72.5kV)$$

The parameters T2, R, and T1 (when needed) can be read from tables given in C37.06. The use of these parameters will give the TRV capability of the breaker when interrupting fault current equal to its interrupting rating. When interrupting fault current which is less than its interrupting rating, the TRV capability of the breaker is increased. C37.06 gives multiplying factors for E2 and R and a dividing factor for T2 to adjust the TRV capability for fault current less than interrupting rating. For breakers rated 121 kV and above, the factors are the following:

For breakers rated 72 kV and below, the factors are the following:

	Multiplying Factor For E2 KE	Dividing Factor For T2 KT	Multiplying Factor For R KR
60% of rated current	1.07	2	2
30% of rated current	1.13	5	0
7% of rated current	1.17	5	0

For breakers rated 72 kV and below, the factors are the following:

	Multiplying Factor For E2 KE	Dividing Factor For T2 KT
60% of rated current	1.07	1.5
30% of rated current	1.13	2.5
7% of rated current	1.17	2.5

For currents in between values in the tables, interpolation is used to obtain the multipliers (dividers). If X is the ratio of fault current to interrupting rating, then the following formulas apply for breakers with voltage ratings of greater than 72.5 kV:

$100\% < X < 60\%$	$KE = 1+.07(1-X)/.4$
$60\% < X < 30\%$	$KE = 1.07+.06(.6-X)/.3$
$30\% < X < 0\%$	$KE = 1.13+.04(.3-X)/.23$
$100\% < X < 60\%$	$KR = 2-(X-.6)/.4$
$60\% < X < 30\%$	$KR = 2(X-.3)/.3$
$30\% < X < 0\%$	$KR = 0$
$100\% < X < 60\%$	$KT = 2-(X-.6)/.4$
$60\% < X < 30\%$	$KT = 2+3(.6-X)/.3$
$30\% < X < 0\%$	$KT = 5$

For breakers with voltage ratings of greater than 72.5 kV, the following formulas apply:

100% < X < 60%	KE= 1+.07(1-X)/.4
60% < X < 30%	KE= 1.07+.06(.6-X)/.3
30% < X < 0%	KE= 1.13+.04(.3-X)/.23
100% < X < 60%	KT= 1.5-.5(X-.6)/.4
60% < X < 30%	KT= 1.5+(.6-X)/.3
30% < X < 0%	KT= 2.5

All of these formulas have been incorporated into TACS statements which can go directly into the EMTP data file which is used to calculate the system TRV. Table 1 gives a listing of the TACS statements. In setting up these statements, much use was made of TACS logical variables. These have a value of one if the defining statement is true and have a value of zero if the defining statement is false. For example TEV has a value of zero if the breaker voltage rating is greater than 72.5 kV and has a value of one if the breaker rating is 72.5 kV or less. TEV1 has the opposite values. These logic variables are then used as multipliers in TACS Fortran expressions to enable or disable portions of the expressions. Another example of this is the variables TE1, TE2, and TE3. These logic variables are used to define which interval the ratio of fault current to interrupting rating is in, i.e. 0-30%, 30%-60%, or 60%-100%.

The circuit breaker TRV standards also define a short line fault capability of a circuit breaker. Like its name implies, the short line fault occurs when the fault is located a short distance down a transmission line from the breaker that is interrupting the current. If fault current equal to the breaker's interrupting rating is available at the breaker location and the fault is moved a short distance down a transmission line, then the current that the breaker interrupts is less than its rating. The short line fault is referred to by the percentage of the breaker's rating that it represents, such as 90% short line fault. The TRV that a breaker experiences when interrupting a short line fault has a triangular waveshape. The TRV capability of a breaker also has a triangular waveshape. C37.04 defines this triangular waveshape in terms of its rate-of-rise and its peak magnitude as follows:

$$\mathrm{PEAK} = \sqrt{\frac{2}{3}} * \mathrm{Vrat} * \mathrm{AF} * \ 1 - \mathrm{F}$$

$$\mathrm{RATE} - \mathrm{OF} - \mathrm{RISE} = \sqrt{2} * \omega * \mathrm{F} * \mathrm{Irat} * \mathrm{Z}$$

where:

Vrat is voltage rating of the breaker
Irat is interrupting rating of the breaker
AF is the amplitude factor (given in C37.04)

F is the ratio of fault current to Irat
Z is the surge impedance of the line (given in C37.04)

Figure 2 gives the TRV capability for a 121 kV, 40 kA breaker when interrupting a fault current of 30 kA. This curve was generated by the TACS expressions given in Table 1. The short line fault TRV capability of the breaker is also included in the TACS expressions in Table 1.

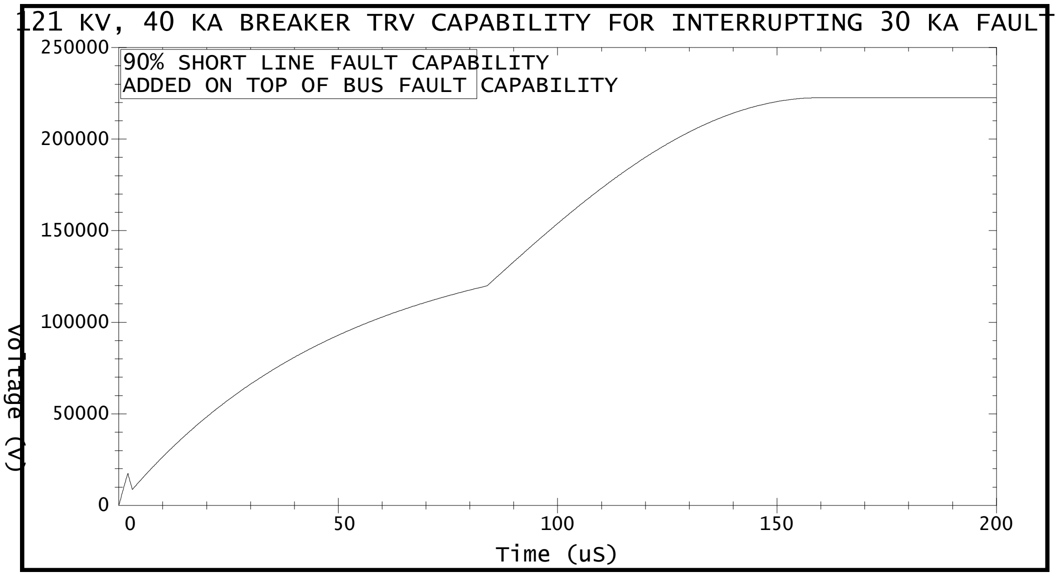

Figure 2

Table 1

```
BEGIN NEW DATA CASE
C
C DATA FILE NAME = TRV.DAT
```

```
C
C
C
   .1E-6 250.E-6      0.      0.
       1       1       1       0       1      -1               2
       5    1000
TACS HYBRID
C
C ENTER THE BREAKER VOLTAGE RATING IN VOLTS
11VRAT       121000.
C ENTER THE BREAKER CURRENT RATING IN AMPS
11IRAT        40000.
C ENTER THE BREAKER T2 TIME IN SECONDS
11T2         .000260
C ENTER THE BREAKER R VALUE IN VOLTS/SECOND
11R            1.8E9
C
C ENTER THE ACTUAL FAULT CURRENT IN AMPS
C
11CUR         30000.
C
C DETERMINE THE TRV PARAMETER MULTIPLIERS
C
99TEV     = (VRAT.LE.72500)
99TEV1    = (VRAT.GT.72500)
99F1      = TEV*2.5 + TEV1*5.
99F2      = TEV*1.5 + TEV1*2.
99F3      = TEV*1.0 + TEV1*3.
99F4      = TEV*.5  + TEV1*1.
99TE      = CUR/IRAT
99TE1     = (TE.GE.0  .AND. TE.LE..3)
99TE2     = (TE.GT..3 .AND. TE.LE..6)
99TE3     = (TE.GT..6 .AND. TE.LE.1.0)
99KRT     = (TE1*0.) + (TE2*((TE-.3)/.3)*2)       +  (TE3*(2-(TE-.6)/.4))
99KR      = (TEV*0.) + (TEV1*KRT)
99KT      = (TE1*F1) + (TE2*(F2+F3*((.6-TE)/.3))) +  (TE3*(F2-F4*(TE-.6)/.4))
99KE      = 1+((1-TE)/.55)*.1
C
C  DETERMINE TRV PARAMETERS
C
99E1      = 1.5*SQRT(2./3.)*VRAT
99E2      = (TEV*1.88*VRAT) + (TEV1*1.76*VRAT)
99T2B     = T2/KT
99E2B     = E2*KE
99RB      = R*KR
C
C
C
C CALCULATE THE TRV
C
C   1-EXPONENTIAL CURVE
C
99BRKTRZ  =E1*(1.-EXP(-RB*TIMEX/E1))
C   1-COSINE CURVE
```

```
99BRKTRX  =(TIMEX.LE.T2B)*E2B/2.*(1-COS(PI/T2B*TIMEX))+(TIMEX.GT.T2B)*E2B
C
C SHORT LINE FAULT PARAMETERS
C
C % SHORT LINE FAULT
11F              .90
C TRANSMISSION LINE SURGE IMPEDANCE
11Z             450.
C  AMPLITUDE FACTOR
11AF             1.8
C
C  CALCULATE SHORT LINE FAULT COMPONENT
99RISE    =533.1585*IRAT*F*Z
99PEAK    =.816497*VRAT*(1-F)*AF
99TIM     =PEAK/RISE
99BRKTRY  =(RISE*TIMEX-2.*RISE*(TIMEX-TIM)*(TIMEX.GT.TIM))*(TIMEX.LT.(2*TIM))
C  TOTAL TRV EQUALS MAXIMUM OF ANY OF THE THREE COMPONENTS
99BRKTRV63+BRKTRX +BRKTRY +BRKTRZ                           1
C
C  DESIRED OUTPUT
33BRKTRVBRKTRXBRKTRYBRKTRZ
C
C
C
C  REST OF EMTP DATA GOES HERE
```

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