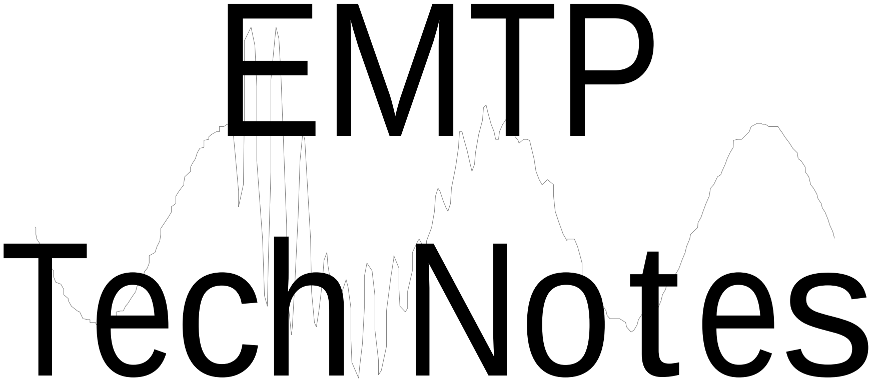
EMTP
Tech Notes



for users of the Electromagnetic Transients Program

Issue # 94-3 ***July, 1994*** ***Editor: Thomas Grebe***

---

in this issue:

Letter from the Editor:

EMTP Tech Notes is the technical newsletter provided to members of the EMTP User's Group. The newsletter is a quarterly technical publication highlighting contributions from members of the User's Group. This newsletter is published using Microsoft Word for Windows 6.0. If you wish to contribute an article, please contact Susie Brockman or myself for appropriate text and figure formats. 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 will help to serve the needs of the members. Thanks to the authors for helping to put this issue together. 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:

Thomas Grebe (x33) or Susie Brockman (x41)
EMTP User's Group
Electrotek Concepts, Inc.
10305 Dutchtown Road, Suite 103
Knoxville, Tennessee 37932
Phone: (615) 675-1500 x33
FAX: (615) 966-5497

(800) 554-4767

Modeling

Simulation of Substation Breaker Failure Using EMTP

Introduction

A breaker failure occurred at a substation of an electric utility after a fault had occurred on a transformer. When the transformer fault occurred (on transformer T1), relaying took the transformer off line and transferred the load of both low sides -T1X and T1Y. A crew was sent out to do the standard procedure for this scenario. They removed the circuit breaker at the X-winding (CB-T1X) from its cubical and were about to do the same to the one at the Y-winding (CB-T1Y). It was at this point that the breaker failure occurred when CB-T1Y closed unexpectedly. This closure tied the hot 13.8 kV but off transformer T2 to the faulted transformer T1. The energized T1 back-fed circuit 1 (a 161 kV line) to sub 200 where a fault recorder recorded the energization.

The EMTP study involved using the reduced circuit model shown in Figure 1 (Sub 100, transmission line 1, and transformers T1 and T2 with their loads and breakers). Studies were performed that modeled various fault conditions on T1 as well as having either one phase or three phases of the breaker operating. The results of the cases were compared against the result obtained from the fault recorder at sub 200.

Figure 1 - Reduced Circuit Model

Model Used for Investigating the problem

In this section, the model used to analyze the breaker failure is discussed in detail. Explanations and derivations of each main component will be given. The entire model is shown in Figure 1 and will be referred to often in this section.

Thevenin's Source Equivalent

The source voltage seen by sub 100 is modeled by the Thevenin's equivalent voltage and impedance. These are shown in the upper right hand portion of Figure 1. The EMTP requires source voltage to be given in peak line-to-ground volts. The input data listed the sinusoidal source voltage as 165.7 kV line-to-line. Making the appropriate conversion gives:

$$V_{pl\text{-}g} = V_{l\text{-}l} * \mathrm{sqrt}\ (2)/\mathrm{sqrt}\ (3) = 135.4\ \mathrm{kV}$$

The above peak line-to-ground value is the one that is entered into the input data file for the EMTP. The Thevenin's equivalent impedance is required to be in positive and zero sequence format for the EMTP and the resistance has units of ohms and the inductance has units of millihenries (mH's). The input data listed the positive and zero sequence impedances on a 100 MVA base as:

$$Z_1 = .1526 + j1.4520\ \%\ \text{per unit} \qquad Z_0 = .4762 + j2.3829\ \%\ \text{per unit}$$

In order to convert these values to ohms and millihenries, the base impedance value is needed. The base voltage is given as 161 kV line-to-line and the base impedance value can now be found by using the equation:

$$Z_{base} = (V_{base})2kVS_{base}MVA=259.21\Omega$$

The impedances can now be converted to ohms and millihenries using the conversions:

$$Z_1 = R_{1pu}{*}Z_{base} + jX_{1pu}{*}Z_{base}{*}1000/(120{*}\pi) = .3956\ \Omega + j9.983\ \mathrm{mH}$$
$$Z_0 = R_{0pu}\ {*}Z_{base} + jX_{0pu}{*}Z_{base}{*}1000/(120{*}\pi) = 1.234\ \Omega + j16.38\ \mathrm{mH}$$

Transmission Line 1

Circuit 1 is a 3.9 mile, 161 kV transmission line that runs between substations 100 and 200 and is shown in the upper left hand corner of Figure 1 (between B1 and MOD1). It was necessary to model this line since the fault recorder, which recorded the problem occurring at sub 100, was located at sub 200.

The line was modeled in the EMTP Line Constants auxiliary file. There are a couple of different model types available for transmission lines in the Line Constants file. These types include a constant distributed parameter model and a frequency dependent mode. Cases were run for both types (1CP.DAT and 1FD.DAT) and the results compared. Since the line was quite short, there was no apparent difference between the two types (lines usually have to be quite short, there was no apparent difference between the two types) (Lines usually have to be several miles long in order for a significant difference to occur between the models). Figures 2 and 3 show the similar wave forms for the two model types. Because of the lack of difference between the two types, the frequency dependent model (Table 1) was chosen arbitrarily to be used in the overall system model.

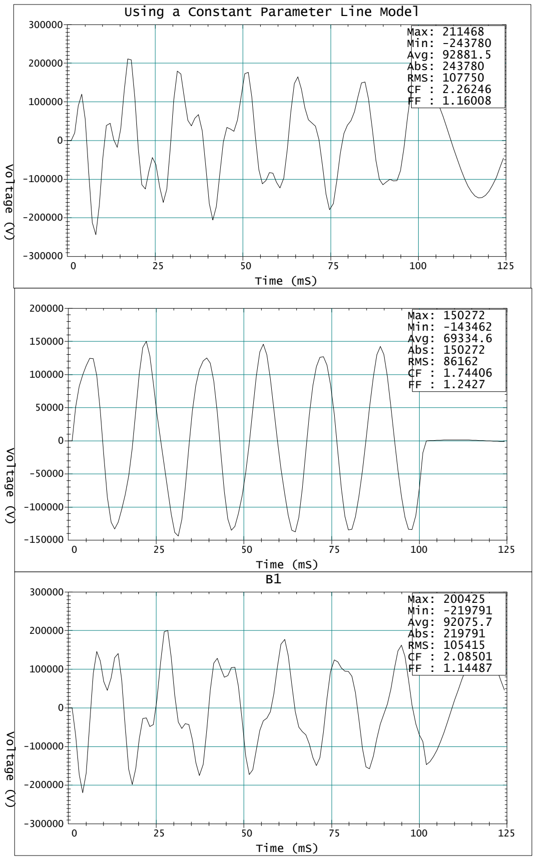


Figure 2 - Using a Constant Parameter Line Model - B1

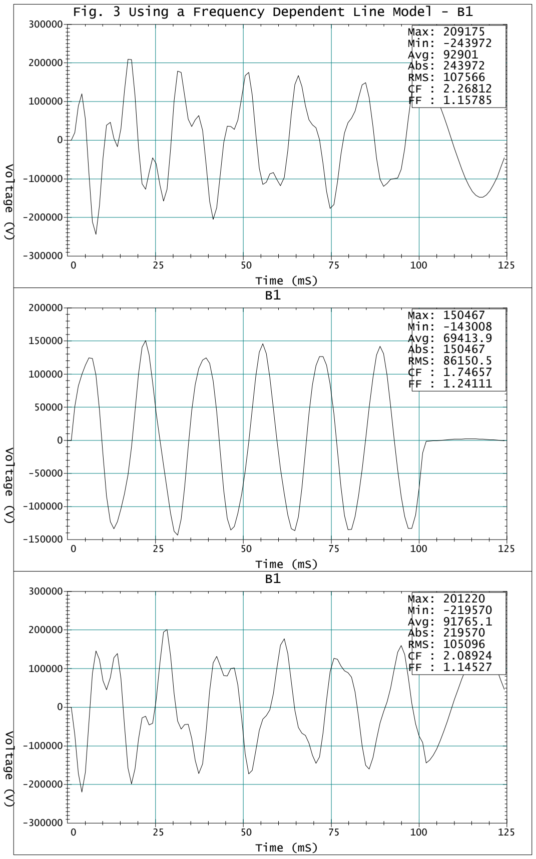


Figure 3 - Using a Frequency Dependent Line Model - B1

Table 1 - 1FD.dat

```
C FILE NAME:     1FD.DAT
C
C This file contains data for CKT 1.
C The zero and positive sequence impedances as well as the susceptance (+) are
C available to us, therefore the line-rebuild option will be used
C to find the line parameters to be used in EMTP.
C
C This file finds the FREQUENCY DEPENDENT PARAMETERS for the line.
C
C Here, I have assumed that Czero ~= 0.5 * Cpos.
C Note that LBUILD will not work if Czero = Cpos.
C
BEGIN NEW DATA CASE
LINE CONSTANTS
C 345678 112345678 212345678 312345678 412345678 512345678 612345678 712345678
C Module           Model---->Matrix--->Scale---->------Fmin<----NPdec<-----Ndec
LINE-MODEL         FD-LINE   LBUILD
ENGLISH
C Conductor cards
```

```
C I              I                               V
C P            R X       R               H       T               S     A       N
C h    S       e T       e       D       o       o       V       e     l     N B
C a    k       s y       a       i       r       w       M       p     p     a u
C s    i       i p       c       a       i       e       i       a     h     m n
C e<---n<------s<e<------t<------m<------z<------r<------d<------r<----a<----e<d
C
C
C 345678 112345678 212345678 312345678 412345678 512345678 612345678 712345678
C        <---Fparam<----Rzero<----Lzero<----Gzero<----Czero<------Rdc
 3              60.     0.527     5.951        0. 0.0077270
C                  <-----Rpos<-----Lpos<-----Gpos<-----Cpos
                        0.098     1.957        0. 0.0154541
BLANK card terminates conductor cards
C Frequency cards                                         M            I
C                                                       I u          M T
C                F         F      I      I I       D    PIt  I  I  I o r
C      R         r         C      C      Z C       i    iSu  D  P  P d n
C      h         e         a      P      P a       s    Pea  e  n  u a s
C -----o<--------q<--------r <----r <----r p<------t <--rgl<-c<-t<-n<l<f
    100.       60.                             3.920
C .nodes           k-a-->    m-a-->    k-b-->    m-b-->    k-c-->    m-c-->
.nodes             BUS1A     MOD1A     BUS1B     MOD1B     BUS1C     MOD1C
BLANK card terminates frequency card
BLANK card terminates LINE CONSTANTS study
BLANK card terminates LINE-MODEL cases
BLANK terminates EMTP solution-mode
```

The input data required for the Line Constants routine is simply the positive and zero sequence impedance and susceptance of the transmission line on a per mile bases. These values on a percent per unit bases as follows:

$$Z_1 = .148 + j1.116 \quad Z_0 = .797 + j3.393 \quad B_1 = .592$$

It is assumed that the zero sequence susceptance will be one half the value of the positive sequence susceptance. The base impedance value for the line is the same as the source base impedance calculated in the previous section. Letting "d" equal the length of the line (3.9 miles) and performing the necessary conversions gives the following values:

$Z_1 = R_{1pu}*Z_{base}/d + jX_{1pu}*Z_{base}*1000/(120\pi*d) = .0984\ \Omega/m + j1.957\ mH/m$

$Y_1 = 0 + jB_{1pu}/(Z_{base}*d*120\pi) = 0 + j0.01545\ \mu F/m$

$Z_0 = R0_{pu}*Z_{base}/d + jX_{0pu}*Z_{base}*1000/(120\pi*d) = .5297\ \Omega/m + j5.951\ mH/m$

$Y_0 = 1/2*Y_1 = 0 + j0.007727\ \mu F/m$

Transformers T1 and T2

Transformers T1 and T2 are 3-phase, 3-winding transformers with one delta-connected, high side, primary winding and two Y-connected, low side, secondary windings. Transformer T2 is shown in Figure 1 directly below the Thevenin equivalent of sub 100. The high side is labeled B100 and the two low sides are labeled T2X and T2Y with loads connected to both low sides. Transformer T1 is shown in Figure 1 on the left hand side of the diagram. The high side is labeled T1P and the two low sides are labeled T1X and T1Y. T1 was the transformer that originally faulted and T1Y is connected to the breaker that failed.

The two transformers were modeled in the EMTP using an auxiliary file titled TRELEG. Using this file is recommended for 3-phase, 3-winding transformers involving at least one delta-connection. The input data required for this file includes the number of delta windings, location and voltage rating of each winding, positive and zero sequence impedances. Dc winding resistances and magnetizing impedances. The titles of the data files used for these transformers are T1.DAT and T2.DAT as given in Tables 2 and 3, respectively.

Table 2 - T1.DAT Data File

```
C FILE NAME:    T1.DAT
C Purpose:  To model transformer T1 at sub100.
C TRELEG -- Calculates [R] and [L] matrices for single-phase
C and three-phase transformers.
C This file is for the transformer T1 on substation 100.
C T1 has a delta primary and Y's for secondary and tertiary windings.
C This template taken from workbook III, p. A-7.
BEGIN NEW DATA CASE
C       1         2         3         4         5         6         7
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C XFORMER card---------------------->< -N
XFORMER                              33.
C
C Branch card (Optional)
C       High (51) Medium (52)   Low (53)
C ----->Bus1->Bus2->Bus1->Bus2->Bus1->Bus2->
C BRANCH
C
C Data for all classes starts at column 2.
C
C Electrical parameters (class #1).
C N<-<-------Freq<-----SBVA
  3 1         60.      15.0
C col: (2-3) N, (4-5) NDelta
C
```

```
C Class #2 (present only if NDelta = 2).
C ------TPKMR<------TPKMX
C -
C col: (2-3) IDT
C ------TZKMR<------TZKMX
C
C Measurement data (class #3).
C   # of cards = (N-1)*N/2 + 1     for NDelta < 2
C                (N-1)(N-2)/2 + 1      NDelta = 2
C I<J<--------TPR<--------TPX<--------TZR<--------TZX
  1 2      0.0025      0.0588      0.0025      0.0576
  1 3      0.0031      0.0625      0.0031      0.0625
  2 3      0.0031      0.0625      0.0031      0.0625
C col: (2-3) I
BLANK card terminates measurement data.
C
C Output units (class #4)
C -
  2
C col: (2-3) KZout
C Winding data (class #5)
C   # of cards = N
C J < <--------VRj<---------RjNAi-->NBi-->NAi1->NBi1->NAi2->NBi2->
  1 0     7.967434     0.01492T1XA        T1XB        T1XC
  2 0     7.967434     0.01665T1YA        T1YB        T1YC
  3 1      161.000       3.165T1PA  T1PB  T1PB  T1PC  T1PC  T1PA
C col: (2-3) J, (5) INDD
BLANK card terminates winding data.
C
C Magnetizing impedance specifier (class #6)
C -
  1
C col: (2-3) NT
C
C Magnetizing impedance (class #7)
C   # of cards = 1 for NT <> 1
C                N     NT  = 1
C -------XPos<------XZero
     100.0000        1.00
       99.870        1.13
        99.67        1.33
BLANK card terminates magnetizing impedance.
C
C Repeat from branch card for additional cases.
BLANK card terminates TRELEG data.
BLANK card terminates EMTP solution mode.
```

Table 3 - T2.dat Data File

```
C File Name:       T2.dat
C Purpose:  To model transformer T2 at sub100.
C TRELEG -- Calculates [R] and [L] matrices for single-phase
C and three-phase transformers.
C This file is for the transformer T2 on substation 100.
C T8 has a delta primary and Y's for secondary and tertiary windings.
C This template taken from workbook III, p. A-7.
BEGIN NEW DATA CASE
C        1         2         3         4         5         6         7
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C XFORMER card----------------------><-N
XFORMER                              33.
C
C Branch card (Optional)
C        High (51) Medium (52)   Low (53)
C ----->Bus1->Bus2->Bus1->Bus2->Bus1->Bus2->
C BRANCH
C
C Data for all classes starts at column 2.
C
C Electrical parameters (class #1).
C N<-<-------Freq<-----SBVA
  3 1         60.      15.0
C col: (2-3) N, (4-5) NDelta
C
C Class #2 (present only if NDelta = 2).
C ------TPKMR<------TPKMX
C -
C col: (2-3) IDT
C ------TZKMR<------TZKMX
C
C Measurement data (class #3).
C   # of cards = (N-1)*N/2 + 1     for NDelta < 2
C                (N-1)(N-2)/2 + 1      NDelta = 2
C I<J<--------TPR<--------TPX<--------TZR<--------TZX
  1 2      0.0025      0.0588      0.0025      0.0576
  1 3      0.0031      0.0625      0.0031      0.0625
  2 3      0.0031      0.0625      0.0031      0.0625
C col: (2-3) I
BLANK card terminates measurement data.
C
C Output units (class #4)
C -
  2
C col: (2-3) KZout
C Winding data (class #5)
C   # of cards = N
C J < <--------VRj<---------RjNAi-->NBi-->NAi1->NBi1->NAi2->NBi2->
```

```
  1 0     7.967434     0.01838T2XA        T2XB        T2XC
  2 0     7.967434     0.01899T2YA        T2YB        T2YC
  3 1      161.000       3.712B100A B100B B100B B100C B100C B100A
C col: (2-3) J, (5) INDD
BLANK card terminates winding data.
C
C Magnetizing impedance specifier (class #6)
C -
  1
C col: (2-3) NT
C
C Magnetizing impedance (class #7)
C   # of cards = 1 for NT <> 1
C                N     NT  = 1
C -------XPos<------XZero
     100.0000        1.00
       99.870        1.13
        99.67        1.33
BLANK card terminates magnetizing impedance.
C
C Repeat from branch card for additional cases.
BLANK card terminates TRELEG data.
BLANK card terminates EMTP solution mode.
```

The nameplate data for both transformers were provided. The voltage ratings, configuration data, and winding resistances were all located on these nameplates. The positive and zero sequence impedances however, were not present. The impedance values from their short circuit tests of the transformers were also provided. The impedance values are listed in the following table.

Table 3 - Impedance Values

Winding	+R-W	+X=mH	0R-W	oX-mH
X--Y	.0025	.0588	.0025	.0576
X--H	.0031	.0625	.0031	.0625
Y--H	.0031	.0625	.0031	.0625

The dc winding resistances in ohms and voltage ratings in kV are listed in the following table for each transformer.

Table 4 - dc Winding Resistances

Wnd.	dcR	V	Wnd.	dcR	V
2X	0.18	7.97	1X	.015	7.97

2Y	.019	7.97	1Y	.017	7.97
2H	3.71	161	1H	3.17	161

The internal capacitance of transformer T1 was also included in the model. Since T1 was the transformer which had originally faulted, it was decided that T1 should be as realistically modeled as possible. The internal capacitances included capacitance from the high side delta-winging to ground (C_H), capacitance between the high side and low side Y-winding (C_{HL}), and capacitance from the low side winding to ground (C_L). These values were provided and are listed as follows:

$C_H = 1.5$ *nF* $C_{HL} = .586$ *nF* $C_L = 2.26$ *nF*

Loads on T2

Loads exist on both low sides of transformer T2. The load on T2Y is resistive and inductive, while the load on T2X is resistive, inductive and capacitive. Some of the load on T2X was originally on T1Y before the fault occurred at T1 causing its load to be transferred. Due to the load's close proximity to the faulted transformer and failed breaker, it was decided that the loads should be included in the mode. These loads are shown in Figure 1 below T2X and T2Y.

The EMTP requires input load data to be given in ohms, millihenries and microfarads for resistance, inductance and capacitance, respectively. The load data was in MW and Mvar. This data is listed as follows:

For T2X: P = 11.49 MW, Q= 6.26 Mvar, Cap. = 3.75 Mvar
For T2Y: P = 11.74 MW, Q = 2.54 Mvar

In order to convert these power values in terms of ohms and millihenries, the equation dividing the voltage (13.8 kV) is squared by the MVA (P + jQ) is used. This results in the following values

For T2X: $Z = (13.8)^2/13.2<-28.37 = 12.72 + J6.871\ \Omega = 12.72\ \Omega + j18.225\ \mu H$
$C= (13.8)^2/3.75,-90 = j50.784\ \Omega = 52.25\ \mu F$
For T2Y: Z = (13.8)2/12.01,-12.21 = 15.5 + j3.354 W = 15.5 W + j8.897 mH

Circuit Breaker T1Y

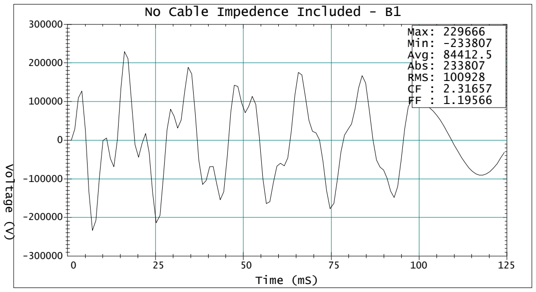
The circuit breaker connected to the Y-winding of transformer T1 (CB-T1Y) is the component that malfunctioned. This is the last main component of the system to be modeled. It is located on Figure 1 directly below T1Y.

The circuit breaker was modeled in the EMTP as an ideal switch. This proved to be the simplest and probably the best way to model the breaker. The option of using a dynamic circuit breaker model was explored extensively. The problems with using the dynamic model involved its nonlinear characteristics and very long simulation time (about 90 minutes per run). Since the ideal switch appeared to be working adequately, it was decided that it would be in the best interest of time to use the ideal switch model.

Al the EMTP requires for input data of an ideal switch is the closing and opening time of the switch. The fault recorder at sub 200 showed the energized wave form to have lasted around six cycles (100 ms) before being taken off line by relaying. To simulate the six cycle energization, the switch was set to close at 1 ms and open at 101 ms.

Miscellaneous Components

Secondary Cable: A 300 foot secondary cable (not shown in Figure 1) exists between the Y-winding of T1 and CB-T1Y. IT was originally thought that the impedance of this cable may have been a significant contributor to the breaker failure. Cases were run with this impedance included in the EMTP and the results were compared to cases without the cable impedance. Figure 4 shows a case without the cable impedance included and Figure 5 shows a case with the cable impedance included. A comparison shows very little difference between the two cases so it was concluded that the cable impedance was not a significant contributor.



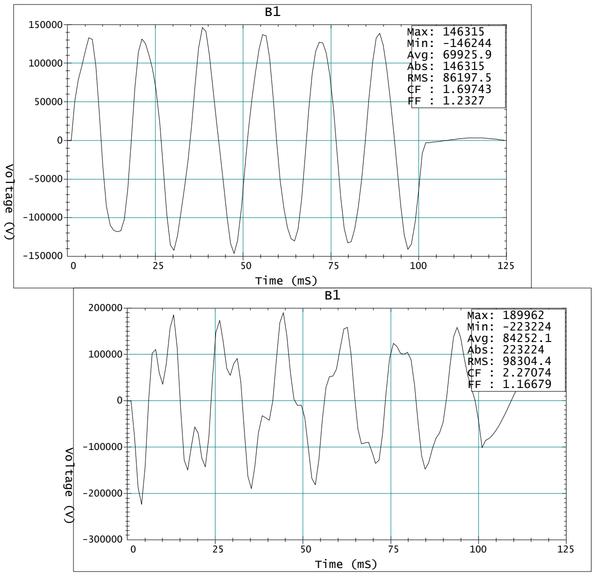


Figure 4 - No Cable Impedence Included

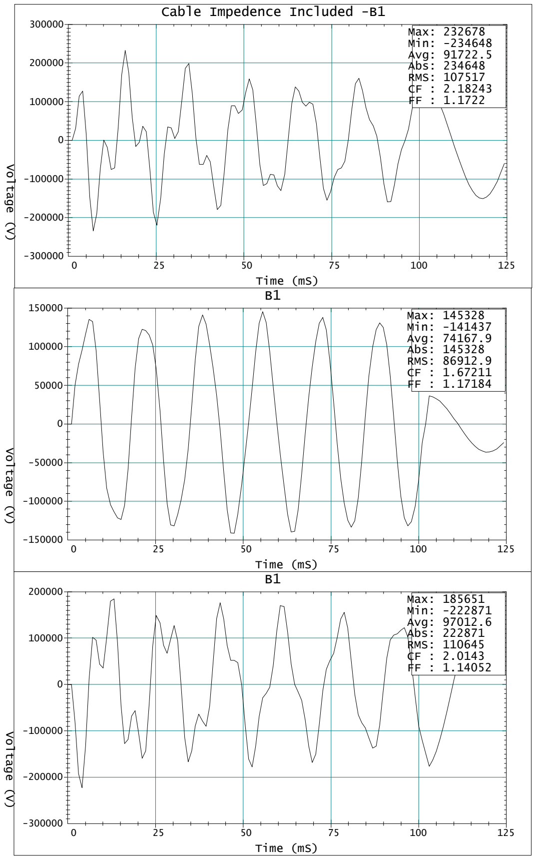


Figure 5- Cable Impedence Included

MOD: The motor-operated-disconnect existing between the transmission line 1 and the high side of transformer T1 was included in the model. It is located in Figure 1 between MOD1 and TIP. It was modeled as an ideal switch, but it was kept closed for the entire run in all the cases and never contributed to the analysis. It had originally been intended to run cases with the MOD open, but this idea was later abandoned since the TMP would only recognize it as an open circuit and not output anything at sub 200.

Results from the EMTP

There were three aspects of the problem that were uncertain when trying to determine what happened at sub 100. The first was trying to determine which side of transformer T1 has originally faulted. Initially, it was thought hat the fault had occurred on the high side of T1 due to results obtained fro a test report of T1. Later, however, further testing indicated that the fault may have occurred on the low side X-winding.

The second uncertain aspect was how many phases of circuit breaker CB-T1Y closed when it malfunctioned. It was determined from the results of the fault recorder at sub 200 that probably either one or else all three phases of the breaker closed.

The third uncertain aspect was the fault impedance in the faulted transformer. Regardless of where the fault occurred on the transformer, the fault impedance would be a key parameter when obtaining results. Each case that was run involved using a difference fault impedance and trying to obtain results that matched those of the fault recorder. For each case, four difference runs had to be made in order to take into account the first two uncertain aspects of the problem, These runs are listed as the following:

1. Fault occurring on the high side of T1 with one phase of BC-T1Y closing.
2. Fault occurring on the high side of T1 with three phases of CB-T1Y closing.
3. Fault occurring on the low side of T1 with one phase of CB-T1Y closing.
4. Fault occurring on the low side of T1 with three phases of CB-T1Y closing.

The fault impedances were initially chosen arbitrarily and then subsequently chosen to try and zero in on the desired results. The results of each run were compared to the results of the fault recorder for similarities.

High Side Fault with One Phase Closing

For these runs, the fault impedance was placed on the high side of T1 between phases A and C (H1 and H3). Only phase B of CB-T1Y closed and operated. Many different values were used for the fault impedance but only two cases are shown here for illustrative purposes.

The first case has a fault impedance of .1 ohms and 5 millihenries. Results are shown in Figures 6 and 7. Figure 6 shows the three phases separate while Figure 7 shows the phases superimposed on each other. The results show that the amplitudes compare well to the actual waveforms, but phases A and C are identical without any phase difference between them and the distortion of the waveforms differs from the actual waveforms.

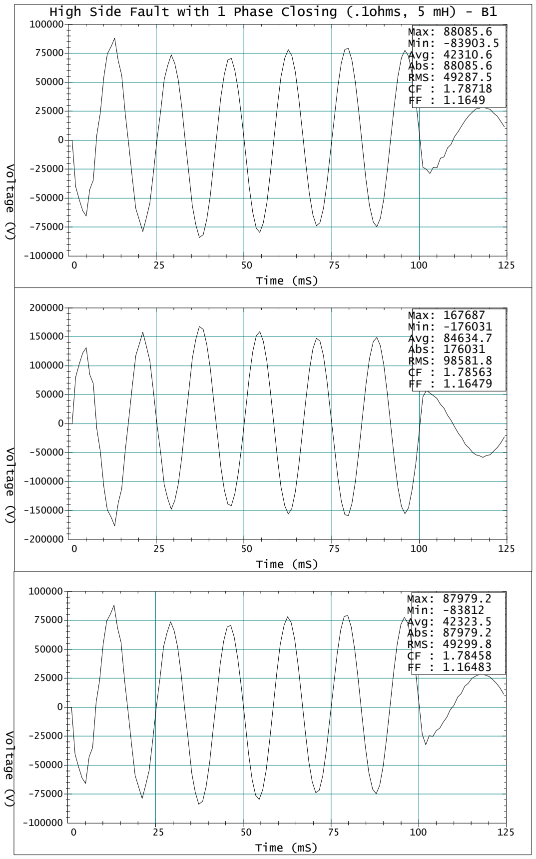


Figure 6 - High Side Fault with 1 Phase Closing (.1ohms,5mH)

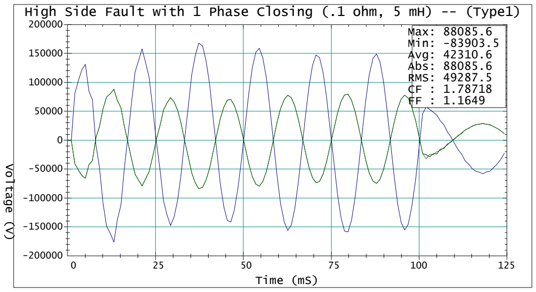


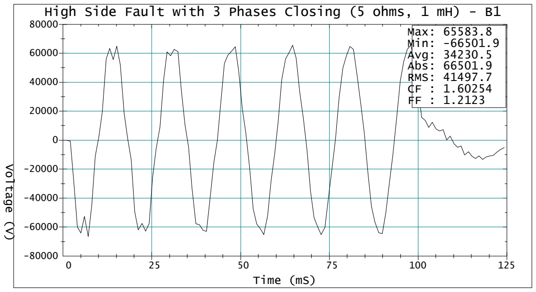
Figure 7 - High Side Fault with 1 Phase Closing (.1 ohm, 5mH) -- (Type 1)

Further testing indicated that the wave forms did not change very much with changes in fault impedance. The differences between these cases and the actual waveforms tend to rule out having the fault on the high side with only one breaker phase closing.

High Side Fault with Three Phases Closing

For these runs, the fault impedance was placed on the high side of T1 between phases A and C (H1 and H3). All three phases of CB-T1Y closed and operated. The two cases described in the previous section will also be used here (using the same fault impedances) for illustrative purposes.

This case has a fault impedance of 5 ohms and 1 millihenry. Results are shown in Figures 8 and 9. Figure 8 shows the three phases separate while Figure 9 shows the phases superimposed. The results show that the amplitude compare well to the actual waveforms, but phases A and C are identical without any phase difference between them. The distortion of the wave forms is closer than the previous section but it still differs from the actual waveforms. These results show that this case is very similar to the cases with fault impedance of .1 ohms and 5 millihenry by a slight difference in amplitude. The amplitude of phase A is slightly less than phase C, but they are still completely in phase.



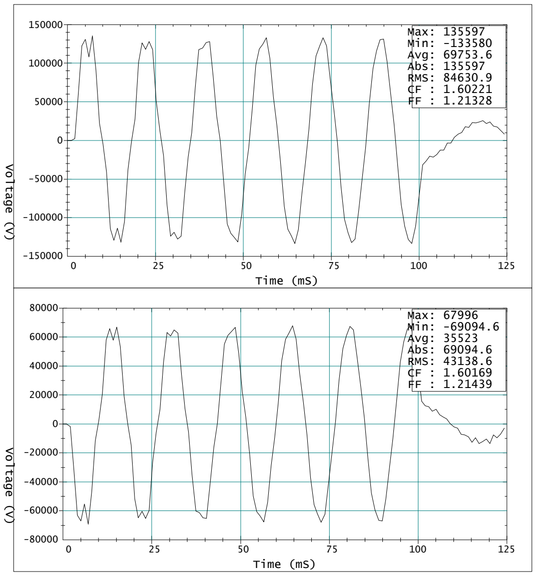


Figure 8 - High Side Fault with 3 Phases Closing (5 ohms, 1mH) - B1

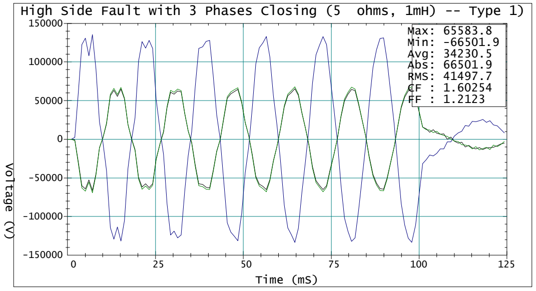


Figure 9 - High Side Fault with 3 Phases Closing (5ohms, 1 mH) -- (Type 1)

The results of other cases with different fault impedances tended to be similar to those described above. Like the previous section, the differences between these results and the results of the actual waveforms tend to rule out the fault being on the high side with all three phases of the breaker closing. Thus, it can be concluded that the original fault on T1 probably did not occur on the high side.

Low Side Fault with One Phase Closing

For these runs, the fault impedance was placed on the low side (X-winding) of T1 between phase A (X1) and ground. Only phase B of CB-T1Y closed and operated. Once again, the two cases described in the previous sections will also be used here (Using the same fault impedances) for illustrative purposes.

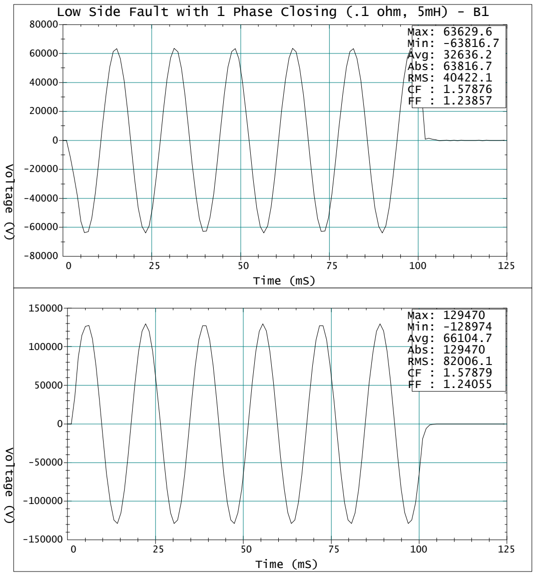
The first case has a fault impedance of .1 ohms and 5 millihenries. This case can be found in file C1OOE_F.DAT (Table 4) and the results are shown in Figures 10 and 11. Figure 10 shows the three phases separate while Figure 11 shows the phases superimposed on each other. The results show that both the amplitudes and phases compare well to the actual waveforms. The only differences are that the amplitude of phase A is slightly less than phase C and there is no apparent distortion in the waveforms.

Table 4 - File C100E_F.DAT

```
C Purpose:  fault on low side of T1.
C
C Template for general EMTP case studies.
C From workbook II, page A-15.
C
C The problem occurs when CB-T1Y does not interrupt a fault at
C bus 100.  This study will model CB-T1Y opening and closing
C exactly as the scenario is described.
C
C In this file, all transmission lines are modeled as frequency dependent
C distributed parameter lines.  Also, all lines are assumed balanced (=
transposed).
C Only phase B of the breaker closes in this case.
C
C Only, the Thevenin's eq. ckt. at B100 is included in this file.
C CKT 1 ends in an open circuit.
C
C
C Transformers, like the T-L's, are modeled in an auxiliary file.
C Loads connected to the transformers are referred to the high voltage
C (161 kV) side.
C
BEGIN NEW DATA CASE
C        1         2         3         4         5         6         7
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C .......................... Miscellaneous data ..............................
C FREQUENCY SCAN------><---Fmin<-DeltaF<---Fmax<--NPDEC>--MODSYM------>
C DeltaT<---TMax<---XOpt<---COpt<-Epsiln<-TolMat<-TStart
  1.0E-5 125.E-3
C --IOut<--IPlot<-IDoubl<-KSSOut<-MaxOut<---IPun<-MemSav<---ICat<-NEnerg<-IPrSup
     500     100                       1                       1
C
C .......................... Circuit data ...................................
C
C Dynamic circuit breaker line
C Bus1->Bus2->Bus3->Bus4->          <F
C 92T1YA T2XA                        2. 7777.
C 92T1YB T2XB                        2. 7777.
C 92T1YC T2XC                        2. 7777.
C --------Tpart<---------Tzero<----------Tarc
C Untransposed distributed parameters line.
C Bus1->Bus2->Bus3->Bus4-><---R'<----A<----B<--len 0 0 0                       O
C ---Ti(x,1)<----Ti(x,2)<----Ti(x,3)<----Ti(x,4)
C Transposed distributed parameters line
```

```
C Bus1->Bus2->Bus3->Bus4-><---R'<---L'<---C'<--len 0 0 0                       O
C
$INCLUDE, 1fd.pun
$VINTAGE, 1
$INCLUDE, T1.pun
$INCLUDE, T2.pun
$VINTAGE, 0
C
C Series RLC branch
C Bus1->Bus2->Bus3->Bus4-><----R<----L<----C                                   O
C
C Simultates a fault on the low side of T10:
  T1XC                        .1    5.                                         0
  T1XA                       10.                                               0
  T1XB                        5.                                               0
C
C Capacitance of T1:
  T1PA                                 .0015                                   0
  T1PB                                 .0015                                   0
  T1PC                                 .0015                                   0
  T1YA                                .13081                                   0
  T1YB                                .13081                                   0
  T1YC                                .13081                                   0
  T1PA  T1YA                          .00059                                   0
  T1PB  T1YB  T1PA  T1YA                                                       0
  T1PC  T1YC  T1PA  T1YA                                                       0
C Load at T2X
  T2XA                     12.7218.225                                         0
  T2XB                     12.7218.225                                         0
  T2XC                     12.7218.225                                         0
  T2XA                                 52.23                                   0
  T2XB                                 52.23                                   0
  T2XC                                 52.23                                   0
C LOAD AT T2Y
  T2YA                      15.5 8.897                                         0
  T2YB        T2YA                                                             0
  T2YC        T2YA                                                             0
C
C Pi-equivalent branch.
C Bus1->Bus2->Bus3->Bus4-><----R<----L<----C<----R<----L<----C<----R<----L<----C
C
C Mutually-coupled RL branches (zero and positive sequence)
C Bus-->Bus-->            <----R<----------L<----R<----------L<----R<----------L
C The following is data for the Th. eq. at bus 100
51T100A B100A             1.2341    16.38386                                   0
52T100B B100B             0.3956     9.98337                                   0
53T100C B100C                                                                  0
C Mutually-coupled branches
C Bus1->Bus2->Bus3->Bus4-><----R<----L<----C<----R<----L<----C<----R<----L<----C
C
BLANK card terminates circuit data
C
C ........................... Switch data ......................................
```

```
C Bus1->Bus2-><---Tclose<----Topen<-------Ie                                   O
  MOD1A T1PA         -1.     9999.         0                                   0
  MOD1B T1PB         -1.     9999.         0                                   0
  MOD1C T1PC         -1.     9999.         0                                   0
C
C   T1YA T2XA      1.E-3   101.E-3         0                                   0
  T1YB  T2XB       1.E-3   101.E-3         0                                   3
C   T1YC T2XC        1.E-3   101.E-3         0                                 0
BLANK card terminates switch data
C
C ........................... Source data ......................................
C Bus--><I<Amplitude<Frequency<--T0|Phi0<---0=Phi0         <----Tstart<----Tstop
14T100A    135.400E3       60.        0.        0.                 -1.     9999.
14T100B    135.400E3       60.     -120.        0.                 -1.     9999.
14T100C    135.400E3       60.      120.        0.                 -1.     9999.
BLANK card terminates source data
C
C ........................... Output request data ..............................
C Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->Bus-->
  BUS1A BUS1B BUS1C
BLANK card terminates output requests
BLANK card terminates plot requests
BEGIN NEW DATA CASE
BLANK card terminates EMTP solution mode
```



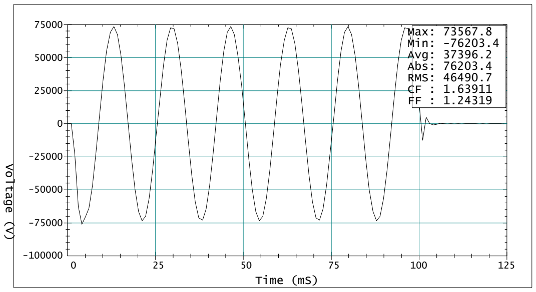


Figure 10 - Low Side Fault with 1 Phase Closing (.1ohm, 5mH) -- B1

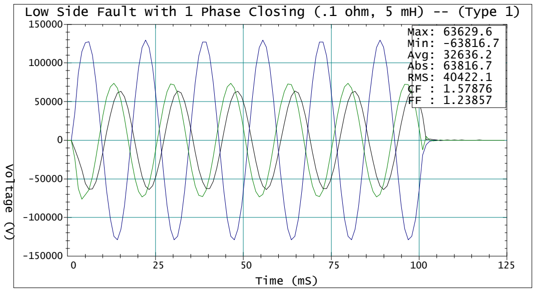


Figure 11 - Low Side Fault with 1 Phase Closing (.1ohm, 5mH) -- (Type 1)

The second case has a fault impedance of 5 ohms and 1 millihenry. These results show a significant difference from the first case in that the amplitude of phase A is greatly decreased while phase B decreased slightly and phase C increased slightly. The other characteristics are similar to the first case.

The results of other cases with low side faults and one breaker phase closing tended to cause amplitude differences like the differences between the two above. Also, a lot of cases did not show the slight phase difference between A and C. When comparing the the actual results of the actual waveforms, the second case can probably be ruled out, but the first case remains as a possible answer.

Low Side Fault with Three Phases Closing

For these runs, the fault impedance was placed on the low side (X-winding) of T1 between phase A (S1) and ground. All three phases of CB-T1Y closed and operated. Once again, the two cases described in the previous sections will also be used here (using the same fault impedance's) for illustrative purposes.

The first case has a fault impedance of .1 ohms and 5 millihenries. Results are shown in Figures 12 and 13. Figure 12 shows the three phases separate while Figure 13 shows the phases superimposed on each other. The results show that none of the characteristics compare favorably to the actual waveforms. The waveforms are highly distorted during the first few cycles, are 120 degrees out of phase, and have amplitudes that are too large.

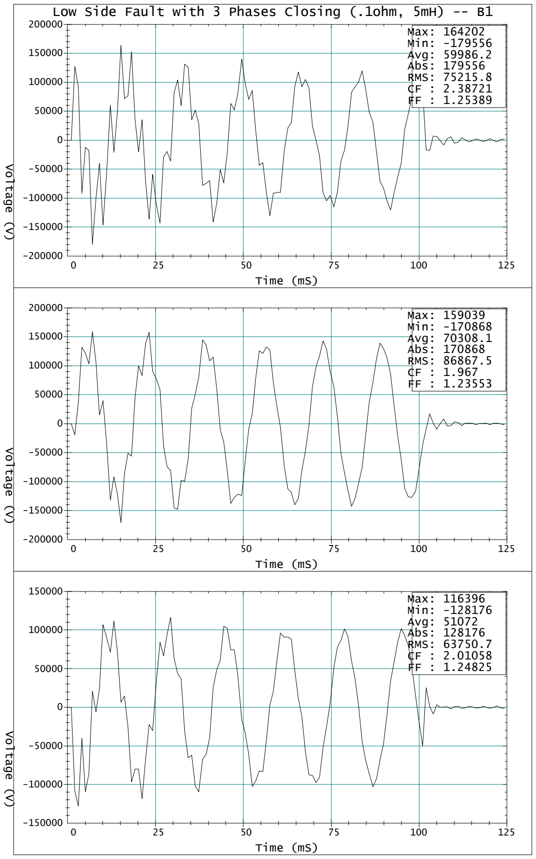


Figure 12 Low Side Fault with 3 Phases Closing (.1ohm, 5mH) -- B1

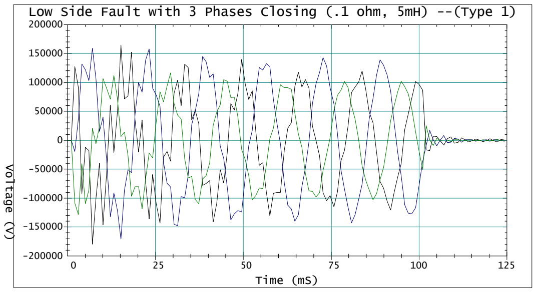


Figure 13 - Low Side Fault with 3 Phases Closing (.1 ohm, 5 mH) -- (Type 1)

The second case has a fault impedance of 5 ohms and 1 millihenry. These results show similarities to the first case only without as much distortion. The phases are still 120 apart and the amplitudes of phases A and C are larger than the actual results of the actual waveforms

The results of other cases tended to have similar results with varying degrees of distortion. The three phases were always 120 degrees apart and the amplitudes at A and C were large compared to the actual results. Because of the significant differences from the actual waveforms, it is unlikely that all three phases of the breaker closed.

Summary

This paper gives a summary of the results obtained from EMTP studies on the breaker failure at substation 100. The model used and the results obtained have been discussed extensively. The model used was a reduced, simplified model of the vicinity surrounding sub 100. The Thevenin's Equivalent of sub 100 was included as well as detailed models of transformers T1 and T2, transmission line 1, the loads off T2 and CB-T1Y.

The results have shown that the most likely occurrence during the failure was one phase (B) of circuit breaker CB-T1Y closing with a fault on the low side (X-winding) of transformer T10. The exact distortion of the actual fault recorder results were never attained, but the 1-phase closure with low side fault did provide the correct amplitudes and phase shifts which the other runs were unable to attain. Also, the results of the EMTP with the fault occurring on the low side and one phase of the breaker closing tend to agree with the findings and expectations.

References

[1] EMTP Revised Rule Book Version 2.0 - EL-6421, Volume 1, Research Project 2149-4, Final Report, June 1989.

[2] Power System Analysis Using the Electromagnetic Transients Program (EMTP) - EMTP Case Study Workbook, In-house Training Edition, by Electrotek, November, 1992 - January, 1993.

[3] EMTP Workbook - EL 4651, Final Report, September 1986.

Dr. Sohrab Asgarpoor, Assistant Professor
Matthew J. Mathine, Graduate Student
University of Nebraska-Lincoln

Lincoln, NB

Computer Lab Case Study

Teaching Through Computer Lab Case Study Experiments

The EMTP Summer course at University of Wisconsin-Madison is designed to provide in-depth knowledge and understanding of Electromagnetic Transients based on the versatile and powerful DCG/EPRI EMTP. This paper describes a rather simple but interesting study case discussed during the course lab session among the conference attendee Kenneth Behrendt and the faculty members Jean Mahseredjian, Fernando Alvarado, and Willis Long.

The conference attendees are always encouraged to apply practical and analytical knowledge to verify and explain the numerical simulator outputs and waveforms. Learning to use the EMTP requires learning many details about features and limitations of the program. The current state of the art is unable to provide models or calculation operation that can be used completely transparently to the underlying numerical constructions and limitations. In most cases, several modeling choices are available for a given network component. These choices are usually bases on the required level of sophistication and linked to the frequency of the simulated phenomena. The test cases studied during the course are designed to challenge the user in the appropriate model selection and to force comparative studies.

The differences between constant parameter and frequency dependent line models is always an interesting topic during the course. What frequency should be used to calculate the constant parameter line model parameters? In which case is it necessary to model the ground wires? One of the most effective means to experiment with the EMTP and appreciate modeling differences is to modify an existing model or case to create a new one. Of particular interest in this note are the problems and pitfalls that can occur as a result of student experimentation with the translation of models between time frames.

The case (Case 1) of Figure 1 is designed to study reclosing into a trapped charge on the three-phase line BKR1-BUS2. Here are the sequence of events and circumstances for the case study:

Figure 1 - A Case Study: Reclosing into a Trapped Charge on Line BKR1--BUS2

a) Case 1 required to create the line model from a previously available lightning case (Case 2) study of the same line. Since lightning needs detailed representation of short sections of lines, with individual line sections and overhead ground wires, the lightning case was using the TD-LINE QREAL (untransposed) model where the line was represented through 5 conductors (3 phase and 2 ground) and 4 individual 300m spans. The frequency selected for the calculation of the transformation matrices was 500kHz

b) A simple methods for converting the Case 2 line model is to select a single span EMTP AUX module file and to replace the line length by the actual total line length of □193km for the switching study of Case 1. The ground wire representation is not needed in Case 1, these wires are therefore combined with the phase conductor.

c) At this stage the students had to experiment with the line model selection. If the CP-LINE model is chosen, then the next step is to study and appreciate the influence of the parameter calculation frequency f_m selection. No difficulties were encountered when f_m was in the typical range of switching transients. But any attempt to use f_m □15kHz resulted in an EMTP error message indicating that something is wrong in the line model calculated by the AUX module. This may appear to be contradictory with Case 2 where a solution was found with f_m = 500kHz. An attempt to recreate the conditions prevailing in Case 2 is to subdivide the CP-LINE of Case 1 into at least 2 sections, then the previous error message disappears and a solution is found. The reason is natural enough for an experienced EMTP user, but not necessary evident a-priori.

d) The explanation of the error message lies in the underlying constant parameter line modal resistance (R') representation for the time-domain solution. It must be recalled that the default model cuts the line in two, inserting half of the modal resistance in the middle and one fourth at each end. This simplified representation is acceptable if $R'\iota << Z_c$ (ι is the line length and Z_c is the modal characteristic impedance). When fm □5kHz the $R'\iota$ becomes excessively high and EMTP refuses to solve (fortunately).

e) It is true that 14kHz is excessive for Case 1, and it must be indicated that the program is capable of automatically selecting an optimum value for f_m within the switching transients range of 500Hz to 5kHz. Both CP-LINE and FD-LINE support this option and the comparative results with CP-LINE and FD-LINE models calculated automatically at 1563Hz are shown in Figure 2. The FD-LINE model is usually closer to the reality.

Figure 2 - Voltage at BUS!, Case Study of Figure 1

The lumped representation of R' was also the cause of the source current dip (see Figure 3) occurring at the propagation delay τ, noticed by some students when an open-ended single phase line is energized by a step voltage source. This step response is an approximation to the step response of a line with continuously distributed resistance and frequency dependent parameters. IF the representation of the line resistance was improved by adding a large number of smaller lumped resistances connected by short lossless lines, then the reflection from the resistance in the center of line shown in Figure 3 would be replaced by many smaller reflections, occurring not only at τ but over a range of time. The replacement of the CP-LINE by FD-LINE is the next logical step to let students appreciate the resulting more realistic smoothly decaying and rounded current waveform.

Figure 3 - Source Current from a Step Function Voltage Connected to an Open-Ended Single Phase Line

The above given explanations are definitely not new for experienced EMTP users but less experienced and particularly first time users need to learn some minimal EMTP line modeling details to understand outcoming error messages and simulation results. In conclusion, teaching and learning the EMTP by using a unified set of cases and contracting various models is extremely instructive. This short article was written during the summer 94 EMTP course.

Jean Mahseredjian, Hydro Quebec
Fernando Alvarado, University of Wisconsin - Madison
Willis Long, University of Wisconsin - Madison
Kenneth Behrendt - Schweitzer Engineering Laboratories