Comparison of an analytical study and EMTP implementation of complicated three-phase schemes for reactor interruption

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by
V.K.I. Kalasek

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ABSTRACT

When small inductive currents are interrupted by High Voltage circuit breakers current chopping will generally occur and will induce overvoltages. This paper describes a comparison between an analytical study and EMTP (= ElectroMagnetic Transient Program) implementation for calculation of such overvoltages in three-phase inductive circuits. Capacitive and/or inductive couplings between phases are included in schemes with grounded and non-grounded neutrals. If the time steps for numerical integration are small enough the EMTP calculation gives reliable and even more detailed and complete results than the analytical approach could do. Complete listing of input files for the EMTP program is given in the appendix.

Kalasek, V.K.I.
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Faculty of Electrical Engineering, Eindhoven University of Technology, The Netherlands, 1988.
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CONTENTS

Comparison of an analytical study and EMTP implementation of complicated three phase schemes for reactor interruption.

1. Introduction

To find out how reliable the EMTP-computing program [1] is for solving complicated transient situations the available results of an analytical study of switching phenomena in three phase inductances (such as reactors) were compared with the computations with EMTP.

Detailed mathematical expressions for current decays and voltage transients derived by Van den Heuvel and Papadias can be found in [2] and [3]. The analytical solution is rather complicated. The current is not interrupted when passing the natural zero but a "current chopping" at a small current value prior to zero occurs in most cases. After that the magnetic energy still present in the interrupted inductance is being transferred into the circuit capacitances causing a single- or multi-frequency HF-oscillation. This oscillation penetrates into the other phases through capacitive links and mutual couplings. These effects can cause very high overvoltages in some circuits (depending on circuit parameters).

2. Analytical and EMTP-approach

The whole problem of current interrupting can be divided into four time intervals:

1. time before the first phase interruption,
2. time interval between the first and the second phase interruption,
3. time interval between the second and the last phase interruption,
4. time after the last phase interruption.

The occurring phenomena are different during each of these intervals. The frequencies of the occuring transient voltages accross the inductances are different during the time intervals 2,3 and 4 while the amplitudes and the shapes of the transients depend strongly on the value of the chopping current. Boundary conditions have to be set for each phase at the beginning of each of the intervals mentioned above. This makes the analytical solution rather complex.

Four different situations have been studied by Van den Heuvel and Papadias for the case of grounded reactors as well as for reactors without grounded neutral:

1. non-coupled reactors,
2. capacitively coupled reactors,
3. inductively coupled reactors,
4. capacitively and inductively coupled reactors.

The amplitudes of transient overvoltages are strongly dependent on the voltages and currents in other phases at the moment of the three successive current choppings. To get seven different starting conditions (different phase angles between 0 and 360 degrees at the moment of second phase interrupting in steps of 60 degrees) for each case mentioned above, small changes of circuit parameters have been carried out.

For the analytical solutions only the network frequency currents have been used. In reality, however, the transient current oscillations after first phase interruption also penetrate into the other phases. This results in a small HF-oscillation superimposed on the network-frequency currents (as shown in the third row of figures representing the current, expecially in the phases B and C). The effect seems relatively small in the proximity of current zero, where chopping occurs. But the phenomenon may have important consequences when interrupting ungrounded inductances, as shown in [3]. It is hardly possible to take the HF current oscillations into account in case of analytical solution.

Another possible approach to solve the given problem is to use the EMTP with only time-controlled switches. This way is much more reliable in case of ungrounded inductances.

Both types of computations have been carried out at Eindhoven University of Technology on the Burroughs B7900 computer of the Computing Centre. Complete listing of input files for the EMTP implementation is given in the appendix. The analytical method was used for grounded inductances, the EMTP (version M35) for ungrounded ones. Later the EMTP version M39 was used on the Apollo 3000 to verify the computations of grounded and ungrouned inductances.

The EMTP takes a different approach when solving the problem and it takes the superposition of high frequency current components well into account. Both types of calculations were compared for a grounded circuit to verify correct operation of the EMTP. Figures at the end of this article

give an example of the results. Comparison of the first row of figures (analytical solution) with the second one (EMTP solution) shows the same overall behaviour with only unimportant differences.

The only problem with the EMTP was to choose the time step for numerical integration small enough so that, at the moment of current chopping, the current would not change more than let say 5% of the given value of the chopping current within two succeeding iterations. Therefore, the time step Δt in our study had to be as small as $0.5\ 10^{-6}$ sec.

Mutually coupled R-L branch elements (ITYPE = 51, 52, 53) {for detailed information see the EMTP Rule Book [1]} were used in case of mutually and mutually + capacitively coupled reactors.

For a complete review of all the sets of figures see [2] and [3]. Figures in Part I [2] were obtained by means of computation according to the analytical formulas and checked with EMTP, while all the figures in Part II [3] (for ungrounded reactors) are based on EMTP computation.

3. Conclusion

From this study the following could be concluded:

The analytical approach gives a better understanding of the whole interrupting process and gives a clear explanation of such complicated shapes of transient voltages, EMTP, however, gives more complete results with all details considering all boundary conditions automatically. It is much easier for the user when studying different situations of current interruption to use the EMTP. Chance to make a mistake when putting in the input variables is in that case also much smaller.

When comparing results obtained by using the exact analytical formulas with the output of EMTP (version M35 as well as version M39) the full agreement in transient frequencies and amplitudes of overvoltages can be confirmed.

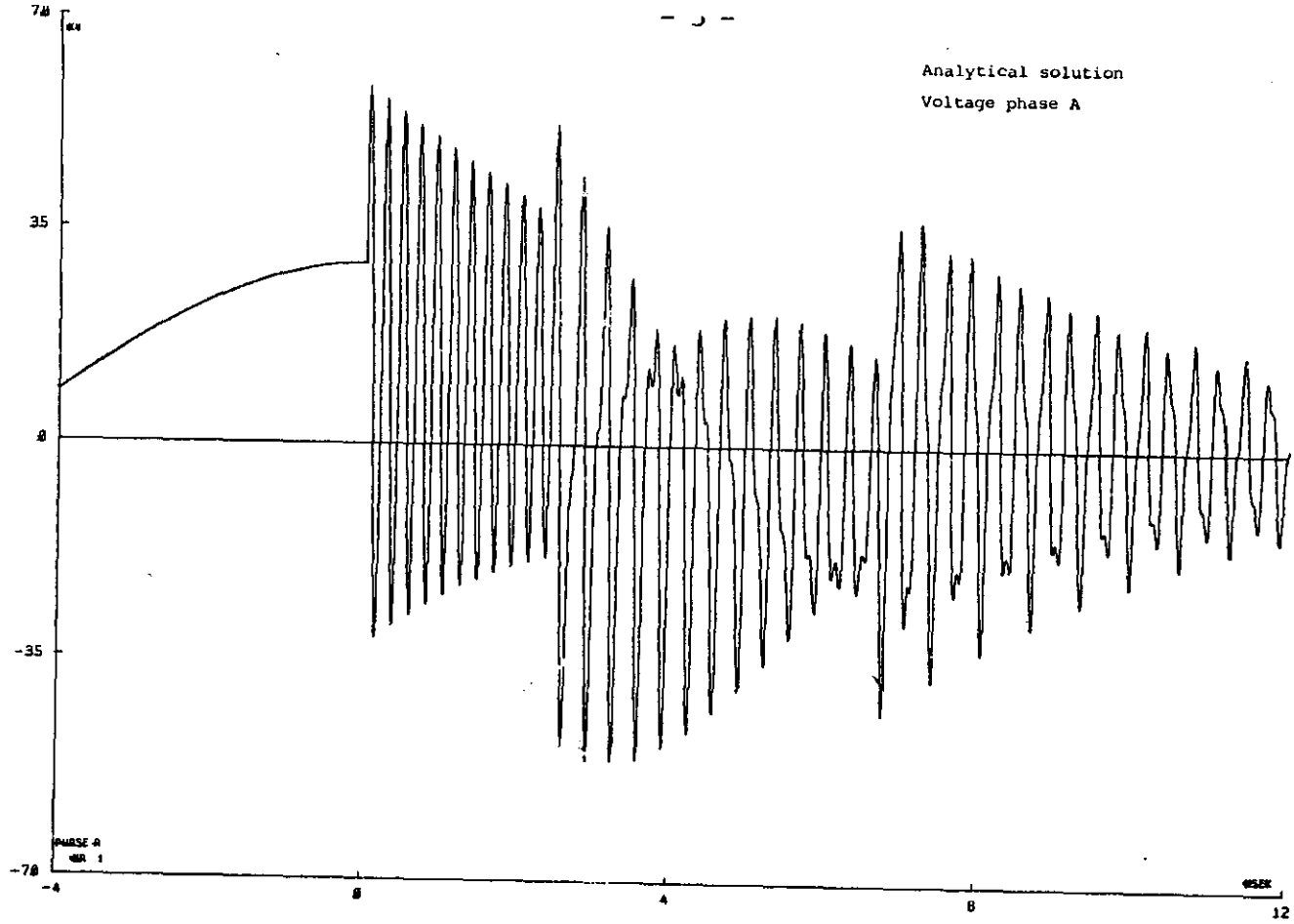
REFERENCES

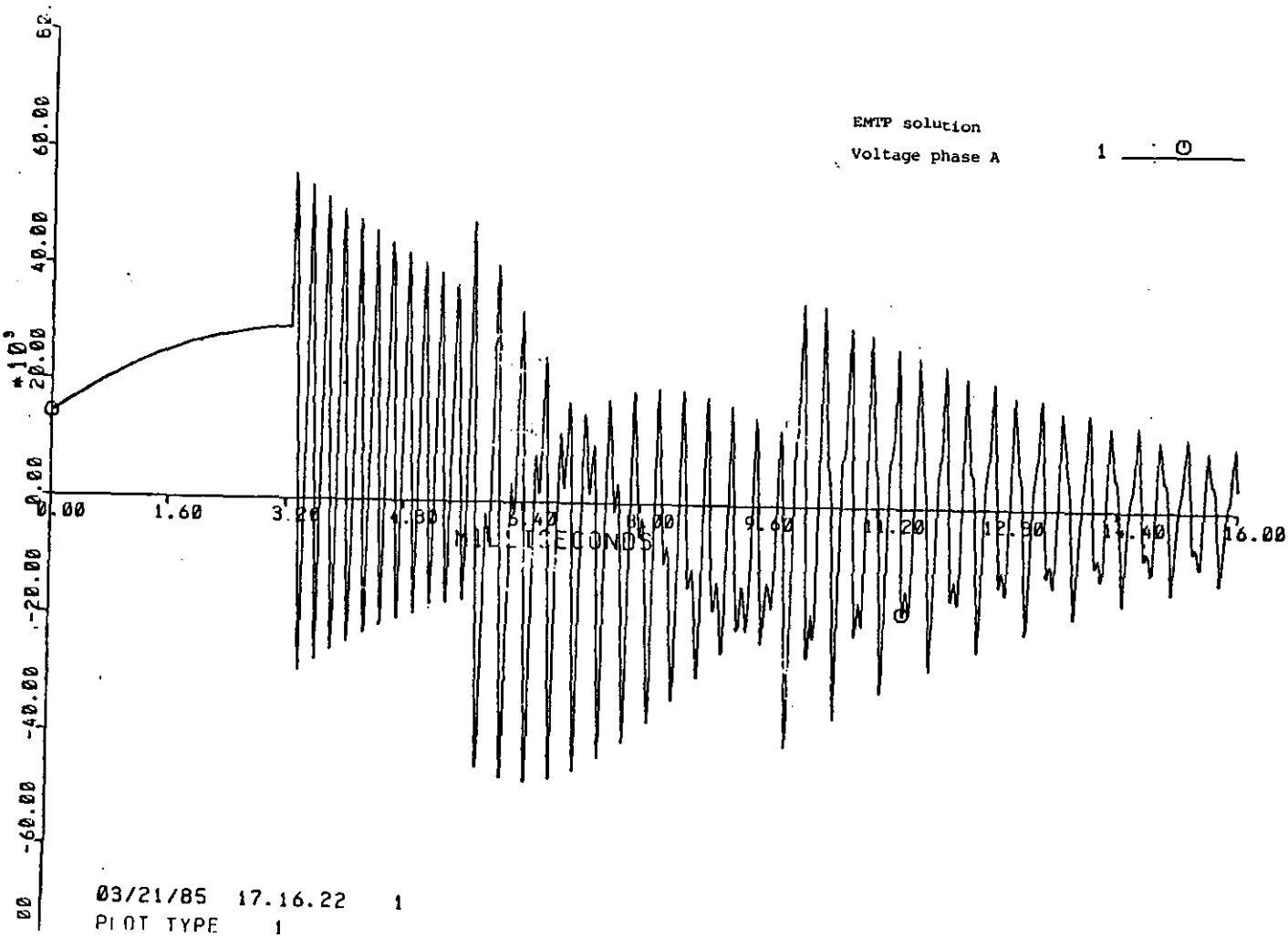
[1] ElectroMagnetic Transients Program [EMTP]. Rule Book.
Rev. version June 1984.
Methods Development Branch, Route EOGB, Division of System Engineering, Bonneville Power Administration, P.O. Box 3621, Portland, Oregon 97208, USA.
More information on EMTP can be obtained at:

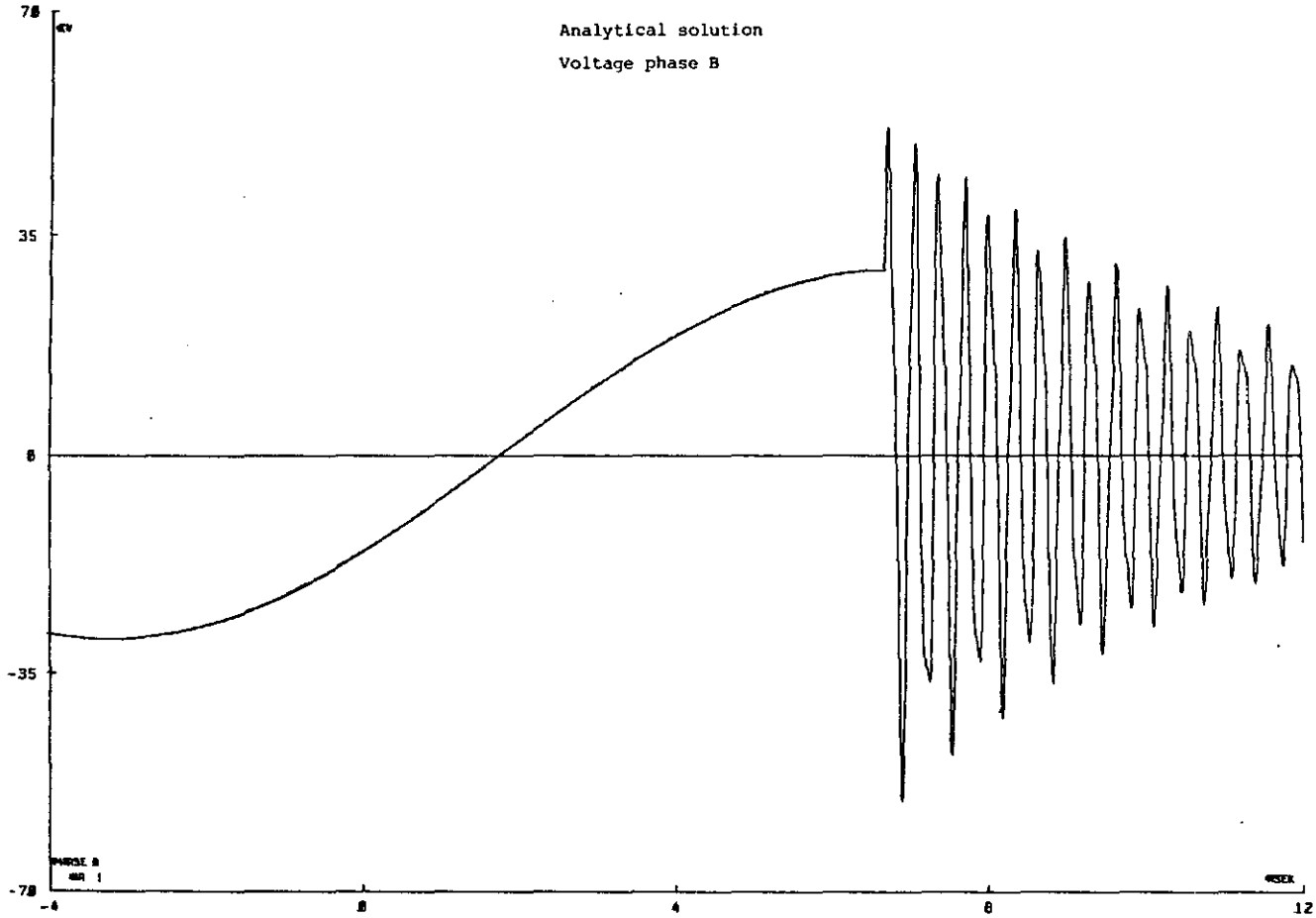
EMTP European Users Group,
K.U. Leuven EMTP Center,
Kard. Mercierlaan 94,
B-3030 Heverlee,
Belgium

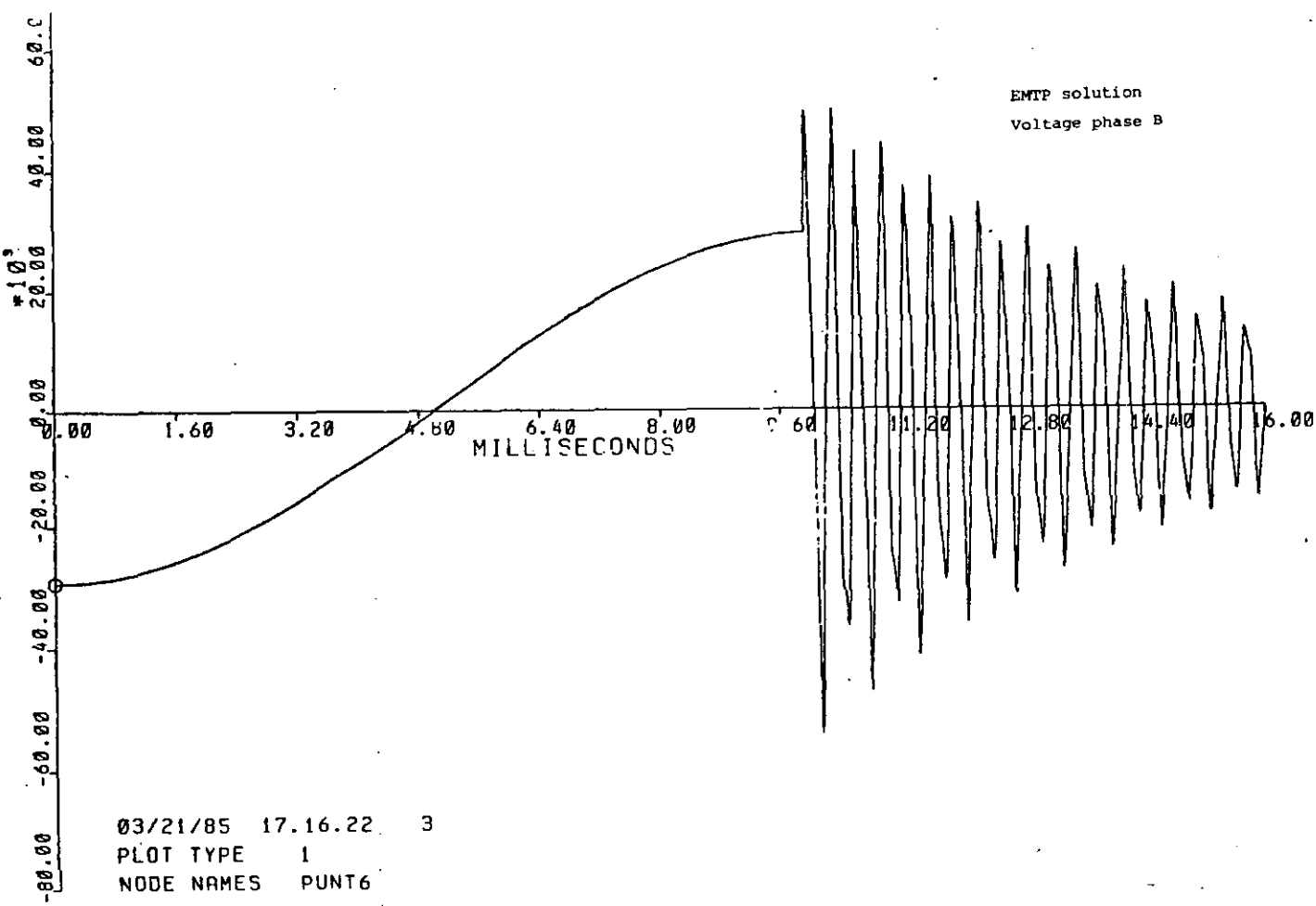
[2] Heuvel, W.M.C. van den and B.C. Papadias
Interaction between phases in three-phase reactor switching.
Part 1: Grounded reactors.
Electra (Paris), No. 91(1984), p. 11-50.

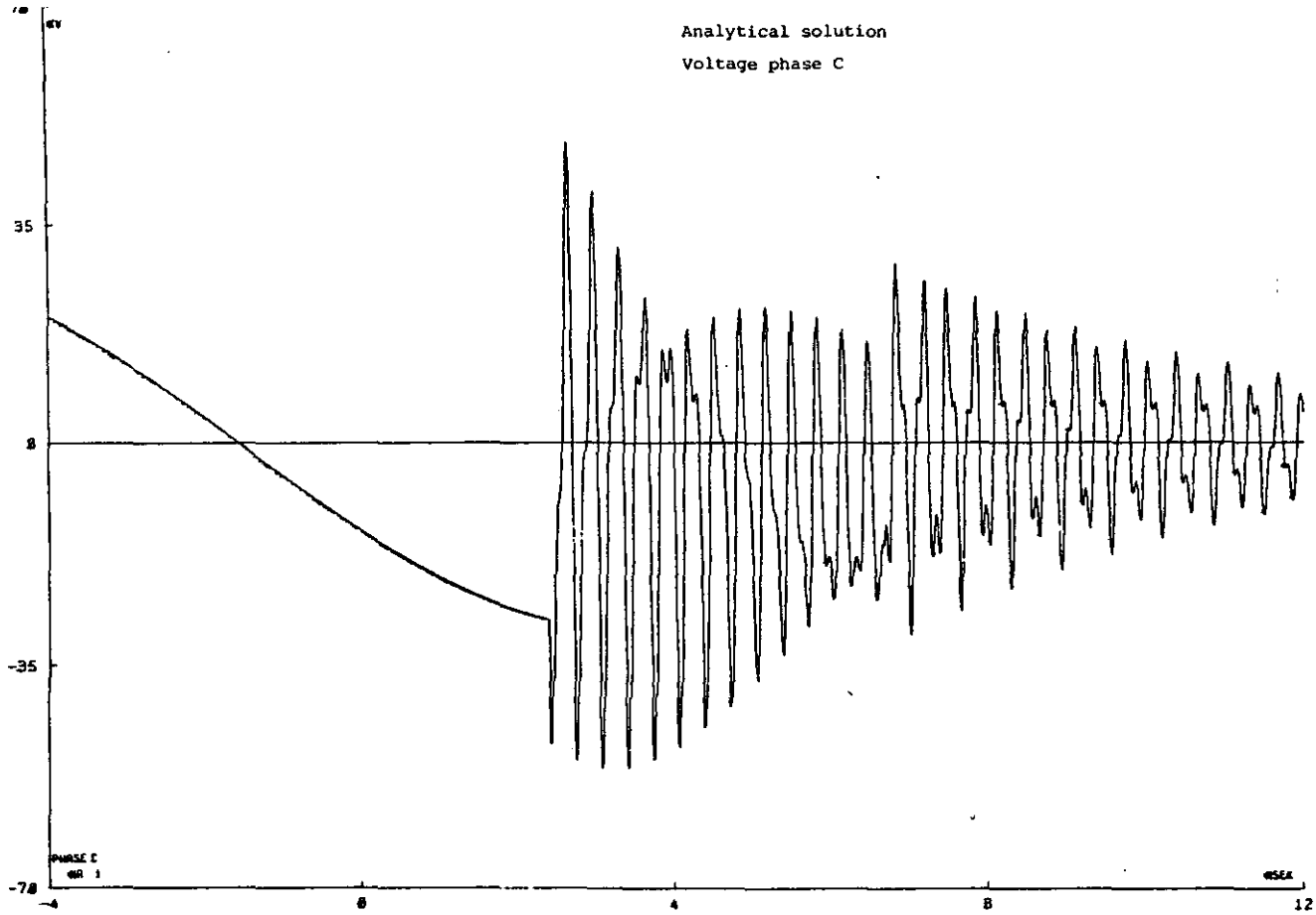
[3] Heuvel, W.M.C. van den and B.C. Papadias
Interaction between phases in three-phase reactor switching.
Part 2: Ungrounded reactors.
Electra (Paris), No. 112(1987), p. 57-81.

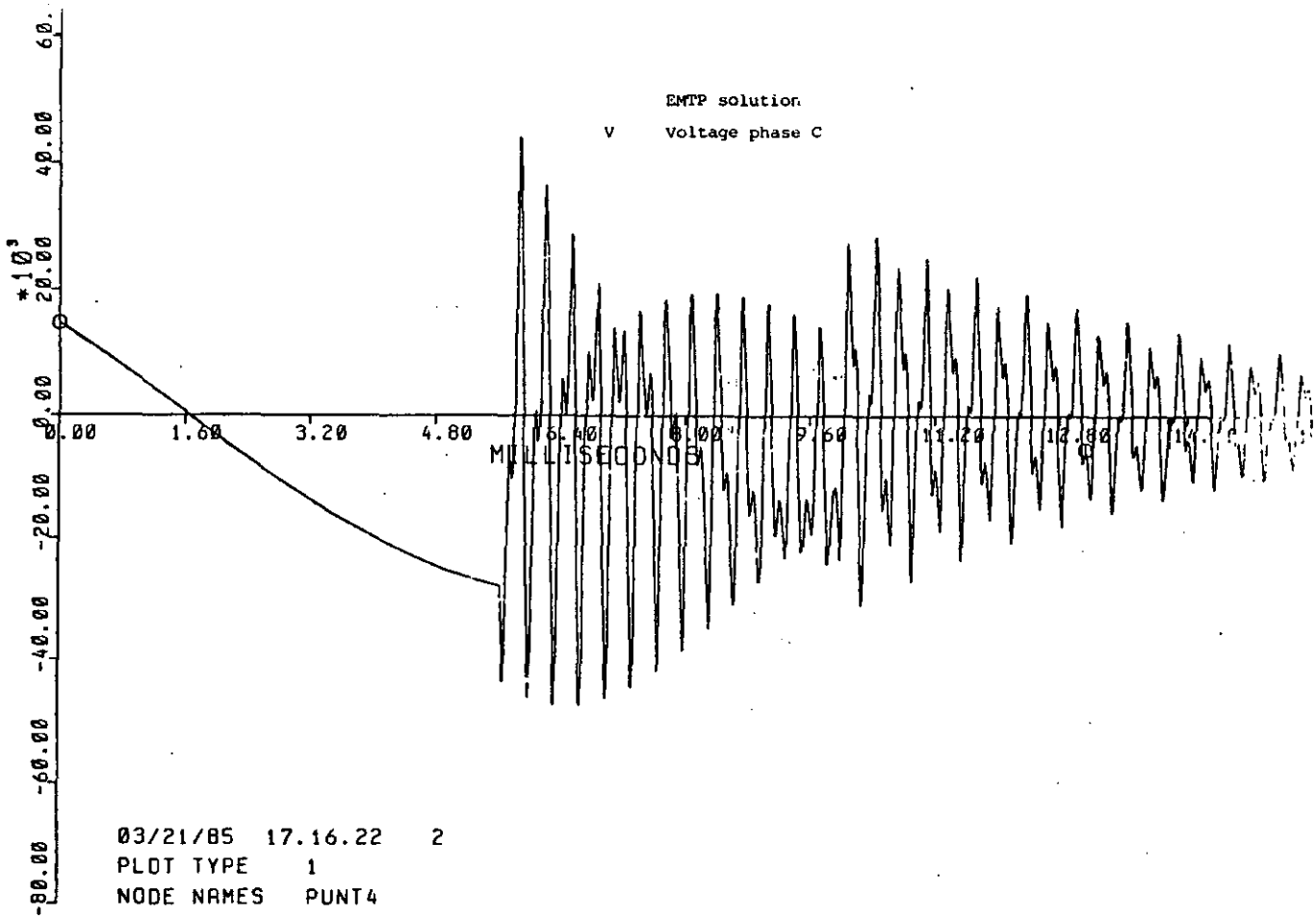

Analytical solution
Voltage phase A
70
35
0
-35
-70
-4
0
4
8
12
MSEC


EMTP solution
Voltage phase A
1
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
0.00
1.60
3.20
4.80
6.40
8.00
9.60
11.20
12.80
14.40
16.00
MILLISECONDS
03/21/85 17.16.22 1
PLOT TYPE 1

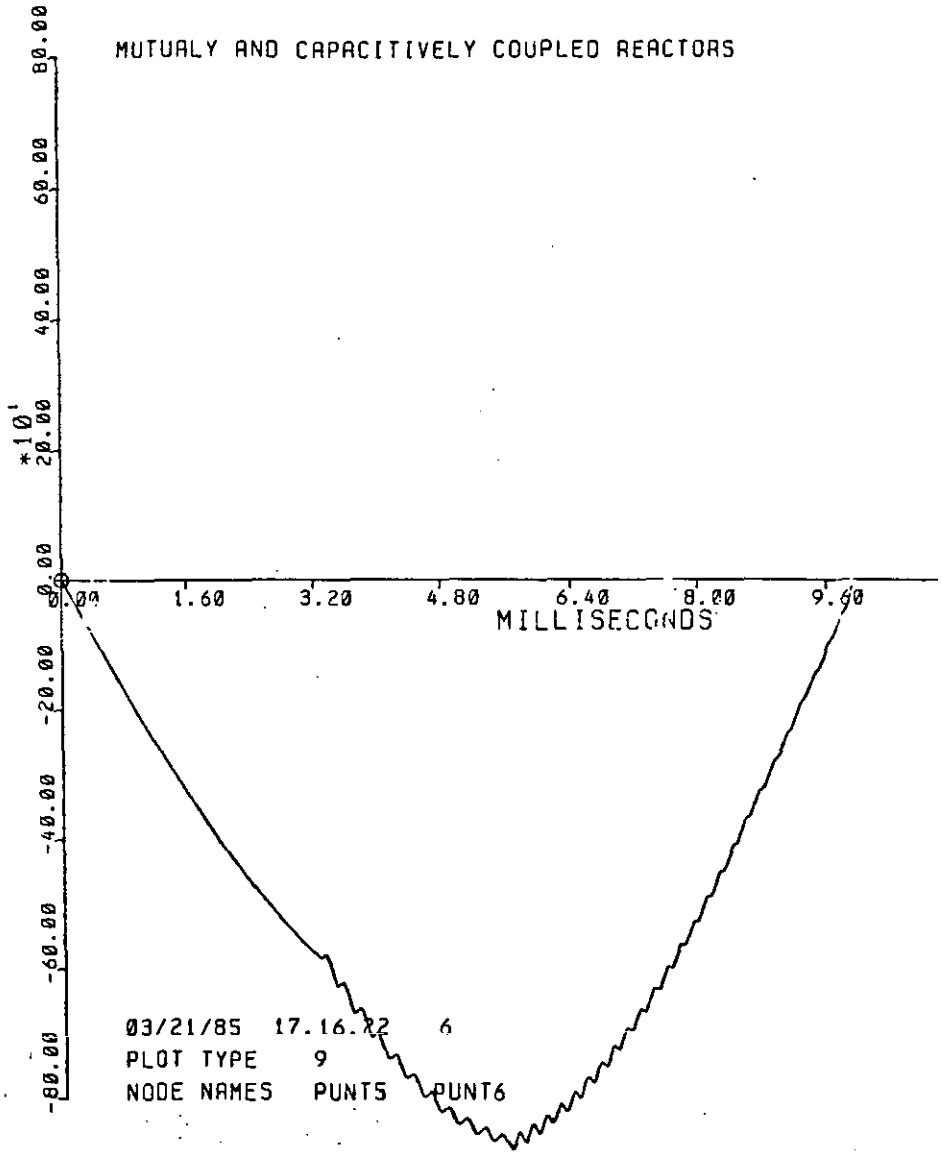

Analytical solution
Voltage phase B
78
35
0
-35
-78
-4
0
4
8
12


EMTP solution
Voltage phase B
60.0
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
1.60
3.20
4.80
6.40
8.00
11.20
12.80
14.40
16.00
MILLISECONDS
03/21/85 17.16.22 3
PLOT TYPE 1
NODE NAMES PUNT6

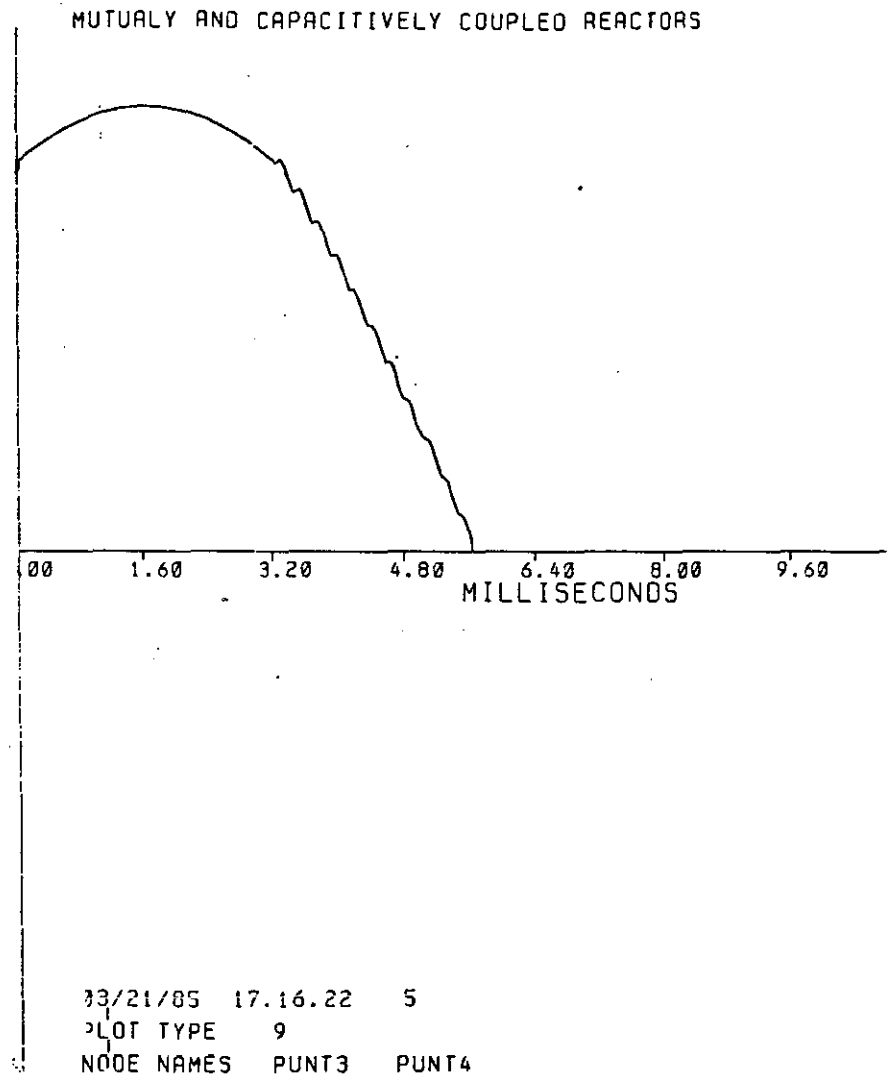

Analytical solution
Voltage phase C
35
0
-35
-70
-4
0
4
8
12


EMTP solution
V Voltage phase C
*10³
60.
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
1.60
3.20
4.80
6.40
8.00
9.60
11.20
12.80
MILLISECONDS
03/21/85 17.16.22 2
PLOT TYPE 1
NODE NAMES PUNT4

Current phase B



Current phase C



Appendix A - 1

```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                         PART I : GROUNDED REACTORS
C                              NON-COUPLED REACTORS
C                                 Electra No 91.
C
C
C
C
C          ^
C          U = 29.4 kV   /                                          138.0 mH
C           -----       /
C      +----¦ U ¦-----o/   o-----------------------------o-----LLLLL-----+
C      ¦    -----     1    2                            ¦                 ¦
C      ¦                                                ¦                 ¦
C      ¦    ^                                           ¦                 ¦
C      ¦    U = 29.4 kV   /                             ¦                 ¦
C      ¦     -----       /                              ¦   138.0 mH     ¦
C      o----¦ U ¦-----o/   o-----------------o----------¦-----LLLLL-----o
C      ¦    -----     3    4                ¦          ¦                 ¦
C      ¦                                    ¦          ¦                 ¦
C      ¦    ^                               ¦          ¦                 ¦
C      ¦    U = 29.4 kV   /                 ¦          ¦                 ¦
C      ¦     -----       /                  ¦          ¦   138.0 mH     ¦
C      o----¦ U ¦-----o/   o-------o----------¦----------¦-----LLLLL-----o
C      ¦    -----     5    6   +---o     +----o     +----o                ¦
C      ¦                        ¦   ¦10 nF¦    ¦10 nF¦    ¦10 nF        ¦
C      ¦                        ¦ CCCCCp  ¦  CCCCCp  ¦  CCCCCp          ¦
C      ¦                       R    ¦     R    ¦     R    ¦             ¦
C      ¦                  240k R    ¦240k R    ¦240k R    ¦             ¦
C      ¦                       R    ¦     R    ¦     R    ¦             ¦
C      ¦                        ¦   ¦     ¦    ¦     ¦    ¦             ¦
C      +----------------------o---o-----o----o-----o----o----------------+
C                                                ¦
C                                               ---
C                                               ///
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000      10
C       1ST MISC. DATA CARD
C DELTAT    TMAX    XOPT    COPT
 .50E-06 .16E-01     0.0     0.0
C       2ND MISC. DATA CARD
C   IOUT   IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50       5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C  BUS1  BUS2                  R     L     C                              OUTPUT
   PUNT2                     138.00                                          0
   PUNT4                     138.00                                          0
   PUNT6                     138.00                                          0
```

Appendix A - 2

```
  PUNT2                    .240E6                                          0
  PUNT4                    .240E6                                          0
  PUNT6                    .240E6                                          0
  PUNT2                                .01000                              0
  PUNT4                                .01000                              0
  PUNT6                                .01000                              0
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .7670E+01                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .7670E+01                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .7670E+01                               1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02      0.0                   -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02 .1200E+03                  -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02-.1200E+03                  -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2NON-COUPLED REACTORS
 114                   PUNT2                                  VOLTAGE
C            HS           HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  2
C      HEADING
 2NON-COUPLED REACTORS
 114                   PUNT4                                  VOLTAGE
C            HS           HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  3
C      HEADING
 2NON-COUPLED REACTORS
 114                   PUNT6                                  VOLTAGE
C            HS           HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix A - 3

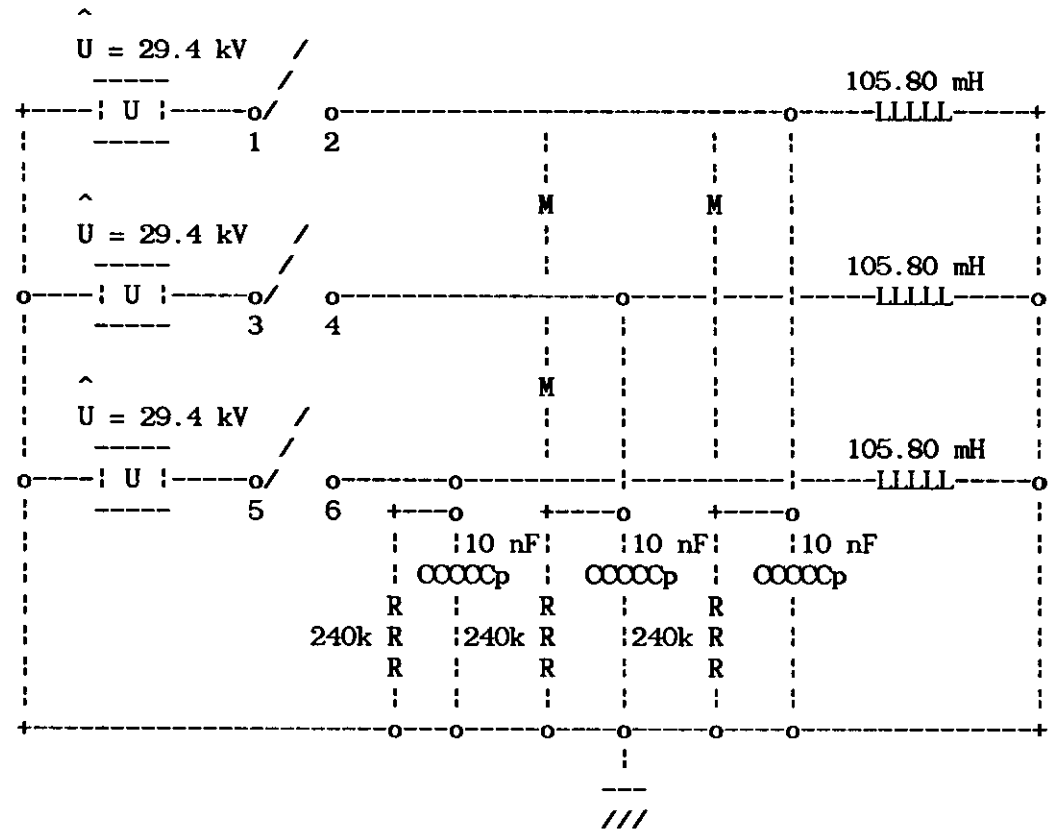
```
BEGIN NEW DATA CASE
C                  W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C         INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                      PART I : GROUNDED REACTORS
C                    CAPACITIVELY COUPLED REACTORS
C                  Electra No 91 p. 35 fig. 4.14 case A
C
C
C
C
C
C                                    7
C                               +---o-----o----o-----o----+
C                          267k R   |267k R    |267k R    |
C                               R   |     R    |     R    |
C          ^                    R   |9 nF R    |9 nF R    | 9 nF
C         U = 29.4 kV   /       |  CCCCCl  |  CCCCCl  |  CCCCCl
C          -----       /        +---o      +----o      +----o   138.00 mH
C      +----| U |-----o/   o-------|----------|----------o-----LLLLL-----+
C      |    -----     1    2      |          |          |                 |
C      |                          |          |          |                 |
C      |    ^                     |          |          |                 |
C      |    U = 29.4 kV   /       |          |          |                 |
C      |     -----       /        |          |          |   138.00 mH     |
C      o----| U |-----o/   o-------|----------o----------|-----LLLLL-----o
C      |    -----     3    4      |          |          |                 |
C      |                          |          |          |                 |
C      |    ^                     |          |          |                 |
C      |    U = 29.4 kV   /       |          |          |                 |
C      |     -----       /        |          |          |   138.00 mH     |
C      o----| U |-----o/   o-------o----------|----------|-----LLLLL-----o
C      |    -----     5    6   +---o      +----o      +----o             |
C      |                          |   |10 nF|    |10 nF|    |10 nF       |
C      |                          |  CCCCCp  |  CCCCCp  |  CCCCCp         |
C      |                          R   |      R    |      R    |            |
C      |                     240k R   |240k R     |240k R     |            |
C      |                          R   |      R    |      R    |            |
C      |                          |   |      |    |      |    |            |
C      +--------------------------o---o------o----o------o----o------------+
C                                                 |
C                                                ---
C                                                ///
C
POWER FREQUENCY                        50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
  .50E-06  .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50        5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C  BUS1  BUS2                   R       L       C                          OUTPUT
   PUNT2                        138.00                                          0
   PUNT4                        138.00                                          0
   PUNT6                        138.00                                          0
```

Appendix A - 4

```
  PUNT2 PUNT7              .267E6                                          0
  PUNT4 PUNT7              .267E6                                          0
  PUNT6 PUNT7              .267E6                                          0
  PUNT2 PUNT7                          .00900                              0
  PUNT4 PUNT7                          .00900                              0
  PUNT6 PUNT7                          .00900                              0
  PUNT2                    .240E6                                          0
  PUNT4                    .240E6                                          0
  PUNT6                    .240E6                                          0
  PUNT2                                .01000                              0
  PUNT4                                .01000                              0
  PUNT6                                .01000                              0
BLANK CARD ENDING BRACH CARDS
C       SWITCH CARDS:
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                          OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1740E+02                                1
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                          OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1740E+02                                1
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                          OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1740E+02                                1
BLANK CARD ENDING SWITCH CARDS
C        SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02       0.0                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02 .1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02-.1200E+03                      -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C       OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C       PLOTTER REQUEST CARDS:
C       METRIC SCALE:
  SCALE                  1.270025
  CALCOMP PLOT
C       FIG.  1
C       HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                     PUNT2                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01              0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C       FIG.  2
C       HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                     PUNT4                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01              0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C       FIG.  3
C       HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                     PUNT6                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01              0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix A - 5

```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                         PART I : GROUNDED REACTORS
C                           MUTUALY COUPLED REACTORS
C                       Electra No 91 p. 48 fig 4.21 case A
C
C
C
C
```



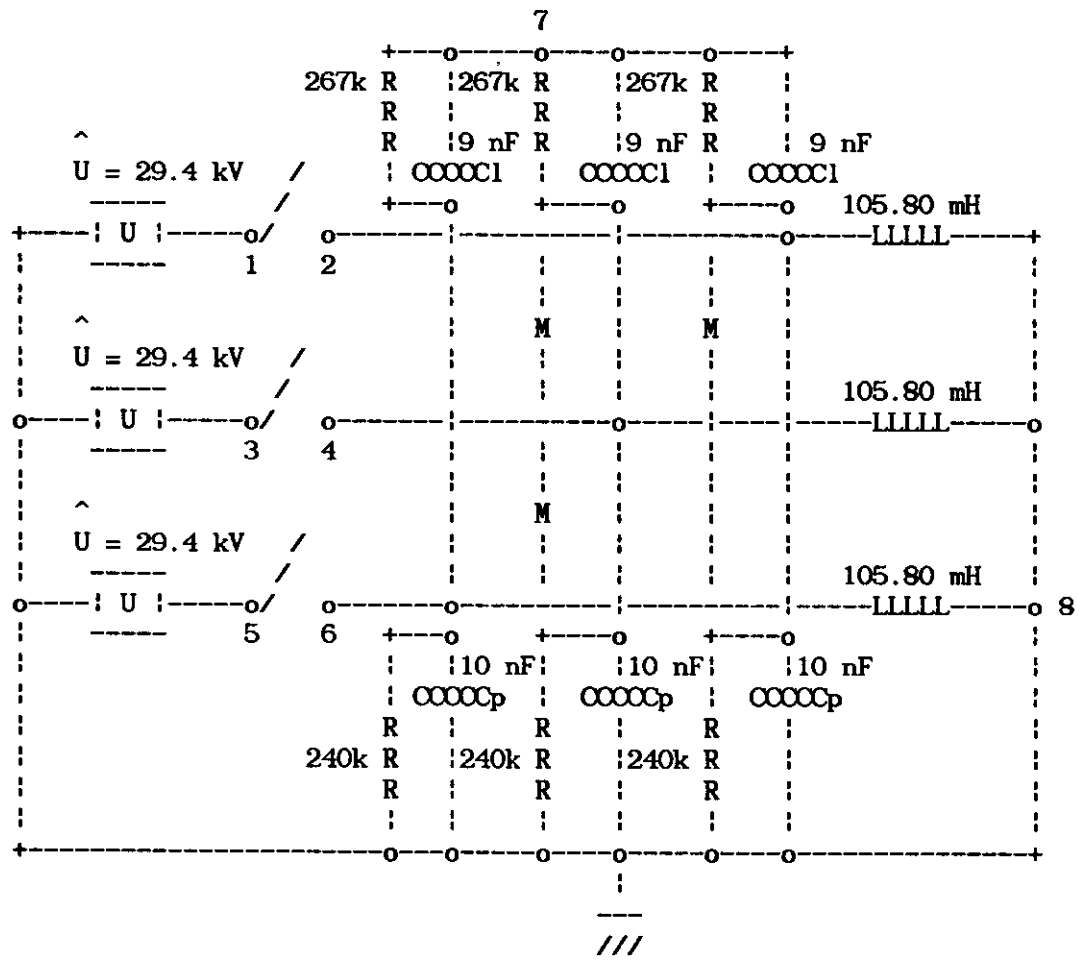

```
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000      10
C       1ST MISC. DATA CARD
C DELTAT    TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C   IOUT   IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50       5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C  BUS1  BUS2                  R     L     C                              OUTPUT
51PUNT2                              105.8
52PUNT4                              -32.2            105.8
53PUNT6                              -32.2            -32.2                105.8
```

```
  PUNT2                  .240E6                                          0
  PUNT4                  .240E6                                          0
  PUNT6                  .240E6                                          0
  PUNT2                               .01000                             0
  PUNT4                               .01000                             0
  PUNT6                               .01000                             0

BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1540E+02                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1540E+02                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1540E+02                               1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02      0.0                   -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02 .1200E+03                  -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02-.1200E+03                  -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                   PUNT2                                  VOLTAGE
C            HS           HMIN           HMAX           VMIN           VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  2
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                   PUNT4                                  VOLTAGE
C            HS           HMIN           HMAX           VMIN           VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  3
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                   PUNT6                                  VOLTAGE
C            HS           HMIN           HMAX           VMIN           VMAX
 .1200000000E+01            0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix A - 7

```
BEGIN NEW DATA CASE
C                  W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                        PART I : GROUNDED REACTORS
C                CAPACITIVELY AND MUTUALLY COUPLED REACTORS
C                   Electra No 91 p. 47 fig. 4.20 case A
C
C
C
C
```




```
C
C
C
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000      10
C       1ST MISC. DATA CARD
C DELTAT    TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C   IOUT   IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50       1       1       1       1       0       0       2       0
C       BRANCH CARDS:
C  BUS1  BUS2                  R      L      C                            OUTPUT
  PUNT2 PUNT8                   105.80                                        0
  PUNT4 PUNT8                   105.80                                        0
  PUNT6 PUNT8                   105.80                                        0
```

```
  PUNT2 PUNT7              .267E6                                          0
  PUNT4 PUNT7              .267E6                                          0
  PUNT6 PUNT7              .267E6                                          0
  PUNT2 PUNT7                          .00900                              0
  PUNT4 PUNT7                          .00900                              0
  PUNT6 PUNT7                          .00900                              0
  PUNT2                    .240E6                                          0
  PUNT4                    .240E6                                          0
  PUNT6                    .240E6                                          0
  PUNT2                                .01000                              0
  PUNT4                                .01000                              0
  PUNT6                                .01000                              0
  PUNT8                         -32.09                                     0
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1770E+02                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1770E+02                               1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                          OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1770E+02                               1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02      0.0                   -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02 .1200E+03                  -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL      FREQ      TNUL        A1            TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02-.1200E+03                  -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2MUTUALY AND CAPACITIVELY COUPLED REACTORS
 114                  PUNT2                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  2
C      HEADING
 2MUTUALY AND CAPACITIVELY COUPLED REACTORS
 114                  PUNT4                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
C      FIG.  3
C      HEADING
 2MUTUALY AND CAPACITIVELY COUPLED REACTORS
 114                  PUNT6                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.8000000000E+05 .8000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix B - 1

```
BEGIN NEW DATA CASE
C                  W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C         INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                       PART II : UNGROUNDED REACTORS
C                   Q = 30 Mvar  U = 36 kV  IC = 7.67 A
C                         NON COUPLED REACTORS
C                   Electra No 112 p. 76 fig. 6.1 case A
C
C
C
C
C
C
C
C         ^
C         U = 29.4 kV   /
C          -----       /                                        138.0 mH
C      +----¦ U ¦-----o/   o-------o--------------------o----LLLLL-----+
C      ¦    -----     1    2       ¦                    ¦               ¦
C      ¦                           ¦                    ¦   533 kohm    ¦
C      ¦   ^                       ¦                    +----RRRRRp----o
C      ¦   U = 29.4 kV   /         ¦                                    ¦
C      ¦    -----       /          ¦                        138.0 mH    ¦
C      o----¦ U ¦-----o/   o-------¦---------o----------o----LLLLL-----o
C      ¦    -----     3    4       ¦         ¦          ¦               ¦
C      ¦                           ¦         ¦          ¦   533 kohm    ¦
C      ¦   ^                       ¦         ¦          +----RRRRRp----o
C      ¦   U = 29.4 kV   /         ¦         ¦                         ¦
C      ¦    -----       /          ¦         ¦            138.0 mH     ¦
C      o----¦ U ¦-----o/   o-------¦---------¦----------o----LLLLL-----o7
C      ¦    -----     5    6       ¦         ¦          ¦               ¦
C      ¦                           ¦         ¦          ¦   533 kohm    ¦
C      ¦                           ¦         ¦          o----RRRRR-----o
C      ¦                           ¦         ¦          ¦               ¦
C      ¦                  3.00 nF¦  3.00 nF¦  3.00 nF¦      9.00 nF    ¦
C      ¦                       OOOOO1    OOOOO1    OOOOO1          OOOOOOn
C      ¦                           ¦         ¦          ¦               ¦
C      +---------------------------o---------o----------o---------------+
C                                  ¦ 9
C                                 ---
C                                 ///
C
POWER FREQUENCY                        50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50        5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C    BUS1  BUS2                 R       L       C                             OUTPUT
   PUNT2 PUNT7                      138.0                                        0
   PUNT4 PUNT7                      138.0                                        0
   PUNT6 PUNT7                      138.0                                        0
```

Appendix B - 2

```
  PUNT2 PUNT7              .533E6                                              0
  PUNT4 PUNT7              .533E6                                              0
  PUNT6 PUNT7              .533E6                                              0
  PUNT2                                .00300                                  0
  PUNT4                                .00300                                  0
  PUNT6                                .00300                                  0
  PUNT7                                .00900                                  0
BLANK CARD ENDING BRACH CARDS
C       SWITCH CARDS:
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .7670E+01                                     1
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .7670E+01                                     1
C   BUS1  BUS2     TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .7670E+01                                     1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02 .1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02-.1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02       0.0                      -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C       OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C       PLOTTER REQUEST CARDS:
C       METRIC SCALE:
  SCALE                  1.270025
  CALCOMP PLOT
C       FIG.  1
C       HEADING
 2NON COUPLED REACTORS
 114                     PUNT2                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01             0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
C       FIG.  2
C       HEADING
 2NON COUPLED REACTORS
 114                     PUNT4                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01             0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
C       FIG.  3
C       HEADING
 2NON COUPLED REACTORS
 114                     PUNT6                                  VOLTAGE
C              HS            HMIN             HMAX             VMIN             VMAX
 .1200000000E+01             0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix B - 3

```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                          PART II : UNGROUNDED REACTORS
c                       Q = 30 Mvar  U = 36 kV  IC = 17.7 A
C                         CAPACITIVELY COUPLED REACTORS
C                       Electra No 112 p. 77 fig. 6.2 case A
C
C
C
C
C
C
C
C       ^
C       U = 29.4 kV   /
C        -----       /                                                  138.0 mH
C    +----¦ U ¦-----o/   o--o----o---------o-----------------o---LLLLL-----+
C    ¦    -----     1    2  ¦    ¦         ¦                 ¦             ¦
C    ¦                       ¦    ¦  3.00 nF¦                 ¦   160 kohm   ¦
C    ¦    ^                  ¦    ¦      CCCCC1               +----RRRRRp----o
C    ¦    U = 29.4 kV   /    ¦    ¦         ¦                               ¦
C    ¦     -----       /     ¦    ¦         ¦                   138.0 mH    ¦
C    o----¦ U ¦-----o/   o--¦----¦---o----o----------------o---LLLLL------o
C    ¦    -----     3    4  ¦    ¦   ¦    ¦                 ¦             ¦
C    ¦                       ¦3.00¦nF  ¦3.00¦nF             ¦   160 kohm   ¦
C    ¦    ^                  ¦  CCCCC1 ¦  CCCCC1           +----RRRRRp----o
C    ¦    U = 29.4 kV   /    ¦    ¦    ¦    ¦                               ¦
C    ¦     -----       /     ¦    ¦    ¦    ¦                   138.0 mH    ¦
C    o----¦ U ¦-----o/   o--¦---o----¦---o----o----------o----LLLLL-----o7
C    ¦    -----     5    6  ¦        ¦        ¦          ¦             ¦
C    ¦                       ¦        ¦        ¦          ¦   160 kohm   ¦
C    ¦                       ¦        ¦        ¦          o----RRRRRp----o
C    ¦                       ¦        ¦        ¦                        ¦
C    ¦              10.00 nF¦ 10.00 nF¦ 10.00 nF¦              9.00 nF   ¦
C    ¦                   CCCCCp    CCCCCp    CCCCCp                  CCCCCn
C    ¦                       ¦        ¦        ¦                        ¦
C    +-----------------------o--------o--------o------------------------+
C                                    ¦ 9
C                                    ---
C                                    ///
C
POWER FREQUENCY                     50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
  .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
       50        5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C     BUS1  BUS2                R      L      C                              OUTPUT
   PUNT2 PUNT7                  138.0                                          0
   PUNT4 PUNT7                  138.0                                          0
   PUNT6 PUNT7                  138.0                                          0
```

Appendix B - 4

```
  PUNT2 PUNT7              .160E6                                          0
  PUNT4 PUNT7              .160E6                                          0
  PUNT6 PUNT7              .160E6                                          0
  PUNT2 PUNT4                          .00300                              0
  PUNT4 PUNT6                          .00300                              0
  PUNT2 PUNT6                          .00300                              0
  PUNT2                                .01000                              0
  PUNT4                                .01000                              0
  PUNT6                                .01000                              0
  PUNT7                                .00900
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                            OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1770E+02                                 1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                            OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1770E+02                                 1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                            OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1770E+02                                 1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02 .1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02-.1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02       0.0                      -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                  PUNT2                                  VOLTAGE
C            HS          HMIN          HMAX          VMIN          VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  2
C      HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                  PUNT4                                  VOLTAGE
C            HS          HMIN          HMAX          VMIN          VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  3
C      HEADING
 2CAPACITIVELY COUPLED REACTORS
 114                  PUNT6                                  VOLTAGE
C            HS          HMIN          HMAX          VMIN          VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix B - 5

```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C.PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                          PART II : UNGROUNDED REACTORS
C                       Q = 30 Mvar  U = 36 kV  IC = 7.67 A
C                            MUTUALY COUPLED REACTORS
C                       Electra No 112 p. 78 fig. 6.3 case A
C
C
C
C
C
C
C
C       ^
C       U = 29.4 kV   /
C        -----       /                                                105.8 mH
C    +---¦ U ¦-----o/   o--o-------------------------------------o----LLLLL-----+
C    ¦   -----     1    2  ¦                                 ¦   ¦   ¦           ¦
C    ¦                     ¦                                 ¦   ¦   ¦  533 kohm  ¦
C    ¦   ^                 ¦                                 ¦   M   +----RRRRRp----o
C    ¦   U = 29.4 kV   /   ¦                                 ¦   ¦                ¦
C    ¦    -----       /    ¦                                 M   ¦       105.8 mH ¦
C    o----¦ U ¦-----o/   o--¦--------o--------------¦-------o----LLLLL-----o
C    ¦    -----     3    4  ¦        ¦              ¦       ¦   ¦           ¦
C    ¦                     ¦        ¦              ¦       ¦   ¦  533 kohm  ¦
C    ¦   ^                 ¦        ¦              ¦       ¦   M   +----RRRRRp----o
C    ¦   U = 29.4 kV   /   ¦        ¦              ¦       ¦   ¦                ¦
C    ¦    -----       /    ¦        ¦              ¦       ¦   ¦       105.8 mH ¦
C    o----¦ U ¦-----o/   o--¦--------¦--------o-----¦-------o----LLLLL-----o7
C    ¦    -----     5    6  ¦        ¦        ¦     ¦               ¦           ¦
C    ¦                     ¦        ¦        ¦     ¦               ¦  533 kohm  ¦
C    ¦                     ¦        ¦        ¦     ¦               o----RRRRRp----o
C    ¦                     ¦        ¦        ¦     ¦                            ¦
C    ¦           3.00 nF¦  3.00 nF¦  3.00 nF¦                      9.00 nF ¦
C    ¦                CCCCCl    CCCCCl    CCCCCl                          CCCCCn
C    ¦                     ¦        ¦        ¦                            ¦
C    ¦                     ¦        ¦        ¦                            ¦
C    +---------------------o--------o--------o----------------------------+
C                          ¦ 9
C                          ---
C                          ///
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50        5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C     BUS1  BUS2                R      L      C                            OUTPUT
51PUNT2 PUNT7                          105.8
52PUNT4 PUNT7                          -32.2           105.8
53PUNT6 PUNT7                          -32.2           -32.2           105.8
```

```
  PUNT2 PUNT7              .533E6                                              0
  PUNT4 PUNT7              .533E6                                              0
  PUNT6 PUNT7              .533E6                                              0
  PUNT2                                .00300                                  0
  PUNT4                                .00300                                  0
  PUNT6                                .00300                                  0
  PUNT7                                .00900                                  0
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .7670E+01                                    1
C   BUS1  BUS2    TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .7670E+01                                    1
C   BUS1  BUS2    TCLOSE      TOPEN      ICHOP                              OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .7670E+01                                    1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02 .1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02-.1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL         A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02       0.0                     -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                  PUNT2                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
C      FIG.  2
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                  PUNT4                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
C      FIG.  3
C      HEADING
 2MUTUALY COUPLED REACTORS
 114                  PUNT6                                  VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01           0.0 .1200000000E+02-.7000000000E+05 .7000000000E+05
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

Appendix B - 7

```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C.PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                          PART II : UNGROUNDED REACTORS
C                      Q = 30 Mvar  U = 36 kV  IC = 17.7 A
C                  CAPACITIVELY AND MUTUALY COUPLED REACTORS
C                     Electra No 112 p. 79 fig. 6.4 case A
C
C
C
C
C
C
C        ^
C        U = 29.4 kV   /
C         -----       /                                              105.8 mH
C    +----¦ U ¦-----o/   o--o----o---------o------------------o----LLLLL-----+
C    ¦    -----     1    2  ¦    ¦         ¦          ¦   ¦   ¦               ¦
C    ¦                       ¦    ¦  3.00 nF¦          ¦   ¦   ¦   160 kohm   ¦
C    ¦    ^                  ¦    ¦      CCCCCl         ¦   M   +----RRRRRp----o
C    ¦    U = 29.4 kV   /    ¦    ¦         ¦          ¦   ¦                   ¦
C    ¦     -----       /     ¦    ¦         ¦          M   ¦       105.8 mH    ¦
C    o----¦ U ¦-----o/   o--¦----¦----o----o----------¦-------o----LLLLL-----o
C    ¦    -----     3    4  ¦    ¦    ¦    ¦          ¦   ¦   ¦               ¦
C    ¦                       ¦3.00¦nF  ¦3.00¦nF       ¦   ¦   ¦   160 kohm   ¦
C    ¦    ^                  ¦  CCCCCl  ¦  CCCCCl       ¦   M   +----RRRRRp----o
C    ¦    U = 29.4 kV   /    ¦    ¦    ¦    ¦          ¦   ¦                   ¦
C    ¦     -----       /     ¦    ¦    ¦    ¦          ¦   ¦       105.8 mH    ¦
C    o----¦ U ¦-----o/   o--¦----o----¦----o----o----------o----LLLLL-----o7
C    ¦    -----     5    6  ¦         ¦         ¦               ¦               ¦
C    ¦                       ¦         ¦         ¦               ¦   160 kohm   ¦
C    ¦                       ¦         ¦         ¦               +----RRRRRp----o
C    ¦                       ¦         ¦         ¦                             ¦
C    ¦              10.00 nF¦ 10.00 nF¦ 10.00 nF¦                  9.00 nF    ¦
C    ¦                   CCCCCp    CCCCCp    CCCCCp                      CCCCCn
C    ¦                       ¦         ¦         ¦                             ¦
C    +-----------------------o---------o---------o-----------------------------+
C                            ¦ 9
C                            ---
C                            ///
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT  IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50        5       1       1       1       0       0       2       0
C       BRANCH CARDS:
C     BUS1  BUS2                R     L     C                                OUTPUT
51PUNT2 PUNT7                          105.8
52PUNT4 PUNT7                          -32.2           105.8
53PUNT6 PUNT7                          -32.2           -32.2           105.8
```

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```
  PUNT2 PUNT7              .160E6                                          0
  PUNT4 PUNT7              .160E6                                          0
  PUNT6 PUNT7              .160E6                                          0
  PUNT2 PUNT4                          .00300                              0
  PUNT4 PUNT6                          .00300                              0
  PUNT2 PUNT6                          .00300                              0
  PUNT2                                .01000                              0
  PUNT4                                .01000                              0
  PUNT6                                .01000                              0
  PUNT7                                .00900
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1770E+02                                   1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1770E+02                                   1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1770E+02                                   1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02 .1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02-.1200E+03                      -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02       0.0                      -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                  PUNT2                                    VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  2
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                  PUNT4                                    VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  3
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                  PUNT6                                    VOLTAGE
C            HS          HMIN            HMAX            VMIN            VMAX
 .1200000000E+01            0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

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```
BEGIN NEW DATA CASE
C                    W.M.C. VAN DEN HEUVEL, B.C. PAPADIAS :
C          INTERACTION BETWEEN PHASES IN THREE-PHASE REACTOR SWITCHING
C                         PART II : UNGROUNDED REACTORS
C                      Q = 30 Mvar  U = 36 kV  IC = 17.9 A
C                   CAPACITIVELY AND MUTUALY COUPLED REACTORS
C                      Electra No 112 p.79 fig. 6.4 case B
C
C
C
C
C
C
C
C       ^
C       U = 29.4 kV   /
C        -----       /                                                  105.8 mH
C    +----¦ U ¦-----o/   o--o----o---------o-------------------o----LLLLL-----+
C    ¦    -----     1    2  ¦    ¦         ¦           ¦   ¦   ¦               ¦
C    ¦                      ¦    ¦ 3.08 nF¦           ¦   ¦   ¦   156 kohm   ¦
C    ¦    ^                 ¦    ¦      CCCCC1        ¦   M   +----RRRRRp----o
C    ¦    U = 29.4 kV   /   ¦    ¦         ¦           ¦   ¦                   ¦
C    ¦     -----       /    ¦    ¦         ¦         M ¦   ¦       105.8 mH    ¦
C    o----¦ U ¦-----o/   o--¦----¦---o----o---------¦-------o----LLLLL-----o
C    ¦    -----     3    4  ¦    ¦   ¦    ¦         ¦   ¦   ¦               ¦
C    ¦                      ¦3.08¦nF ¦3.08¦nF       ¦   ¦   ¦   156 kohm   ¦
C    ¦    ^                 ¦  CCCCC1 ¦  CCCCC1      ¦   M   +----RRRRRp----o
C    ¦    U = 29.4 kV   /   ¦    ¦   ¦    ¦         ¦   ¦                   ¦
C    ¦     -----       /    ¦    ¦   ¦    ¦         ¦   ¦       105.8 mH    ¦
C    o----¦ U ¦-----o/   o--¦----o---¦----o----o------------o----LLLLL-----o7
C    ¦    -----     5    6  ¦        ¦         ¦           ¦               ¦
C    ¦                      ¦        ¦         ¦           ¦   156 kohm   ¦
C    ¦                      ¦        ¦         ¦           +----RRRRRp----o
C    ¦                      ¦        ¦         ¦                           ¦
C    ¦            10.27 nF¦ 10.27 nF¦ 10.27 nF¦                 9.00 nF   ¦
C    ¦                 CCCCCp    CCCCCp    CCCCCp                     CCCCCn
C    ¦                      ¦        ¦         ¦                           ¦
C    +----------------------o--------o---------o---------------------------+
C                           ¦ 9
C                           ---
C                           ///
C
POWER FREQUENCY                    50.0
CHANGE PRINTOUT FREQUENCY
    6000       10
C       1ST MISC. DATA CARD
C DELTAT     TMAX     XOPT     COPT
 .50E-06 .16E-01      0.0      0.0
C       2ND MISC. DATA CARD
C    IOUT    IPLOT   IDOUBL  KSSOUT  MAXOUT    IPUN  MEMSAV    ICAT  NENERG  IPRSUP
      50        5        1       1       1       0       0       2       0
C       BRANCH CARDS:
C     BUS1  BUS2                R      L      C                              OUTPUT
51PUNT2 PUNT7                          105.8
52PUNT4 PUNT7                         -32.22          105.8
53PUNT6 PUNT7                         -32.22         -32.22           105.8
```

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```
  PUNT2 PUNT7              .156E6                                          0
  PUNT4 PUNT7              .156E6                                          0
  PUNT6 PUNT7              .156E6                                          0
  PUNT2 PUNT4                          .00308                              0
  PUNT4 PUNT6                          .00308                              0
  PUNT2 PUNT6                          .00308                              0
  PUNT2                                .01027                              0
  PUNT4                                .01027                              0
  PUNT6                                .01027                              0
  PUNT7                                .00900
BLANK CARD ENDING BRACH CARDS
C      SWITCH CARDS:
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT1 PUNT2 -.1000E-01 .1000E-02 .1790E+02                                   1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT3 PUNT4 -.1000E-01 .1000E-02 .1790E+02                                   1
C   BUS1  BUS2    TCLOSE     TOPEN      ICHOP                              OUTPUT
  PUNT5 PUNT6 -.1000E-01 .1000E-02 .1790E+02                                   1
BLANK CARD ENDING SWITCH CARDS
C       SOURCE CARDS:
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT1  1-.2939E+05 .5000E+02 .1200E+03                     -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT3  1-.2939E+05 .5000E+02-.1200E+03                     -.1000E+02 .1000E+02
C TYPE BUS V/C  AMPL       FREQ       TNUL        A1              TSTART     TSTOP
14PUNT5  1-.2939E+05 .5000E+02       0.0                     -.1000E+02 .1000E+02
BLANK CARD ENDING SOURCE CARDS
C      OUTPUT REQUEST CARDS:
  PUNT2 PUNT4 PUNT6
BLANK CARD ENDING OUTPUT REQUEST CARDS
C      PLOTTER REQUEST CARDS:
C      METRIC SCALE:
  SCALE                1.270025
  CALCOMP PLOT
C      FIG.  1
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                   PUNT2                                  VOLTAGE
C            HS            HMIN            HMAX            VMIN            VMAX
 .1200000000E+01             0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  2
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                   PUNT4                                  VOLTAGE
C            HS            HMIN            HMAX            VMIN            VMAX
 .1200000000E+01             0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
C      FIG.  3
C      HEADING
 2CAPACITIVELY AND MUTUALY COUPLED REACTORS
 114                   PUNT6                                  VOLTAGE
C            HS            HMIN            HMAX            VMIN            VMAX
 .1200000000E+01             0.0 .1200000000E+02-.1000000000E+06 .1000000000E+06
BLANK CARD TERMINATING PLOTTER REQUESTS
BEGIN NEW DATA CASE
BLANK CARD ENDING TOTAL EMTP INPUT
```

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