

# TOPMAG data calculation function

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## 1 Introduction

Conceptually, this model takes into account the topology of the magnetic circuit formed by the core and the windings to assemble an equivalent electric circuit representation for the transformer (Figure 1–1 below). For three-limbed and five-limbed units, each core-limb is modelled individually, and interfaced to an admittance matrix reproducing the correct magnetic coupling among windings. An additional 3-phase winding (termed fictitious winding) is needed to establish this interface, since core limbs are electrically isolated from the windings. Node names for fictitious windings are assigned by the user, and ought to be unique for each transformer.

The output from the model consists of the following data (N is the number of windings):

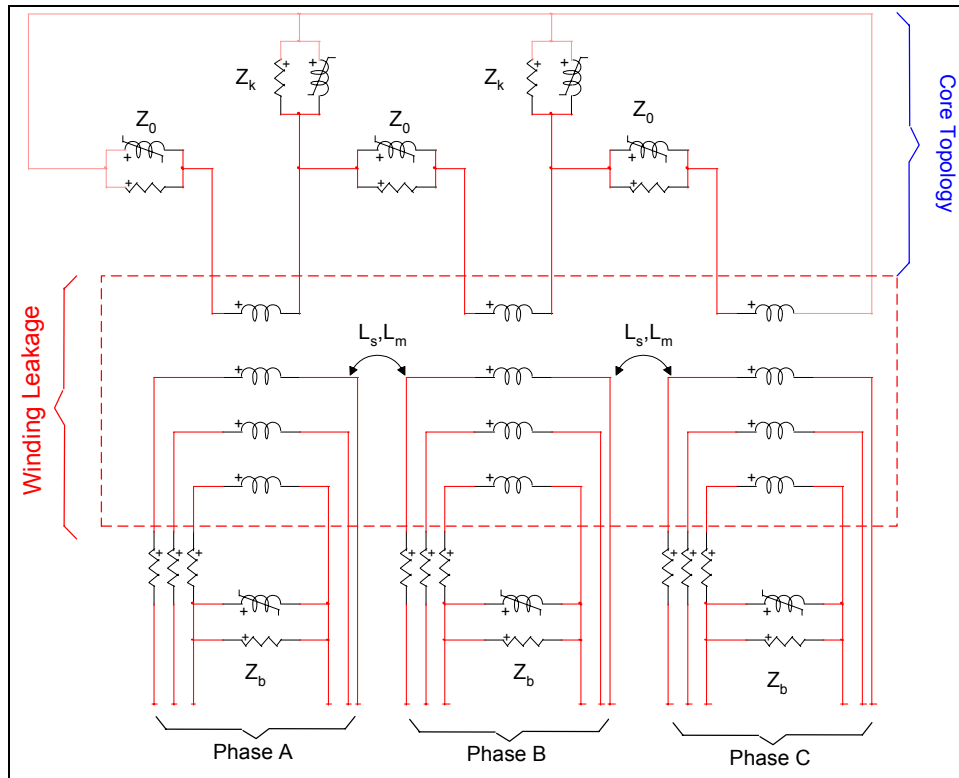
- ❑ A symmetric admittance matrix of order up to  $3(N+1)$ , depending on the core type and the specified modeling options.
- ❑ A network of parallel RL branches modelling magnetizing currents due to the wound limbs ( $Z_b$ ), the horizontal yokes ( $Z_k$ ), and the zero-sequence return path through air for 3-limbed transformers, or through the outer limbs in 5-limbed transformers ( $Z_0$ ).

The program requires that  $N(N-1)/2$  positive-sequence short circuit test values be specified for an N-winding 5-limbed or single-phase transformers. For 3-limbed transformers, at least one additional parameter is needed to characterize the zero-sequence performance, as follows:

- ❑ Zero-sequence excitation current, or
- ❑ One zero-sequence short-circuit test impedance, performed with excitation on winding 1 and short-circuit on any other winding "m", provided that no other winding is connected in delta during the test.

For more accuracy, a full complement of  $N(N-1)/2$  zero-sequence short-circuit test values may be specified, if they are available, provided that no more than one of the windings is connected in delta during tests.

Windings should be numbered from 1 to n, such that the winding positioned outermost on the wound limb is "1". This is normally the winding carrying the highest voltage rating. Winding "N" ought to be innermost on the core, and is normally the one with the lowest voltage rating. Windings are assumed to be concentric, fully covering the wound limb, (which may not always be the case in practice). For example a tapped HV winding may comprise two separate winding sections, one outermost on the core and a second (tapped) section innermost on the core. For higher accuracy, and perhaps for some studies, each such winding section ought to be modelled as a separate winding (requiring additional short-circuit test data, which is not normally available). However this is unlikely to be needed for most studies.



**Figure 1–1 Schematic representation of model for 3-phase, 3-winding core type transformer**

The electrical data required for calculating a transformer TOPMAG model are divided into three tabs:

- ❑ **Excitation data**
- ❑ **Windings**
- ❑ **Short-circuit test data**

The next sections detail the information entered on these tabs.

## 2 Excitation data

The excitation data section allows the definition of:

- ❑ **Number of windings per core leg.** This the number  $N$  presently limited to 10. For example a 230/500 kV three-phase transformer without a tertiary winding has  $N=2$ ; if a tertiary winding is added, then  $N=3$ .
- ❑ **Rated frequency** in Hz needed to convert reactances into inductances.
- ❑ **Positive sequence excitation test section.**
  - **Exciting current**  $I_{excit}^{pos}$  in percent, based on three-phase power rating  $S_{rating}^{pos}$  and rated voltage.
  - **Three-phase power rating**  $S_{rating}^{pos}$ .
  - **Excitation loss**  $Loss_{excit}^{pos}$ . This value may be changed by the program based on specification for “LOSS” under short-circuit test data.
- ❑ **Zero sequence excitation test section.**
  - **Exciting current**  $I_{excit}^{zero}$  in percent, based on three-phase power rating  $S_{rating}^{zero}$  and rated voltage.

- **Three-phase power rating**  $S_{rating}^{zero}$  .
- **Excitation loss**  $Loss_{excit}^{zero}$  .

If the transformer has delta-connected windings, then the excitation test becomes a short-circuit test since a closed delta acts as a short-circuit for zero-sequence currents. It is, therefore, assumed that delta connections are open in the zero sequence excitation test.

For 3-phase transformer banks consisting of single-phase or 5-limbed units, input the data as positive-sequence parameters and leave the fields for the zero-sequence parameters blank.

For 3-limb units,  $I_{excit}^{zero}$  will be estimated by default if this entry is left blank. This is the recommended option, provided that at least one zero-sequence short-circuit test is specified with excitation on winding 1, and without any other winding connected in delta during the test. If  $I_{excit}^{zero}$  value is specified, it is used directly.

- Connection** type which is one of the following options:
  - Three-phase transformer banks consisting of **single-phase** units.
  - **Three-phase 3-limbed core.**
  - **Three-phase 5-limbed core.**
- Winding from which zero-sequence test was made.**
- Incomplete zero sequence data** checkbox which can be:
  - Unchecked, which is the recommended option for modeling 3-limbed transformers, provided a full complement of reliable  $N(N-1)/2$  zero-sequence short-circuit impedances is available. The resulting coupling matrix is of order  $3(N+1)$ , matching the specified positive- and zero-sequence impedances. For single-phase or 5-limbed units, this data is irrelevant.
  - ON for the case where a full complement of zero-sequence tests data is not available. In this event, even if zero-sequence short-circuit impedances are specified for 3-limbed units, they are ignored except for estimating  $I_{excit}^{zero}$  if it has not already been specified. The other zero-sequence short-circuit impedances are therefore established by default on a physical basis.
- Select calculated matrices** to be saved into the model data file.

### 3 Winding data

A wye-wye connected 230/500 kV three-phase transformer with a delta connected tertiary of 30 kV would have 3 windings: 1 for high voltage 500 kV, 2 for low voltage 230 kV and 3 for tertiary 30 kV.

For each transformer winding the required data are:

- V rating (kV)** is the rated voltage. It is line-to-ground for wye-connected windings, and line-to-line for delta connected windings. In the above example,
- R (Ohms)** is the winding resistance of one phase (if the values differ in the three phases, use the average value). If the winding resistances are not known, they can be calculated from the load losses supplied with the short-circuit data if  $N=2$  or 3.

Strictly speaking, the load losses are not only  $I^2R$  losses, but contain stray losses as well; however, this is ignored. In the calculation of winding resistances from load losses, it is assumed that in pu  $R_1 = R_2$  for two winding transformers. For three-winding transformers, there are three equations in three unknowns  $R_1$ ,  $R_2$  and  $R_3$ . For transformers with four or more windings (per phase), there is no easy way to find winding resistances from the load losses. Therefore, winding resistance must be specified as input data for  $N \geq 4$ .

- k-node and m-node** are used for naming the left and right nodes for each phase on each winding. The names are mandatory, only trailing blanks are acceptable. The code name GND can be used to denote ground. The node names will appear on the "RL coupled multiphase" device drawing after loading the data from this data calculation function. The

names are used for reference; the actual connections must be made through the signals connected to the pins of the "RL coupled multiphase" device.

## 4 Short circuit test data

The required data for each short-circuit test between a pair of windings i and k are:

- **P (kW)** is for load losses in the positive sequence test for the winding pair i,k. If  $P_{ik} > 0$  then this value is used in the following equation to find the positive sequence reactance (all units are pu):

$$X_{ik} = \sqrt{Z_{ik}^2 - (R_i + R_k)^2}$$

with  $Z_{ik}$  is the short-circuit impedance in test between i and k and  $R_i + R_k$  are the load losses on the same MVA basis as  $Z_{ik}$  if load losses are nonzero. If load losses are not given, these are the specified pu winding resistances on the same MVA basis.

$P_{ik}$  can also be used to calculate winding resistance for  $N < 3$  (N is the number of winding), provided  $P_{ik} \geq 0$  for all short-circuit test (see parameter LOSS below). Read-in resistances are then ignored.

- **Z pos (%)** is the short-circuit input impedance  $Z_{ik}^{pos}$  in percent in the positive sequence test between the specified winding pair i and k, based on  $S_{rating}^{pos}$  (three phase) and on the rated voltages of both windings. In North-American standards, the short-circuit input impedance is called "impedance voltage"; in some European standards it is called "short-circuit voltage".
- **S pos rating (MVA)** is the three-phase power rating  $S_{rating}^{pos}$  on which  $Z_{ik}^{pos}$  is based.
- **Z zero (%)** and **S zero rating (MVA)** are the same as the preceding two parameters, respectively, except that they correspond to zero-sequence test. For single-phase and 5-limbed units, these can be left blank.

For 3-limb units, a facility is provided for the model to be computed based on physical considerations, such that it is not necessary to specify all  $Z_{ik}^{zero}$  values. This option is recommended only if a full complement of measured test values is not available. In this event, the "Incomplete zero sequence data" checkbox on the Data tab has to be checked and the zero-sequence excitation current  $I_{excit}^{zero} = 0$  (or it is left blank). The  $I_{excit}^{zero}$  is estimated using one zero-sequence test values and all others are ignored. In these cases, the model is computed using positive-sequence short-circuit impedance, based on physical considerations. All zero-sequence impedance are established by default.

If the parameter DELTA=0, then  $P_{ik}$  from the positive sequence test is also used to calculate the zero sequence reactance with the above equation. If  $S_{rating}^{zero} = 0$  it is assumed to be equal to  $S_{rating}^{pos}$ .

If DELTA>0 then the winding resistances are used to obtain reactances from impedances.

- **DELTA**
  - DELTA=0 means that the zero sequence short-circuit test involves only windings i and k, as in transformers where all windings are wye-connected with grounded neutrals. If a transformer has a delta-connected winding and if the winding is not k, then the delta must be open in the test between i and k.
  - DELTA>0 gives the number of additional winding which is short-circuited in addition to winding k in zero sequence test between i and k, as described earlier. This additional winding will normally be delta-connected (in the case of a closed delta). For the most important case of three-winding

transformers, the program can presently handle Yyd (wye-wye-delta) connections only. In the Yyd connection, "d" would be the additional shorted winding in the zero sequence test between "Y" and "y". The program cannot handle Ydd and Ddd connections with DELTA>0.

For three-phase transformer banks consisting of single-phase transformers, input the single-phase data as positive sequence parameters and set the fields for the zero sequence input parameters to 0, including DELTA.

- **LOSS**
  - Set LOSS to 0 to use provided winding resistances.
  - Set LOSS to 1 to calculate the winding resistance from load losses P, provided the number of winding is  $\leq 3$  and  $P \geq 0$  for all short circuit tests. Read-in winding resistances are then ignored.

## 5 Data for Duality Winding (and Optionally, Limb Dimensions)

This section specifies the data required by the fictitious winding which implements the duality based magnetic model for the core. The program produces a complete linear topological model for 3-limbed and 5-limbed core-type transformers. This includes generation of the coupling matrix, and linear magnetizing branches (including shunt conductance branches) for the wound limbs, the yokes and the zero-sequence magnetic path.

The required data for this section are:

- Node names are used for naming the left and right nodes for each phase on each fictitious winding. The names are mandatory, only trailing blanks are acceptable. The code name GND can be used to denote ground. The node names will appear in the model data file.
- **Length ratio** section represents the ratio of limb lengths, which can be specified if desired, otherwise a default value is assigned. This determines the unbalance in excitation current among phases for 3-limbed and 5-limbed units. The computed model reproduces the specified excitation current in the centre phase. For 3-limbed units, the established excitation current is a little higher in the outer phases (eg. about 39% higher for  $YkLm=0.5$ ). Two length ratios are defined:
  - YkLm: Ratio of yoke length to limb length;
  - OtLm: Ratio of outer limb length (including horizontal section) to vertical (wound) limb length.
- **Area ratio** section represents the ratio of the effective limb cross-sectional areas, which can be specified if desired for 5-limbed units. If no input is specified, a default value is assigned. For 3-limbed units, a value of 1 (unity) is always assumed. Again two ratios can be specified:
  - YkLm: Ratio of yoke area to limb area;
  - OtLm: Ratio of outer limb area (including horizontal section) to vertical (wound) limb area.

## 6 TOPMAG model data file format

After entering all the required data, The TOPMAG Data Calculation Function can be invoked from ("Save and run this case" data tab) to generate the model data file. The output from the model consists of two main sections:

- A symmetric admittance matrix of order up to  $3(N+1)$ , depending on the core type and the specified modeling options.
- A network of parallel RL branches modelling magnetizing currents due to the wound limbs ( $Z_b$ ), the horizontal yokes ( $Z_k$ ), and the zero-sequence return path through air for 3-limbed transformers, or through the outer limbs in 5-limbed transformers ( $Z_0$ ).

The example used here can be found in Examples\transformer\_data\test1.ecf.

The sample model data file for three-phase 3-limbed core transformer with 3 winding per core leg is shown in Figure 6–1. The file is identified in the first comment line as being generated by the TOPMAG device. The format is similar to the one for BCTRAN. The only difference is the extra section holding data for magnetizing branches. The first part can be automatically loaded into the “RL coupled multiphase” using the “Load data from file” option of this device. The second part and its related network topology must be created and entered manually by users in this release of EMTPWorks. The format of this section is from old EMTP-V3 data files:

- ❑ Data in columns 3 to 8 gives the k-node (left) name of the R-L branch.
- ❑ Data in columns 9 to 14 gives the m-node (right) name of the R-L branch.
- ❑ Data in columns 27 to 42 gives the resistance value in ohms.
- ❑ Data in columns 43 to 58 gives the inductance value in mH.

```

C TOPMAG BRANCH DATA - [R] IN (OHMS) AND INVERSE [L] IN (1/MILLIHENRIES)
$VINTAGE, 1
USE RB
1RH1   HN           0.000000000E+000.8304389654E+01
2RX1   GND          0.000000000E+00-.1801035049E-01
          0.000000000E+000.6620583675E-01
3RY1   RY2          0.000000000E+000.3596835669E-02
          0.000000000E+00-.1419503310E+00
          0.000000000E+000.6653891847E+00
4WH1   HN           0.000000000E+000.6915401425E-04
          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1398805501E-04
          0.000000000E+000.8304389654E+01
5WX1   GND          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1474875358E-03
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.1801035049E-01
          0.000000000E+000.6620583675E-01
6WY1   WY2          0.000000000E+000.1398805501E-04
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.4027043419E-02
          0.000000000E+000.3596835669E-02
          0.000000000E+00-.1419503310E+00
          0.000000000E+000.6653891847E+00
7BH1   HN           0.000000000E+000.6915401425E-04
          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1398805501E-04
          0.000000000E+000.6915401425E-04
          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1398805501E-04
          0.000000000E+000.8304389654E+01
8BX1   GND          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1474875358E-03
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.1468974682E-03
          0.000000000E+000.1474875358E-03
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.1801035049E-01
          0.000000000E+000.6620583675E-01
9BY1   BY2          0.000000000E+000.1398805501E-04
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.4027043419E-02
          0.000000000E+000.1398805501E-04
          0.000000000E+000.7846133560E-03
          0.000000000E+00-.4027043419E-02
          0.000000000E+000.3596835669E-02
          0.000000000E+00-.1419503310E+00
          0.000000000E+000.6653891847E+00
10RZ1  RZ2          0.000000000E+00-.8553128168E+02
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
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          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.8818126378E+03
11WZ1  WZ2          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+000.000000000E+00
          0.000000000E+00-.8553128168E+02

```

```

0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.8818126378E+03
12BZ1  BZ2 0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
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0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.000000000E+00
0.000000000E+00.8818126378E+03
USE RL
C MAGNETIZING BRANCHES - RESISTANCE (OHMS) AND INDUCTANCE (MILLIHENRIES)
C BRANCHES FOR WOUND LIMBS ON WDG 3 VOLTAGE BASE
RY1  RY2  0.000000000E+00.5258451736E+05
WY1  WY2  0.000000000E+00.5258451736E+05
BY1  BY2  0.000000000E+00.5258451736E+05
RY1  RY2  0.196000000E+05
WY1  WY2  0.196000000E+05
BY1  BY2  0.196000000E+05
C BRANCHES FOR TOP & BOTTOM YOKES ON WDG 3 VOLTAGE BASE
BZ2  RZ2  0.000000000E+00.5258451736E+05
BZ2  WZ2  0.000000000E+00.5258451736E+05
BZ2  RZ2  0.196000000E+05
BZ2  WZ2  0.196000000E+05
C ZERO SEQ MAGNETIZING BRANCHES ON WDG 3 VOLTAGE BASE
RZ1  BZ2  0.000000000E+00.2427597025E+02
WZ1  RZ2  0.000000000E+00.2427597025E+02
BZ1  WZ2  0.000000000E+00.2427597025E+02
C TIE ONE CORNER OF CORE MODEL TO GROUND
RZ2  0.100000000E+01
$VINTAGE, 0

```

Figure 6-1 TOPMAG model data file example