Multiphase Transformer

On this page:

Multiphase transformers can represent either a 1, 2, or 3-phase transformer. In the corresponding Excel tab, there are columns for declaration of up to 6 connection points (3 for **Winding From** end and 3 for **Winding To** end).

The sending and receiving connection points must be filled in correspondingly:

- For example, if **Winding From/Bus 1** is filled, **Winding To/Bus 1** must be filled as well.
- The unused connection points can be left empty. However, these empty fields must be located immediately after any completed connection point. For example, data in which **Winding From/Bus 2** and **Winding To/Bus 2** fields are filled out but **Winding From/Bus 1** and **Winding To/Bus 1** are empty is not valid and it causes an error.

Finally, the sending and receiving points can be connected to different phases. For example, **Winding From/Bus 1** can be connected to phase A while **Winding To/Bus 1** is connected to phase B.

In summary:

To represent a ...	Fill these columns to add connection points...
single-phase transformer	Only **Winding From/Bus 1** and **Winding To/Bus 1** columns.
two-phase transformer	The **Winding From/Bus1** and **Winding From/Bus 2** as well as **Winding To/Bus 1** and **Winding To/Bus 2**.
three-phase transformer	The **Winding From/Bus1**, **Winding From/Bus 2**, **Winding From/Bus 3** as well as **Winding To/Bus 1**, **Winding To/Bus 2** and **Winding To/Bus 3**.

Multiphase 2W Transformer

Symbol		Description	Unit
ID		Transformer name	unique name
Status		Connect/Disconnect status	Initial value 1 (0 for disconnected)
Number of Phases		Phase count in use	1, 2, or 3
Winding From	**Bus1**	Primary side: Bus 1	a unique name
	Bus2	Primary side: Bus 2	a unique name
	Bus3	Primary side: Bus 3	a unique name
	V (kV)	Primary winding nominal voltage (phase-to-phase)	kV
	S_base (kVA)	Nominal power in primary side	kVA
	Conn. type (*)	Primary winding connection type	‘wye’ and ‘delta’
Winding To	**Bus1**	Secondary side: Bus 1	a unique name
	Bus2	Secondary side: Bus 2	a unique name
	Bus3	Secondary side: Bus 3	a unique name
	V (kV)	Secondary winding nominal voltage (phase-to-phase)	kV
	S_base (kVA)	Nominal power in secondary side	NOT APPLICABLE
	Conn. type (*)	Secondary winding connection type	‘wye’ and ‘delta’

Tap 1	Initial tap position: winding 1	Integer between Lowest and Highest Tap
Tap 2	Initial tap position: winding 2	
Tap 3	Initial tap position: winding 3	
Lowest Tap	The lowest tap position	Integer value
Highest Tap	The highest tap position	Integer value
Min Range (%)	Max voltage buck	0 < value < 100
Max Range (%)	Max voltage boost	value > 0
X (pu)	Total reactance	p.u.
Rw1 (p.u.)	Primary winding resistance	p.u.
Rw2 (p.u.)	Secondary winding resistance	p.u.

Multiphase 2W Transformer with Mutual Impedance

Symbol		**Description**	**Unit**
ID		Transformer name	a unique name
Status		Connect/Disconnect status	Initial value 1 (0 for disconnected)
Number of Phases		Phase count in use	1, 2, or 3
Winding From	**Bus1**	Primary side: Bus 1	a unique name
	Bus2	Primary side: Bus 2	a unique name
	Bus3	Primary side: Bus 3	a unique name
	V (kV)	Primary winding nominal voltage (phase-to-phase)	kV
	S_base (kVA)	Nominal power in primary side	kVA
	Conn. type (*)	Primary winding connection type	‘wye’ and ‘delta’
Winding To	**Bus1**	Secondary side: Bus 1	a unique name
	Bus2	Secondary side: Bus 2	a unique name
	Bus3	Secondary side: Bus 3	a unique name
	V (kV)	Secondary winding nominal voltage (phase-to-phase)	kV
	S_base (kVA)	Nominal power in secondary side	NOT APPLICABLE
	Conn. type (*)	Secondary winding connection type	‘wye’ and ‘delta’
Tap 1		Initial tap position: winding 1	Integer between Lowest and Highest Tap
Tap 2		Initial tap position: winding 2	
Tap 3		Initial tap position: winding 3	
Lowest Tap		The lowest tap position	Integer value
Highest Tap		The highest tap position	Integer value
Min Range (%)		Max voltage buck	0 < value < 100
Max Range (%)		Max voltage boost	value > 0
Z0 leakage (pu)		Zero-sequence impedance	transformer p.u.

Z1 leakage (pu)	Positive-sequence impedance	transformer p.u.
X0/R0	Zero-sequence reactance to resistance ratio	ratio
X1/R1	Positive-sequence reactance to resistance ratio	ratio
No Load Loss (kW)	No-load power loss	NOT APPLICABLE

Note: (*) Four types of winding configurations are supported: 'DD0', 'YgYg0', 'DYg1', 'YgD1'.

Available I/O Pins

No	Pin Description	Pin Type	Value/Unit	Instruction
1	Get sending end current magnitude of wire *j*	O	A (RMS)	**transformerID**/ImagFrom*j* where *j* is 1, 2 or 3
2	Get receiving end current magnitude of wire *j*	O	A (RMS)	**transformerID**/ImagTo*j* where *j* is 1, 2 or 3
3	Get sending end current angle of wire *j*	O	Degree	**transformerID**/IangFrom*j* where *j* is 1, 2 or 3
4	Get receiving end current angle of wire *j*	O	Degree	**transformerID**/IangTo*j* where *j* is 1, 2 or 3
5	Set/Get tap position	I/O	Integer between [min_tap, max_tap]	**transformerID**/tap_*j* where *j* is 1, 2 or 3

Model Equations

This multiphase transformer is modeled based on the primitive nodal admittance matrix **Yprim** [1],[2].

$\mathbf{Yprim} = \mathbf{A\ N\ B\ Z_B^{-1}\ B^T\ N^T\ A^T}$ matrix dimension: np*m x np*m, np = number of phases, m= number of windings

$\mathbf{Y_1 = B\ Z_B^{-1}\ B^T}$; $\mathbf{Y_w = N\ Y_1\ N^T}$; $\mathbf{Yprim = A\ Y_w\ A^T}$

$\mathbf{Y_1}$ is the ground-referenced nodal admittance matrix on a 1 volt base. Matrix dimension: np*m x np*m

N is the incidence matrix whose non-zero elements are the inverse of the numbers of turns in the windings. This matrix represents the effect of the ideal transformers shown to obtain actual windings voltages. Matrix dimension: 2*np*m x np*m

B is the incidence matrix whose elements are either 1,-1 or 0. It relates currents in the short circuit reference frame where the first winding is assumed shorted to the currents in the nodal admittance reference frame on a 1 volt base. Matrix dimension: np*m x np

A is the incidence matrix whose non-zero elements are generally either 1 and -1, that relates the winding currents to the actual terminal currents. Matrix dimension: nc x 2*np*m, nc = number of terminal currents

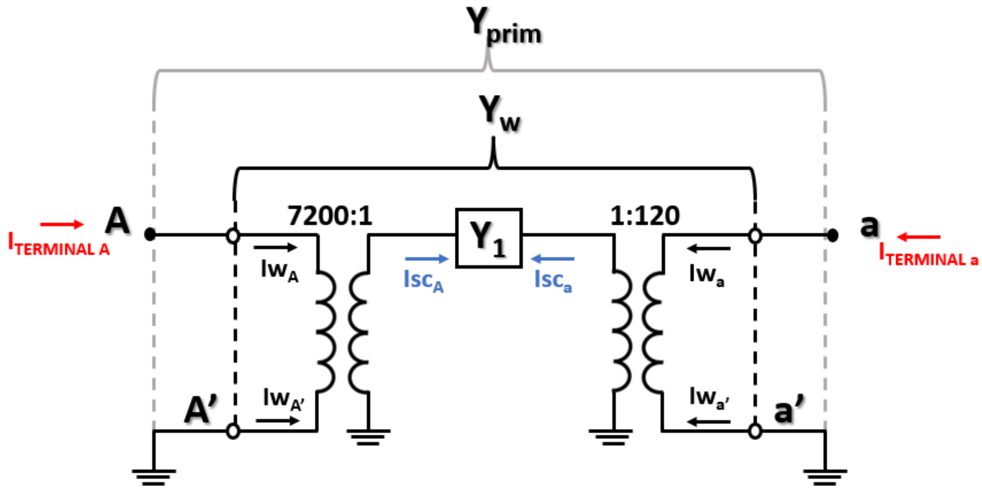
$\mathbf{Z_B}$ is the short circuit impedance matrix. Matrix dimension: np*(m-1) x np*(m-1)

$\mathbf{Y_w}$ is the winding admittance matrix. Matrix dimension: 2*np*m x 2*np*m

Examples

1) A single-phase 2W transformer with the following data: 7.2/0.12 kV, 25 kVA, X = 20%, R=1.1%

In this case np = 1, m = 2.



Z_B in pu = 0.011+0.02i, ZB in 1V base = (Z_B in pu)*1^2/25 kVA = 4.4e-7 + 8e-7i. Z_B^{-1}= 527.831e3 - 959.692e3i

$\mathbf{Y_1} = \mathbf{B}\,\mathbf{Z_B}^{-1}\,\mathbf{B}^T$; **B** is a matrix [np*m=2 x np=1]

B =

1
-1

$\mathbf{Y_1}$ =

527.831e3 - 959.692e3i	-527.831e3+959.692e3i
-527.831e3+959.692e3i	527.831e3 - 959.692e3i

N is a matrix [2*np*m=4 x np*m=2]

N =

1 /7200	0
-1 /7200	0
0	1/120
0	-1/120

$\mathbf{Y_w} = \mathbf{N}\,\mathbf{Y_1}\,\mathbf{N}^T$ =

0.0102-0.0185i	-0.0102+0.0185i	-0.6109+1.1108i	0.6109-1.1108i
-0.0102+0.0185i	0.0102-0.0185i	0.6109-1.1108i	-0.6109+1.1108i
-0.6109+1.1108i	0.6109-1.1108i	36.6549-66.6453i	-36.6549+66.6453i
0.6109-1.1108i	-0.6109+1.1108i	-36.6549+66.6453i	36.6549-66.6453i

To generate matrix **A** is necessary to define the number of terminal currents in the model. In this case there are 2 terminal currents (see the red currents in the figure above) so nc=2 and **A** matrix is [nc=2 x 2*np*m=4]

A =

1	0	0	0
0	0	1	0

Finally the matrix Yprim is calculated

Yprim = $\mathbf{A}\,\mathbf{Y_w}\,\mathbf{A}^T$ =

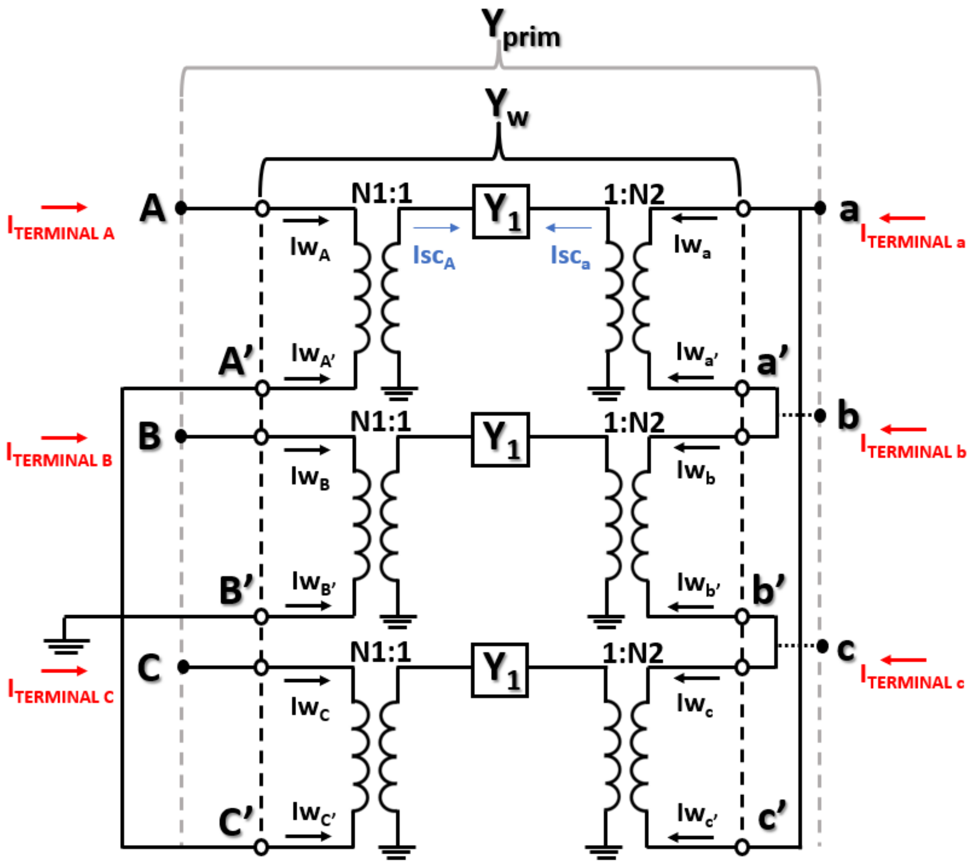
0.0101-0.0185i	-0.6105+1.1100i
-0.6105+1.1100i	36.6007-66.5467i

Below it can be seen how to add this single-phase transformer in the excel file. The total resistance was divided equally between the 2 windings (RW1 = RW2 = 0.011 pu/2 = 0.0055 pu). Note that the voltages voltages must be added as phase to phase voltages even though the model is single-phase (according to the table above)

Multiphase 2W-Transformer			Go to Type List																					
ID	Status	Number of phases	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. type	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. type	Tap 1	Tap 2	Tap 3	Lowest Ta	Highest Ta	Min Range	Max Range	X (pu)	RW1 (pu)	RW2 (pu)
TRX_B1_B2_a	1	1	B1_a			12.47	25	wye	B2_a			0.208	25	wye	0			0	0	0	0	0.02	0.0055	0.0055
End of Multiphase 2W-Transformer																								

2) A three-phase 2W transformer with the following data: 12.47/0.208 kV (wye/delta), 75 kVA, X = 20%, R=1.1%

In this case np = 3, m = 2.



Z_B in pu = 0.011+0.02i, ZB in 1V base = (Z_B in pu)*1^2/75 kVA = 1.4667e-7 + 2.6667e-7i. Z_B^{-1}= 158.349e3 - 287.907e3i

$Y_1 = B\, Z_B^{-1}\, B^T$; B is a matrix [np*m=6 x np=3]

B =

1	0	0
-1	0	0
0	1	0
0	-1	0
0	0	1
0	0	-1

Y_1 =

158.349e3 - 287.907e3i	-158.349e3 + 287.907e3i	0	0	0	0
-158.349e3 + 287.907e3i	158.349e3 - 287.907e3i	0	0	0	0
0	0	158.349e3 - 287.907e3i	-158.349e3 + 287.907e3i	0	0
0	0	-158.349e3 + 287.907e3i	158.349e3 - 287.907e3i	0	0
0	0	0	0	158.349e3 - 287.907e3i	-158.349e3 + 287.907e3i
0	0	0	0	-158.349e3 + 287.907e3i	158.349e3 - 287.907e3i

N is a matrix [2*np*m=12 x np*m=6]

N =

1 /12470	0	0	0	0	0
-1 /12470	0	0	0	0	0
0	1/(208*sqrt(3))	0	0	0	0
0	-1/(208*sqrt(3))	0	0	0	0
0	0	1 /12470	0	0	0
0	0	-1 /12470	0	0	0
0	0	0	1/(208*sqrt(3))	0	0
0	0	0	-1/(208*sqrt(3))	0	0
0	0	0	0	1 /12470	0
0	0	0	0	-1 /12470	0
0	0	0	0	0	1/(208*sqrt(3))
0	0	0	0	0	-1/(208*sqrt(3))

$\mathbf{Y_w} = \mathbf{N}\,\mathbf{Y_1}\,\mathbf{N}^T$ =

0.0102-0.0185i	-0.0102+0.0185i	-0.3525+0.6409i	0.3525-0.6409i	0	0	0	0	0	0	0	0
-0.0102+0.0185i	0.0102-0.0185i	0.3525-0.6409i	-0.3525+0.6409i	0	0	0	0	0	0	0	0
-0.3525+0.6409i	0.3525-0.6409i	12.2002-22.1823i	-12.2002+22.1823i	0	0	0	0	0	0	0	0
0.3525-0.6409i	-0.3525+0.6409i	-12.2002+22.1823i	12.2002-22.1823i	0	0	0	0	0	0	0	0
0	0	0	0	0.0102-0.0185i	-0.0102+0.0185i	-0.3525+0.6409i	0.3525-0.6409i	0	0	0	0
0	0	0	0	-0.0102+0.0185i	0.0102-0.0185i	0.3525-0.6409i	-0.3525+0.6409i	0	0	0	0
0	0	0	0	-0.3525+0.6409i	0.3525-0.6409i	12.2002-22.1823i	-12.2002+22.1823i	0	0	0	0
0	0	0	0	0.3525-0.6409i	-0.3525+0.6409i	-12.2002+22.1823i	12.2002-22.1823i	0	0	0	0
0	0	0	0	0	0	0	0	0.0102-0.0185i	-0.0102+0.0185i	-0.3525+0.6409i	0.3525-0.6409i
0	0	0	0	0	0	0	0	-0.0102+0.0185i	0.0102-0.0185i	0.3525-0.6409i	-0.3525+0.6409i
0	0	0	0	0	0	0	0	-0.3525+0.6409i	0.3525-0.6409i	12.2002-22.1823i	-12.2002+22.1823i
0	0	0	0	0	0	0	0	0.3525-0.6409i	-0.3525+0.6409i	-12.2002+22.1823i	12.2002-22.1823i

To generate matrix **A** is necessary to define the number of terminal currents in the model. In this case there are 6 terminal currents (see figure above) so nc=6 and **A** matrix is [nc=6 x 2*np*m=12]

A =

1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0
0	0	1	0	0	0	0	0	0	0	0	1
0	0	0	1	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	1	0

Yprim = **A** Y_w **A**^{T} =

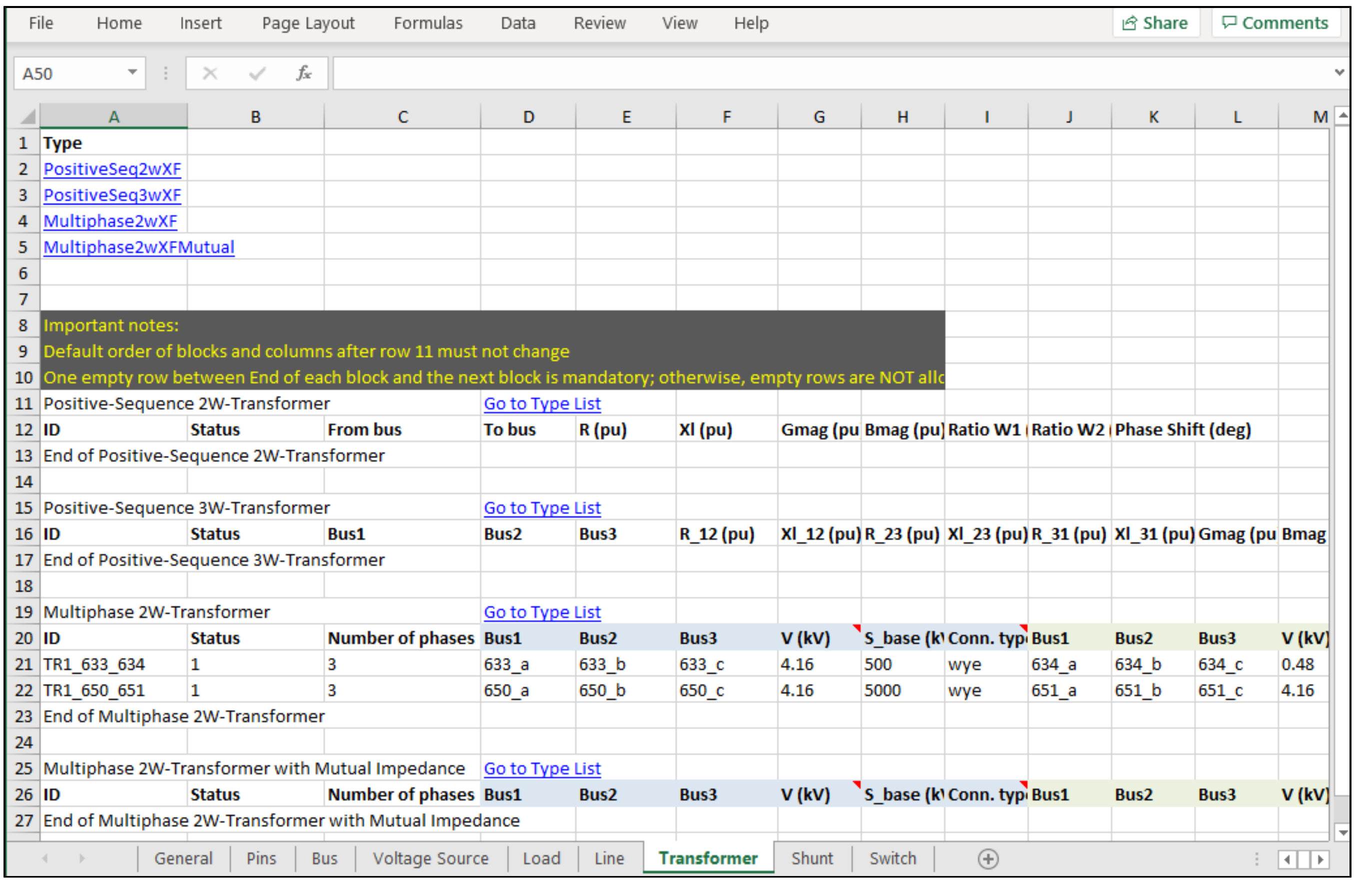
0.0101-0.0185i	0	0	-0.3524+0.6408i	0.3524-0.6408i	0
0	0.0101-0.0185i	0	0	-0.3524+0.6408i	0.3524-0.6408i
0	0	0.0101-0.0185i	0.3524-0.6408i	0	-0.3524+0.6408i
-0.3524+0.6408i	0	0.3524-0.6408i	24.4004-44.3645i	-12.2002+22.1822i	-12.2002+22.1822i
0.3524-0.6408i	-0.3524+0.6408i	0	-12.2002+22.1822i	24.4004-44.3645i	-12.2002+22.1822i
0	0.3524-0.6408i	-0.3524+0.6408i	-12.2002+22.1822i	-12.2002+22.1822i	24.4004-44.3645i

The following image shows how to add this component in the excel file.

Multiphase 2W-Transformer			Go to Type List																					
ID	Status	Number of phases	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. type	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. type	Tap 1	Tap 2	Tap 3	Lowest Ta	Highest Ta	Min Range	Max Range	X (pu)	RW1 (pu)	RW2 (pu)
TRX_B1_B2	1	3	B1_a	B1_b	B1_c	12.47	75	wye	B2_a	B2_b	B2_c	0.208		delta	0	0	0	0	0	0	0	0.02	0.0055	0.0055
End of Multiphase 2W-Transformer																								

3) Multiple transformers in the same model

See the **Transformer** page in phasor08_IEEE13.xls file in demo PHASOR-08.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Type												
2	PositiveSeq2wXF												
3	PositiveSeq3wXF												
4	Multiphase2wXF												
5	Multiphase2wXFMutual												
6													
7													
8	Important notes:												
9	Default order of blocks and columns after row 11 must not change												
10	One empty row between End of each block and the next block is mandatory; otherwise, empty rows are NOT allo												
11	Positive-Sequence 2W-Transformer			Go to Type List									
12	ID	Status	From bus	To bus	R (pu)	Xl (pu)	Gmag (pu	Bmag (pu)	Ratio W1 (	Ratio W2 (	Phase Shift (deg)		
13	End of Positive-Sequence 2W-Transformer												
14													
15	Positive-Sequence 3W-Transformer			Go to Type List									
16	ID	Status	Bus1	Bus2	Bus3	R_12 (pu)	Xl_12 (pu)	R_23 (pu)	Xl_23 (pu)	R_31 (pu)	Xl_31 (pu)	Gmag (pu	Bmag
17	End of Positive-Sequence 3W-Transformer												
18													
19	Multiphase 2W-Transformer			Go to Type List									
20	ID	Status	Number of phases	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. typ	Bus1	Bus2	Bus3	V (kV)
21	TR1_633_634	1	3	633_a	633_b	633_c	4.16	500	wye	634_a	634_b	634_c	0.48
22	TR1_650_651	1	3	650_a	650_b	650_c	4.16	5000	wye	651_a	651_b	651_c	4.16
23	End of Multiphase 2W-Transformer												
24													
25	Multiphase 2W-Transformer with Mutual Impedance			Go to Type List									
26	ID	Status	Number of phases	Bus1	Bus2	Bus3	V (kV)	S_base (kV	Conn. typ	Bus1	Bus2	Bus3	V (kV)
27	End of Multiphase 2W-Transformer with Mutual Impedance												

References

[1] Roger C. Dugan, "A Perspective on Transformer Modeling for Distribution Systems Analysis". 2003 IEEE Power Engineering Society General Meeting. DOI: 10.1109/PES.2003.1267146

[2] Roger C. Dugan and Surya Santoso, "An Example of 3-phase Transformer Modeling for Distribution Systems Analysis". 2003 IEEE PES Transmission and Distribution Conference and Exposition. DOI: 10.1109/TDC.2003.1335084