POWERFACTORY

PowerFactory 2021

Technical Reference

Booster Transformer

ElmTrb,TypTrb

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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Contents

1 General Description

PowerFactory comes with a built-in model for three-phase booster transformers. The booster transformers are also called phase angle regulating transformers or phase-shifters. The model of the booster transformer is presented in this document.

The single-line representation of the booster transformer is shown in Figure 1.1.

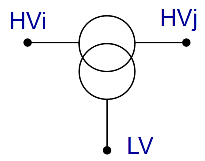

Figure 1.1: Single-line representation of the booster transformer

The booster transformer is a three-port element connecting three cubicles in the network. The transformer model in *PowerFactory* consists of the booster transformer element (*ElmTrb*), and the booster transformer type (*TypTrb*). The transformer element allows input of data relating to the control of the transformer under steady-state conditions, and the transformer type allows input of the physical properties of the transformer.

The booster transformer can be used to control the flow of active and reactive power through the HV sides by modifying the voltage in magnitude and angle at the LV side. For example, this can be done by connecting a regulating transformer or power electronic equipment at the LV side.

The three phase circuit diagrams for a LV YN and a LV delta connection are shown in Figure 1.2.

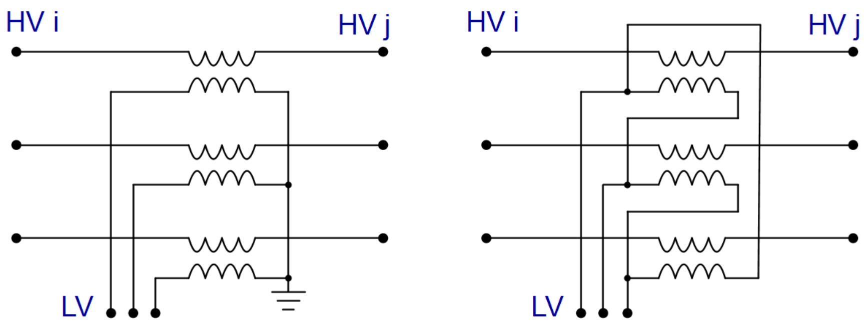

Figure 1.2: Circuit diagram of the booster transformer (left YN connection, right Δ connection)

Saturation can be defined in the booster transformer type and it is modelled in the same way as for the three-phase transformer model. Hysteresis is not supported for the booster transformer.

2 Model description

The detailed positive- and negative-sequence model with impedances in per-unit is shown in Figure 2.1.

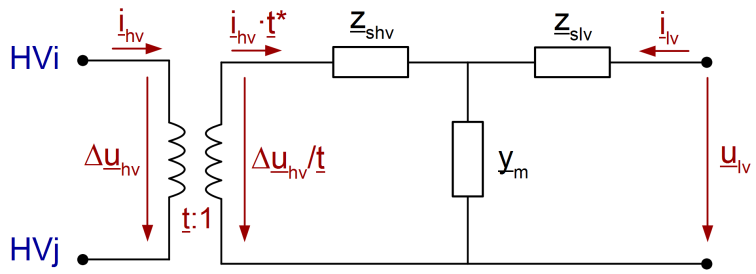

Figure 2.1: Positive-sequence equivalent circuit of the booster transformer

In Figure 2.2, the zero-sequence equivalent circuits in per-unit are shown for several different combinations of LV connection groups.

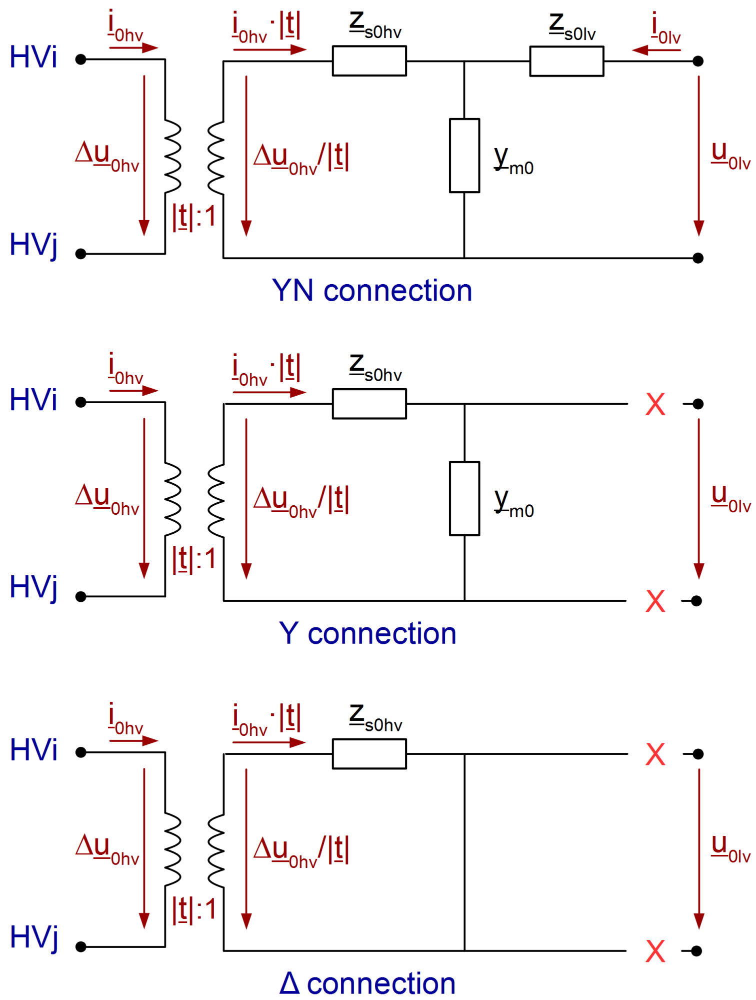

Figure 2.2: Zero-sequence equivalent circuits of the booster transformer

2.1 Input and equivalent circuit parameters

Using the transformer input data, the impedances used by the booster transformer model are calculated.

The nominal power of the booster transformer in *PowerFactory* is the full nominal power (input parameter $strn$) multiplied by the number of parallel booster transformers (input parameter $ntnum$):

$$S_{nom} = ntnum \cdot strn \tag{1}$$

An impedance in Ω as seen from one of the connection sides, referred to the voltage of that connection side, needs to be divided by the base impedance to get the $p.u.$ value and then multiplied with 100 to get the value in $\%$:

$$uktr = \frac{Z_\Omega}{Z_{base}} \cdot 100 \qquad \% \tag{2}$$

where the base impedance is calculated depending on which side Z_Ω is measured:

$$Z_{base} = \begin{cases} \dfrac{uktr\_h^2}{strn} & [\Omega] \quad \text{when } Z_\Omega \text{ is measured at the HV side} \\ \dfrac{uktr\_l^2}{strn} & [\Omega] \quad \text{when} Z_\Omega \text{ is measured at the LV side} \end{cases} \tag{3}$$

where $uktr\_h$ is the nominal voltage difference of the HV connection sides and $uktr\_l$ is the nominal voltage of the LV winding.

The no-load current $curmg$ in $\%$, based on the apparent power of the transformer, is calculated from the measured no-load current I_0 in kA at the LV winding as:

$$curmg = \frac{I_0}{I_{base\_lv}} \cdot 100 \qquad where \qquad I_{base\_lv} = \frac{strn}{\sqrt{3} \cdot utrn\_l} \tag{4}$$

The nominal voltage difference of the HV connection sides $utrn\_h$ is used when calculating the per-unit value of the HV side voltage difference (shown in Figure 2.1):

$$\Delta \underline{u}_{hv} = \frac{\underline{U}_{bus\_HVi} \cdot \underline{u}_{hvi} - \underline{U}_{bus\_HVj} \cdot \underline{u}_{hvj}}{utrn\_h} \qquad p.u. \tag{5}$$

where $\underline{U}_{bus\_HVi}$ and $\underline{U}_{bus\_HVj}$ are the nominal voltages of the connected terminals ($uknom$) and $\underline{u}_{HVi}$ and $\underline{u}_{HVj}$ are the actual voltage per-unit values. The negative and zero sequence voltage differences are calculated similarly. The per-unit value of the LV voltage is calculated as:

$$\underline{u}_{lv} = \frac{\underline{U}_{bus\_LV} \cdot \underline{u}_{lv}}{utrn\_l} \qquad p.u. \tag{6}$$

2.1.1 Positive- and negative sequence

Having the short-circuit voltages $uktr$ and copper losses $pcutr$, the positive sequence impedance $\underline{z}$ can be calculated and then using the distribution of the short circuit impedance $itrdz$ also the impedances of the HV and LV sides:

$$\underline{z}.r = \frac{pcutr}{1000 \cdot strn} \qquad p.u. \tag{7}$$

$$\underline{z}.i = \sqrt{\frac{uktr}{100}^2 - \underline{z}.r^2} \qquad p.u. \tag{8}$$

$$\underline{z}_{shv} = \underline{z} \cdot itrdz \qquad p.u. \tag{9}$$

$$\underline{z}_{slv} = \underline{z} \cdot (1 - itrdz) \qquad p.u. \tag{10}$$

The magnetising admittance $\underline{y_m}$ is calculated using the no-load current in $\%\ curmg$ (no-load losses are neglected):

$$\underline{y}_m = -\jmath \cdot \frac{curmg}{100} \qquad p.u. \tag{11}$$

The complex winding ratio of the LV-HV side is calculated only using the phase shift $nt2ag$ of the transformer:

$$\underline{t} = \cos\left(\frac{nt2ag \cdot \pi}{6}\right) - \jmath \cdot \sin\left(\frac{nt2ag \cdot \pi}{6}\right) \tag{12}$$

2.1.2 Zero sequence

Using the zero sequence short-circuit voltages $uk0tr$ and the resistive part $ur0tr$, the zero sequence impedance $\underline{z}_0$ can be calculated:

$$\underline{z}_0.r = \frac{ur0tr}{100} \qquad p.u. \tag{13}$$

$$\underline{z}_0.i = \sqrt{\frac{uk0tr}{100}^2 - \underline{z}.r^2} \qquad p.u. \tag{14}$$

The HV zero sequence impedance is calculated using the zero-seq. distribution factor as:

$$\underline{z}_{s0hv} = \underline{z}_0 \cdot zx0hl\_h \qquad p.u. \tag{15}$$

The LV zero sequence impedance is calculated using the zero-seq. distribution factor as:

$$\underline{z}_{s0lv} = \begin{cases} \underline{z}_0 \cdot zx0hl\_l + 3 \cdot \underline{z}_{elv} & [p.u.] \quad \text{for YN connection} \\ 0 & [p.u.] \quad \text{for Y and D connections} \end{cases} \tag{16}$$

where the earthing impedance $\underline{z}_{elv}$ is calculated using the LV-side internal grounding impedances and is based on the apparent power of the transformer and the LV winding nominal voltage $utrn\_l$:

$$\underline{z}_{elv} = (re0tr\_l + \jmath \cdot xe0tr\_l) \cdot \frac{strn}{utrn\_l^2} \tag{17}$$

The zero-sequence magnetising admittance $\underline{y}_{m0}$ is calculated using the zero-sequence magnetizing reactance to $uk0tr$ ratio $zx0hl\_n$:

$$\underline{y}_{m0} = \begin{cases} -\jmath \cdot \dfrac{1}{\dfrac{uk0tr}{100} \cdot zx0hl\_n} & [p.u.] \quad \text{for Y and YN connections} \\ 0 & [p.u.] \quad \text{for D connections} \end{cases} \tag{18}$$

The absolute value of the complex winding ratio $|\underline{t}|$ is always 1 since it is calculated only by using the phase shift $nt2ag$ of the transformer.

2.1.3 Positive-, negative- and zero sequence for the EMT simulation

The resistances and inductances used for the EMT model are obtained from the complex impedance values calculated above as follows:

$$r = \underline{z}.r \tag{19}$$

$$l = \frac{\underline{z}.i}{2 \cdot \pi \cdot F_{nom}} \tag{20}$$

$$\tag{21}$$

where F_{nom} is the nominal frequency in Hz.

The magnetising susceptance is calculated using the no-load current $curmg$ as:

$$b_m = \frac{curmg}{100} \cdot 2 \cdot \pi \cdot f_{nom} \qquad p.u. \tag{22}$$

The zero-sequence magnetising susceptance is calculated using the zero-sequence magnetizing reactance to $uk0tr$ ratio $zx0hl\_n$:

$$b_{m0} = \begin{cases} \dfrac{2 \cdot \pi \cdot f_{nom}}{\frac{uk0tr}{100} \cdot zx0hl\_n} & [p.u.] \quad \text{for Y and YN connections} \\ 0 & [p.u.] \quad \text{for D connections} \end{cases} \tag{23}$$

2.2 Inputs/Outputs/State variables of the dynamic models

2.2.1 EMT-Model

Table 2.1: State variables definition of the EMT-model

Parameter	Description	Unit
psimd	Magnetising Flux, alpha component	p.u.
psimq	Magnetising Flux, beta component	p.u.
psim0	Magnetising Flux, gamma component	p.u.

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