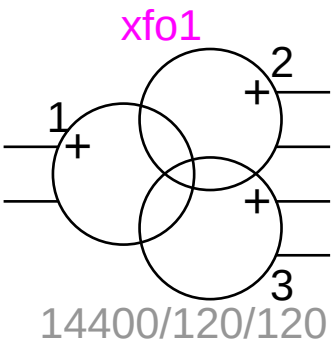
Single-phase 3-winding transformer



Henry Gras, 2017-05-01 18:10:00

1 Introduction

This device is a single-phase 3-winding transformer model including the winding impedances and the magnetization branch.
The magnetization branch is composed of a resistance in parallel with a non-linear inductance. If hysteresis is simulated, the non-linear inductance is replaced by a hysteresis reactor. The non-linear behavior of the magnetization branch can be defined with different data types:

- the current-flux points of the non-linear inductance
- the current-voltage points of the excitation test report
- the magnetic field-induction points of the material

Initial flux conditions can be specified in order to simulate a residual flux at the beginning of the simulation.

2 Parameters

- **Nominal frequency:** Frequency of application for this device (surrounding network frequency). Used when the inductance values are specified in Ohms and for the calculation of the flux points for the magnetization branch
- **Winding 1 voltage:** Winding 1 nominal voltage in RMS line-to-line
- **Winding 2 voltage:** Winding 2 nominal voltage in RMS line-to-line
- **Winding 3 voltage:** Winding 3 nominal voltage in RMS line-to-line
- **Nominal power:** Nominal power of the transformer. Used as a base when parameters are defined in per unit.
- **Winding R_{ij}:** short-circuit resistance between windings *i* and *j* seen from the winding *i*. Displayed only if the resistances unit is *pu*.
- **Winding X_{ij}:** short-circuit inductance between windings *i* and *j* seen from the winding *i*. Displayed only if the inductances unit is *pu*.

- **Winding *i* R:** resistance of the winding *i*. Displayed only if the inductances unit is not *pu*.
- **Winding *i* X:** inductance of the winding *i*. Displayed only if the inductances unit is not *pu*.
- **Magnetization curve definition:** select the type of data and the units used to define the magnetization reactance.
  - If Current-Voltage is selected, the excitation test data points are entered in the table.
  - If Current-*Flux* is selected, the magnetization non-linear inductance current-flux data points are entered.
  - If *Magnetic Field-Induction* is selected, the magnetic material H-B curve data points are entered. In that case, **the saturation point current and flux** must be entered. The saturation point is the point on the H-B curve where the upward and downward branches of the major hysteresis loop meets for positive value of H.

    If **Add Air-core inductance segment** is checked, the last point of the characteristic corresponds to the positive saturation point, else it is a point before the last. In it is not checked, the air-core inductance is defined by the slope of the last entered segment.

  The characteristic entered must be monotonically increasing.
- **Saturation point current**: current corresponding to the saturation point. Only when *Magnetic Field-Induction* input type is selected. If **Add air-core inductance segment** is checked, it corresponds to the last point of the H-B table, else, it is point n-1.
- **Saturation point flux**: flux corresponding to the saturation point. Only when *Magnetic Field-Induction* input type is selected. If **Add air-core inductance segment** is checked, it corresponds to the last point of the H-B table, else, it is point n-1.
- **Add air-core inductance segment**: Add an extra segment to the characteristic entered in the table. This segment corresponds to the air-core reactance inductance.
- $\mathbf{L_{sat}}$: Air-core reactance value.
- **Magnetization resistance/losses:** If the unit is set to ohm, this is the resistance in parallel with the nonlinear inductance of the transformer magnetization branch.

  If the unit is set to kW, this is the losses for 1pu of voltage during the excitation test. The resistance is calculated using the loss value.
- **Simulate hysteresis loops:** include the hysteresis reactor of the magnetization branch and exclude the non-linear inductance. If this box is checked, the full upward (lower) branch of the major hysteresis loop must be entered in the table. The negative abscise points must be entered.

  If hysteresis are simulated, the following constraints apply to the non-linear characteristic data:
  - the negative saturation point should not be entered.
  - the first point entered must have lower magnitude of current and flux than the positive saturation point, else it is discarded. If **Add air-core inductance segment** is checked, the positive saturation point is the last point entered in the non-linear characteristic magnetization data table. If it is not checked, the positive saturation point is the one before the last in the table.
  - At least 3 points must be entered
  - The segment slopes cannot be zero.
- **Exclude magnetization branch model:** Exclude the magnetization branch of the model.

The initial flux conditions are entered on the second data tab (IC):

- **Initial flux (φ_0):** residual flux of the transformer at the beginning of the simulation.

When resistances and inductances units are pu, then the conversion is:

$$R1 = \frac{1}{2}\left(R12 + R13 - R23\right) \tag{1}$$

$$X1 = \frac{1}{2}\left(X12 + X13 - X23\right) \tag{2}$$

$$R2 = \frac{1}{2}\left(R12 - R13 + R23\right) \tag{3}$$

$$X2 = \frac{1}{2}\left(X12 - X13 + X23\right) \tag{4}$$

$$R3 = \frac{1}{2}\left(-R12 + R13 + R23\right) \quad (5)$$

$$X3 = \frac{1}{2}\left(-X12 + X13 + X23\right) \quad (6)$$

Where Ri, Xi are respectively the resistance and inductance of winding *i*, Rij, Xij are the short-circuit resistance and inductance between winding *i* and *j* seen from the winding *i.*

3 Steady-state model

Steady-state representation based on subnetwork contents.

4 Initial conditions

Automatic initial conditions are found from the steady-state solution. Manual initial conditions can be provided for individual transformer phase unit fluxes.

5 Frequency Scan model

Steady-state representation based on subnetwork (power) contents for each frequency.

6 Time-domain model

Time-domain representation based on subnetwork contents.