#### Distribution transformers

##### Electrical model

Figure 14 shows the classes that model power transformer instances. They can use the Wires package exclusively to define impedance parameters, or make use of the AssetInfo classes detailed in Figure 15, to define a library of transformer types.

NOTE This part of IEC 61968 (documenting DCIM11) and the corresponding IEC 61970-301 (documenting base CIM15) reflect consolidated transformer models for transmission and distribution (T&D). Therefore, the classes from IEC 61968-11:2010 (1st edition) have been slightly modified and moved from model package IEC61968::WiresExt into model package IEC61970::Wires of the base CIM, IEC 61970-301 (5th edition).

startUmlDiagram.DocIEC61968.DCIMTransformerModel.endUml

Figure 14 – DCIM transformer connectivity model

PowerTransformer is the top-most instance for a power transformer, whether composed of a three-phase tank, or possibly different single-phase tanks. It descends from ConductingEquipment, and therefore, has associated Terminals with phases attribute values at each winding connection point. In the CIM, a transformer winding is referred to as an “end”.

When composed of different tanks, a PowerTransformer has often been called a “transformer bank”, and the CIM supports modelling with or without tanks. In distribution systems, independent phase voltage regulators and open wye/open delta transformers provide two examples that require tank-level modelling. At the transmission level, EHV transformer banks may also contain single-phase transformers, which need not be identical, especially when a spare is in service. The vectorGroup attribute for protective relaying is derived from the internal winding connections and phase angles; it uses IEC 60076-1 nomenclature to describe any number of windings that may be included in the bank.

When used, the TransformerTank must be associated with a PowerTransformer. It inherits from Equipment, not ConductingEquipment. The tank may have associated TransformerTankInfo from the AssetInfo package, for asset datasheet modelling, described in more detail later with Figure 15 and 4.4.3.4.2. Because transformer testing is done on tanks, the datasheets are fundamentally associated with tanks. When not using tanks in the model, the PowerTransformer can still have an association to PowerTransformerInfo, for asset datasheet modelling. In both cases, the data actually resides in TransformerEndInfo instances, associated to a TransformerTankInfo.

There are two methods of referencing transformer asset datasheets, and a profile may prefer one over the other:

* (PowerSystemResource–AssetInfo) Use the AssetDatasheet association end of either PowerTransfomer or TransformerTank, to reference either PowerTransformerInfo or TransformerTankInfo, respectively, or
* (PowerSystemResource–Asset–AssetInfo) Instantiate the Asset class, in which AssetInfo association end references either the PowerTransformerInfo or TransfomerTankInfo, and multiple PowerSystemResources reference each PowerTransformer or TransformerTank using that datasheet.

TransformerEnd, which was called TransformerWinding in earlier versions of CIM and was a ConductingEquipment, is not anymore a ConductingEquipment, but it does have one associated Terminal with phasing information. The magBaseU, magSatFlux, and bmagSat attributes represent core saturation, typically modelled at no more than one of the ends. The other instance attributes define the grounding options:

* solidly grounded: grounded = true, rground = 0, xground = 0;
* impedance grounded: grounded = true, rground ≥ 0, xground ≥ 0;
* ungrounded: grounded = false.

TransformerEnd should not be instantiated directly; one of its two descendants should be instantiated:

* PowerTransformerEnd, if not using tank-level modelling. Specify the ratedU and ratedS attribute values for winding rating data, and connectionKind for the wye, delta, or other type of connection.
* TransformerTankEnd, if using tank-level modelling. The winding connection and rating values come from a TransformerTankEndInfo instance, which means that the AssetInfo package is required for tank-level modelling. The phases attribute supports by-phase tank modelling.

With PowerTransformer and PowerTransformerEnd, there are three ways of specifying impedance parameters using only the IEC61970::Wires model package from IEC 61970-301:

* Use the r, x, r0, x0, b, b0, g, and g0 attributes of PowerTransformerEnd to specify pi impedance parameters. This is the option most compatible with earlier versions of IEC 61970-301, and there are some important conventions described in that standard.
* Use one associated TransformerStarImpedance for each PowerTransformerEnd, comprising a star equivalent (also sometimes called tee or wye equivalent). This can be mathematically exact for up to three ends (windings). However, negative attribute values may occur in the case of three ends. Optionally, use one TransformerCoreAdmittance associated to one of the PowerTransformerEnds, representing the exciting current and core losses. This can be the lowest-voltage winding (i.e. closest to the core), or the winding that was actually subjected to a no-load test, if known. The reference voltage for all attribute values, which have units of ohms or siemens, must be ratedU for the end to which the impedance or admittance is connected.
* Use a TransformerMeshImpedance associated to each combination of PowerTransformerEnd pairs. There shall be (numberEnds-1) × numberEnds / 2 of these; for example, one TransformerMeshImpedance between two ends, three of them between three ends, six of them between four ends, etc. The advantages of a mesh model are: (a) it is mathematically exact for more than three ends, (b) it has no negative attribute values, and (c) it corresponds more directly with transformer short-circuit test data. The reference voltage shall be ratedU of the FromTransformerEnd (note the other end nearly always has a different rated voltage). Optionally, use one TransformerCoreAdmittance as described for the star equivalent.

##### Tap changer model

Figure 16 shows the classes used to model a possibly unbalanced distribution voltage regulator. A RatioTapChanger is associated to a TransformerEnd. Each regulator uses autonomous local control, so that RegulationSchedule and TapSchedule (present in IEC 61970-301 and typically used in transmission) are not used here. Phase angle regulators and variation curves are also not generally used on distribution systems.

startUmlDiagram.DocIEC61968.DCIMTapChangerModel.endUml

Figure 16 – SupportCIM tap changer model

A three-phase line voltage regulator usually has three independent regulators to help correct voltage unbalance. The regulators are usually connected in wye. The model starts with a PowerTransformer containing three TransformerTanks, and a total of six TransformerTankEnds. There will be three instances of RatioTapChanger, each associated to a different TransformerTankEnd. The RegulatingControl.monitoredPhase attribute should be included among the Terminal.phases associated with the PowerTransformer. The tap positions, and sometimes the other attributes, will not be the same in each phase of the regulator. An open-delta regulator is also fairly common; this consists of two single-phase regulators connected line-to-line in a bank, with partial capability to correct voltage unbalance.

A three-phase substation voltage regulator usually changes all three taps together, with no ability to correct voltage unbalance. In this case, tank-level modelling is not required and the model might consist of one PowerTransformer with two PowerTransformerEnds. There would be just one RatioTapChanger associated to one PowerTransformerEnd. The RegulatingControl.monitoredPhase attribute can be A, B, or C if the potential transformer is connected line-to-ground. It can also be AB, AC, or BC for line-to-line potential transformers. Typically, only one potential transformer controls this type of regulator.

##### Example distribution transformer

The transformer in Figure 17 shows an open wye/open delta bank, which is used to supply inexpensive, three-phase service to smaller customers.



*IEC 292/13*

Figure 17 – Example of a distribution transformer that can be modelled with SupportCIM

Table 1 shows some of the important attribute values for this example. It requires tank-level modelling.

Table 1 – Open wye/open delta transformer bank connections

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| TransformerTank | TransformerTankEnd | ratedU | ratedS | connectionType | phaseAngleClock | TransformerTankEnd.phases |
| Xfmr 1 | Wdg 1 | 7 200 | 100e3 | I | 0 | AN |
|  | Wdg 2 | 120 | 50e3 | I | 0 | AN |
|  | Wdg 3 | 120 | 50e3 | I | 6 | BN |
| Xfmr 2 | Wdg 1 | 7 200 | 50e3 | I | 0 | BN |
|  | Wdg 2 | 240 | 50e3 | I | 0 | BC |

A phase angle clock value of “6” indicates that Wdg 3 is actually from N to B, rather than B to N. Through the Terminals, ConnectivityNode 1 will have phases ABN present. Other connected equipment, such as a line segment, could add phase C. ConnectivityNode 2 will have phases ABCN present. The “lighting leg” (Xfmr 1) usually has a different rating than the “power leg” (Xfmr 2). This means that phase and rating assignments to the bank might be ambiguous, and thus need to be specified on TransformerTankEnd.

##### Example autotransformer

An autotransformer is made by connecting two transformer windings in series, so there is a metallic connection between the two voltage levels. The main advantage is a cost savings, because the MVA rating is higher than for the same two windings connected as a conventional transformer. Autotransformers are also more efficient and have less voltage drop. The main disadvantage is probably higher short circuit current in fully developed systems, because autotransformers have lower impedance. Two common applications are:

* Transformations between two extra-high voltage (EHV) levels in a substation, where the cost savings are important for turns ratios up to approximately 2:1.
* Line voltage regulators on distribution feeders, where the regulating (buck/boost) winding is connected in auto.

Figure 18 shows a two-winding transformer to the left, with a short-circuit test connection on the L winding terminal. All of the current is transformed magnetically, and the turns ratio is *n*1:*n*2. To the right, the same two windings are connected as an autotransformer. The red current flows directly to the short-circuit test connection on the L winding terminal. In addition, the magnetically transformed blue current also contributes to the short-circuit current, which is higher than in the two-winding case. The autotransformer turns ratio is (*n*1+*n*2):*n*2. The H winding is sometimes called the series (S) winding in an autotransformer, and the L winding is sometimes called the common (C) winding in an autotransformer.



*IEC 293/13*

Figure 18 – Example of a two-winding transformer connected as an autotransformer

The IEC 60076-1 vector groups define grounding and phase shift characteristics of each winding, which are important for protective relaying, paralleling, and other applications – Figure 18 shows these in parentheses. “Ynyn” denotes a transformer with two windings, both wye grounded. (External neutral impedance may still be added, but is not listed in the vector group). The autotransformer could also be denoted “Ynyn”, because it has the same neutral connection and phase shift characteristics. However, some transformer vendors use “A” or “a” to denote an autotransformer winding. Figure 18 shows the “Yan” vector group for an autotransformer. Even though the H terminal has a conducting path to neutral through the L winding, the H winding itself is not connected to the neutral. As per IEC 60076-1, the highest voltage winding is capitalized in the vector group, while all other windings are lower-case. In practice, this means the “a” for an autotransformer would always be lower case.

Many autotransformers have a delta tertiary, shown to the right of Figure 18. The vector group would be “Yand1”, where the 1 refers to a 30° lag (1 o’clock) with respect to the H winding. The *Z*HT mesh impedance value is affected by the auto connection, but not the *Z*LT mesh impedance value. The effect on *Z*HT is not presented here, but may be found in several technical references.

The conversions from two-winding data (left side of Figure 18) to autotransformer turns ratio (*N*), volt-ampere rating (*S*auto) and mesh impedance (*Z*auto) on the right side of Figure 18 are:

*N* = 1 + *n*1 / *n*2

*S*auto = *S*2-wdg [*N* / (*N* – 1)]

*Z*auto = *Z*2-wdg [(*N* – 1) / *N*]2

In per-unit, the converted autotransformer impedance (*Z*pu-auto) is:

*Z*pu-auto = *Z*pu-2-wdg / *N*

For example, suppose the 2-winding transformer is 115/115 kV, rated 100 MVA, with 10 % impedance on 100 MVA. The turns ratio is 1:1. Viewed from either winding, the short-circuit impedance is 13,225 Ω. Connected as an autotransformer, 230/115 kV, the turns ratio is 2:1 (*N*=2) and the rating is 200 MVA. Viewed from the 115-kV terminal, the short-circuit impedance is 3,306 25 Ω, which is 5 % on the new rating of 200 MVA. The iron core and copper winding costs are half of what they would be for a conventional 2-winding transformer of the same rating. The total cost is somewhat more than 50 %, because the L winding leads must carry more current, and the H winding must be insulated for a higher voltage. The test sheet for this autotransformer would show a voltage ratio of 230 / 115 kV, a rating of 200 MVA, and a short-circuit impedance of 5 %.

It is common to model an autotransformer as a conventional two-winding transformer, using data from the test sheet, ignoring the fact that the windings are actually connected in series. However, there are times when the difference is important, such as more accurate core modelling, or more accurate modelling of the impedance vs. tap characteristic. It is possible to derive the physical autotransformer model in Figure 18, if the series and common windings have been identified.

In the CIM, an autotransformer should be modelled with conventional two-winding data for impedances, admittances, and ratings, as typically found on autotransformer test reports. Each physical winding will have a corresponding PowerTransformerEnd or TransformerTankEnd in the CIM. It is optional to specify the autotransformer connection with an attribute value A for connectionKind on the common end, and with “an” appearing as part of PowerTransformer.vectorGroup for that end. The series end shall then have attribute value Y for connectionKind. The series and common endNumbers should be 1 and 2, respectively. The receiving application may then derive the physical autotransformer model if needed. To ignore autotransformer connections in the model, specify Yn for connectionKind on both series and common ends; there is no restriction on the endNumbers. The connectionKind attribute appears on TransformerEndInfo if using tank-level modelling and on PowerTransformerEnd if not using tank-level modelling. Note that A, Y, D, and Z are always capitalized in connectionKind, but whenever the endNumber is greater than 1, they should be lower-cased in the vectorGroup.