Two Winding Transformer Equivalent Model of Three Winding Transformers for MATPOWER

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Abstract. MATPOWER is one of wide used authoritative open source software of power flow calculation in the world. However, it only provides a model of the two-winding transformer thus limiting its application in power system with a three-winding transformer which is very popular in the power system. This paper proposes a method to convert three-winding transformer into a model with two-winding transformer structure. The effectiveness of treatment method has been proved through a case study of the power system.

Introduction

Using commercial power system simulation software packages will cost a lots and need corresponding special data interfaces, so it is necessary to find more authoritative open source code. MATPOWER [1] is internationally renowned and authoritative open source software, which has been widely used tools in research and teaching for static grid operation planning and analysis [2-7].

![Figure 1. Transformer model of MATPOWER.](image)

However, the transformer model of MATPOWER is only a two-winding structure as shown in Fig.1, so it need a conversion to extend to three windings which is the necessity of this paper.

Equivalent Circuit of the Transformer

Standard Value Equivalent Circuit of the Power Grid with Multiple Voltage Levels [8]

This method is theoretically correct, but it is actually more troublesome to perform parameter conversion. Especially when the transformer tap changes its position, its transformation ratio changes accordingly and the relevant parameters are recalculated. Therefore a better method is to use an equivalent circuit with a variable ratio parameter to reflect the true voltage and current on each side. When the transformers use this equivalent circuit with a ratio at that time different voltages there is no need to convert parameters and voltages and currents between the grids. After obtaining the transformer equivalent circuit with the variable ratio parameter it is converted into the standard value.
equivalent circuit and all the parameters will have the transformation ratio and the standard value is
adopted. Then the transformers and circuits of different voltage levels can directly connect their
equivalent circuits to form a completely original circuit. The specific methods are as follows:

Consider double winding transformer first its 1 side and 2 the rated voltage of the side windings is
$U_{1N}$ with $U_{2N}$, and convert the leakage impedance and the excitation admittance to 1 side, respectively
$Z_{1T}$ with $Y_{1T}$ express. In this case, the general equivalent circuit is shown in Fig. 2. As shown there $U_1$ in
with $I_1$, $U_2$, $I_2$ they are the values of the transformer 2 side voltages and current converted to the 1 side. If it
wants to get the actual voltage and current on the 2 sides, it must convert it back. In fact, the
transformer ratio is the turn's ratio of the windings on both sides, and since the rated voltage is
proportional to the number of turns, the turn's ratio is numerically equal to the ratio of the rated
voltages of the two windings. Obviously, in the 2 sides of the equivalent circuit of Fig. 2, an ideal
transformer which only reflects the variable ratio relationship without the excitation current and
the leakage impedance is equal to zero, the output voltage and current of the ideal transformer are the true
voltage and current of the original transformer 2 sides, as shown in Fig. 3. The general equivalent
circuit of the three-winding transformer is shown in Fig. 4. One side is the high voltage side, the two
sides and the three sides are the medium voltage side and the low voltage side, respectively, and the
impedance and the admittance are considered to be converted to the high voltage side. The
three-winding transformer can be regarded as two double-winding transformers [9]. An equivalent
circuit with an ideal transformer is shown in Fig. 5. Only two ideal transformers are serially
connected, and the "ratio" is taken as a parameter the structure sample will be the two-winding
equivalent model of a three-winding transformer which is shown in this paper.

With the data input mode [10] MATPOWER has only the standard value and the following
equivalent value of the circuit with the transformer between ratio transformers.

**Standard Value Equivalent Circuit with Variable Ratio Transformer [11]**

When the ideal transformer is introduced into the equivalent circuit of the transformer exist the
double winding the core of the ideal transformer can be divided into two circuits belonging to two
different voltage levels and the three windings belong to three different voltage level circuit. Then
they are respectively taken as the reference voltage of the grid rated voltage of the voltage level and the unified reference capacity is taken to be the corresponding standard value. As shown in Fig.3. for the 1 side of the ideal transformer core which is taken the rated voltage of the network as the reference voltage $U_{1B}$ the relationship between the motor reference values:

\[
\begin{align*}
I_B &= \frac{S_B}{\sqrt{3}U_B} \\
Z_B &= \frac{U_B}{\sqrt{3}I_B} = U_B \frac{2}{S_B} \\
Y_B &= \frac{1}{Z_B} = \frac{S_B}{U_B^2}
\end{align*}
\]

And corresponding current, impedance and admittance values

\[
\begin{align*}
I^* &= I \frac{\sqrt{3}U_B}{S_B} \\
Z^* &= Z \frac{S_B}{U_B^2} \\
Y^* &= Y \frac{U_B^2}{S_B}
\end{align*}
\]

Convert $Z_{1T}$, $Y_{1T}$ and $U_1$, $I_1$ into standard values

\[
\begin{align*}
I_{1*} &= I_1 \frac{\sqrt{3}U_{1AB}}{S_B} \\
Z_{1T*} &= Z_{1T} \frac{S_B}{U_{2AB}^2} \\
Y_{1T*} &= Y_{1T} \frac{U_{2AB}^2}{S_B} \\
U_{1*} &= \frac{U_1}{U_{1AB}}
\end{align*}
\]

Similarly, for the 2 sides of the transformer core, it is taken the rated voltage of the network where is located at the reference voltage $U_{2B}$ and convert $U_2$ and $I_2$ into standard values. At the same time, the ratio of the ideal transformer $U_{1N}$: $U_{2N}$

\[
\begin{align*}
I_{2*} &= I_2 \frac{\sqrt{3}U_{2B}}{S_B} \\
U_{2*} &= \frac{U_2}{U_{2B}}
\end{align*}
\]

Figure 6. Double winding standard value equivalent circuit with variable ratio.
Correspondingly the reference voltages on both sides are respectively converted into standard values thereby obtaining a ratio expressed by the standard value:

\[
U_{1N} \cdot U_{2N} = \frac{U_{1N} \cdot U_{2N}}{U_{1B} \cdot U_{2B}}
\]

Since the ratio of the ideal transformer only reflects the relationship between the turns on both sides, the value of the above ratio can be used. 1:k’ To express

\[
U_{1N} \cdot U_{2N} = \frac{U_{1N} \cdot U_{2N}}{U_{1B} \cdot U_{2B}} = 1 \cdot k^*
\]

And thus can be derived:

\[
k^* = \frac{U_{2N} \cdot U_{1B}}{U_{2B} \cdot U_{1N}}
\]

Where K* is called the non-standard ratio of the transformer or the value of the ratio. Note that when the transformer is running on the tap, the rated voltage of the transformer winding in equation (7) should be the rated voltage corresponding to the tap. Fig. 6, shows the equivalent value circuit of the double-winding transformer with a variable ratio.

The equivalent values of the three-winding transformer standard value equivalent circuit Fig. 7 are

\[
k_{T12}^* = \frac{U_{2N}}{U_{2B}} \cdot \frac{U_{1N}}{U_{1B}}
\]

\[
k_{T13}^* = \frac{U_{3N}}{U_{3B}} \cdot \frac{U_{1N}}{U_{1B}}
\]

However, when the three-winding transformer is used to convert the equivalent value of the equivalent value circuit the impedance and admittance are converted to the high voltage side where the ratio of the ideal transformer is changed. 1:k* Position: The side connected to the transformer impedance is 1 and the other side is k*. When the transformer adopts the standard value equivalent circuit with a variable ratio each side of the transformer can be directly connected with the original line and other originals without any conversion because the standard equivalent circuit of the line is also rated by the network. The voltage is used as a reference. Obviously it can be seen from Fig. 7 that a three-winding transformer is actually equivalent to two double-winding transformers.
Results and Comparison of Case Studies

Table 1. MATPOWER calculation result with comparison of PSASP.

| Voltage | Phase angle |
|---------|-------------|
| PSASP   | MATPOWER    | PSASP | MATPOWER |
| 1.015   | 1.015       | 0     | 0        |
| 1.028   | 1.028       | -0.196| -0.196   |
| 1.029   | 1.029       | -0.285| -0.285   |
| 1.044   | 1.044       | -0.52 | -0.52    |
| 1.042   | 1.042       | -0.175| -0.175   |
| 1.032   | 1.032       | -0.56 | -0.56    |
| 1.029   | 1.029       | -0.521| -0.521   |
| 1.044   | 1.044       | -0.171| -0.171   |

Table 2. Losses by MATPOWER calculation.

| Branch No | Loss P (MW) | Loss Q (MVAr) |
|-----------|-------------|--------------|
| 1         | 1.135       | 0.22         |
| 2         | 2.424       | 0.38         |
| 3         | 0.312       | 0.08         |
| 4         | 0.731       | 0.02         |
| 5         | 0.955       | 0.50         |
| 6         | 0.011       | 0.00         |
| 7         | 0.005       | 0.00         |
| 8         | 0.001       | 0.00         |
| 9         | 0.001       | 0.00         |
| Total     | 5.574       | 1.20         |

Fig.8(a) shows a 9-node closed-loop power system.[12]. The capacity of $T_1$ and $T_2$ is 63MVA, rated voltage (121±2x2.5%) kV /10.5kV, short circuit voltage percentage UK% = 10.5, the high voltage side runs on a -2 x 2.5% tap; the $T_3$ capacity is 50 MVA, the three windings have a capacity ratio of 100/100/100, and the rated voltages are 110 kV, 38.8 kV, 11 kV, respectively, high-medium, high-low, medium - the percentage of short-circuit voltage between the low-voltage windings is 10.5, 18, 6.5, respectively. The high-voltage winding and the medium-voltage winding operate on the +2.5% and -2.5% taps respectively; all 110kV lines use the LGJ-150 type conductor, $r_1 : r_1 = 0.21 \Omega/km$, $l_1 : l_2 = 0.21 \Omega/km$. 


$x_1 = 0.4 \Omega/km$, $b_1 = 2.85 \times 10^{-6} S/km$; $L_1 = 150 km$, $L_2 = 100 km$, $L_3 = 75 km$. Fig. 8(b) is the equivalent circuits using the method in this paper.

The results of power flow calculations of MATPOWER with conversion in this paper are listed in Table 1 and Table 2. The China Academy of Electric Power’s PSASP is taken as comparison in Table 1 which shows that the three-winding equivalent modeling proposed in this paper is successful.

**Conclusion**

In this paper, the equivalent processing of the three-winding transformer in MATPOWER the power flow calculation is carried out. From the theoretical analysis and the actual example verification, the equivalent method of this paper is simple to implement easy to operate and practical. The theory and examples show that the equivalent processing of this paper is a fast and effective processing method and the processing method of the three-winding transformer in MATPOWER is clarified. The actual case also checked the validity of the proposed model.

The proposed model provides the possibility for MATPOWER to be applied in real power systems and has also been applied in the a grid of 35kV/110kV/220kV grid in Shaoxing.

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