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GENERIC APPROACH TO CALCULATION OF SHORT CIRCUIT CURRENTS IN POWER TRANSFORMERS

SUMMARY

Power transformer in service is exposed to various voltage and current stresses. The ability to withstand short circuit is an essential requirement for power transformers.

There are different types of short circuit: single - phase to earth, double - phase with or without simultaneous earth fault and three - phase short circuit. These various short circuit conditions result in different stress conditions for the windings. Mesh analysis and symmetrical components are the two methods most commonly used for determining the magnitude of short circuit currents. In this paper, both methods will be presented with results compared on a real-case transformer. Also, a generic scheme using the symmetrical components approach is designed in order to standardize the short-circuit currents calculation for all power transformer types and to reduce the time required for obtaining results.

Key words: power transformer, symmetrical components, short circuit, inductance matrix, model, mesh analysis

1. INTRODUCTION

For each winding, the short circuit currents with highest magnitudes are the input for the calculation of mechanical forces and stresses for which the transformer is then dimensioned. The worst mechanical stresses arise in different conditions for different types of transformers and network configurations (autotransformers and full transformers, parallel loading cases etc.). Additionally, the costumers requests related to transformer documentation often include calculation of currents for all types of short - circuit faults, with all cases of interest included. This can exceed to more than one hundred calculations per transformer.

Input parameters for the calculation vary for each power transformer, which complicates the standardization of the calculation process. A power transformer can be two or three - winding transformer, it can be fed by one, two or more active networks, its windings can be delta or star connected, its neutral point can be isolated or earthed (solid or through impedance) etc. All of the mentioned parameters influence the structure of the model used for the calculation. Detailed analysis has shown that theory of symmetrical components is more suitable for the development of a standardized approach. In this paper, a generic scheme for positive-sequence, negative-sequence and zero-sequence system is presented, with built-in variables covering all calculation and model possibilities. Application of these schemes provides standardized short-circuit currents calculations for all types of power transformers. This enables automatization of the calculation process and significantly reduces the time required for obtaining all required results. It also allows simple upgrading of the calculation system with additional possibilities due to oncoming requirements and requests.

2. MODELS FOR SHORT-CIRCUIT CURRENTS CALCULATIONS

The calculation of short-circuit currents is most commonly performed with one of the two methods – mesh analysis method or symmetrical components method. [1]

2.1. Mesh Analysis Method

This method is based on creating a transformer model consisting of winding self-inductances and corresponding mutual inductances between windings. In power transformers the resistance component of the impedance is negligible in comparison with the inductance component. Using mesh analysis and by appliying Kirchhoff's voltage law, short-circuit currents are calculated according to formula:

$$[I] = [U] \times [Z]^{-1}, \tag{1}$$

where voltage matrix [U] consists of rated voltages according to the specified model. This method is in detail described in [2], [3].

It is important to emphasize that the model varies for each transformer configuration, as well as each short circuit type.

This method will be used as a comparison method to verify the results obtained with symetrical components method, extended by using generic approach to the calculation.

2.2. Symmetrical Components Method

Symmetrical components method is commonly used to analyze unsymmetrical faults in three-phase power systems. This method is based on the fact that each asymetrical system can be analysed using three symetrical systems: positive-sequence, negative-sequence and zero-sequence system. Impedances of each of the three symetrical systems (z_1 - positive sequence impedance, z_2 - negative sequence impedance and z_0 – zero sequence impedance) are calculated separately and the short-circuit surrents (i_1, i_2, i_0) are calculated for each case according to the specified models (Figure 1). Corresponding formulas are presented in relative units, with electromotive force of 1 p.u. (100%) [4].

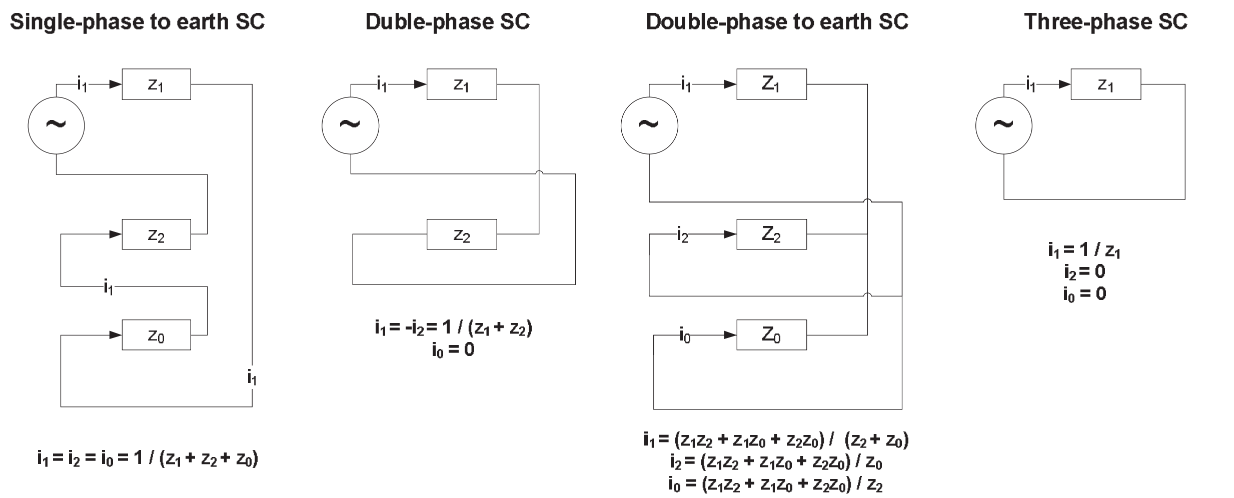

Figure 1 - Symetrical components models for different types of short-circuit

Impedances for positive-sequence, negative-sequence and zero-sequence system are influenced by a number of parameters. In order to insure simple, and unified calculation for these impedances, a generic formula has been developed and presented in the next chapter.

3. GENERIC APPROACH FOR SYMETRICAL COMPONENTS METHOD

Negative-sequence impedance is equal to positive-sequence impedance; therefore they will be presented on a mutual model. Zero-sequence impedance is influenced by more parameters and is presented on a separated model.

3.1. Positive- and negative-sequence model

Basic positive-sequence model for three – winding transformer is presented in Figure 2.

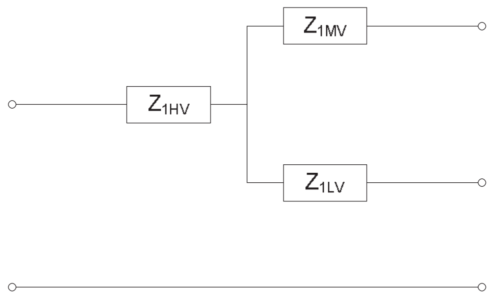

Figure 2 - Basic positive-sequence model

Impedances for each transformer winding presented in Figure 2 are calculated according to equations (2) - (4) and are usualy equal for all three systems:

$$z_{1HV} = z_{2HV} = z_{0HV} = \frac{1}{2}\left(u_{scHV/MV} + u_{scHV/LV} - u_{scMV/LV}\right)j/100 \text{ [p.u.]} \quad (2)$$

$$z_{1MV} = z_{2MV} = z_{0MV} = \frac{1}{2}\left(u_{scHV/MV} + u_{scMV/LV} - u_{scHV/LV}\right)j/100 \text{ [p.u.]} \quad (3)$$

$$z_{1LV} = z_{2LV} = z_{0LV} = \frac{1}{2}\left(u_{scHV/LV} + u_{scMV/LV} - u_{scHV/MV}\right)j/100 \text{ [p.u.]}, \quad (4)$$

where $u_{scHV/MV}$, $u_{scHV/LV}$ and $u_{scMV/LV}$ are percentage rated short-circuit voltages between windings referred to rated power S_r.

Positive-sequence model must take into account active networks to which the transformer is connected. This influence is presented in extended model in Figure 3.

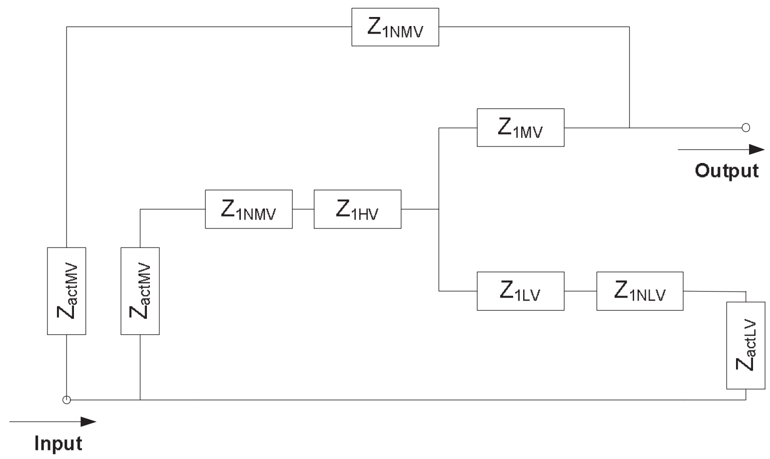

Figure 3 - Extended positive-sequence model

$Z_{activHV}$, $Z_{activMV}$, $Z_{activLV}$ in Figure 3 determine whether the corresponding winding is connected to the active network or not. All combinations are presented in Table I.

Table I - Active network impedances

Active networks	$Z_{activHV}$	$Z_{activMV}$	$Z_{activLV}$
HV	0	∞	∞
MV	∞	0	∞
LV	∞	∞	0
HV and MV	0	0	∞
HV and LV	0	∞	0
MV and LV	∞	0	0
HV, MV and LV	0	0	0

If connected to the active network, impedance of the network must be taken into account. This is presented with network impedances Z_{1NHV}, Z_{1NMV}, Z_{NLV} for each voltage side of the transformer, and calculated according to:

$$z_{1NHV} = z_{2NHV} = z_{0NHV} = \frac{S_r}{S_{scHV}} j \text{ [p.u.]} \tag{5}$$

$$z_{1NMV} = z_{2NMV} = z_{0NMV} = \frac{S_r}{S_{scMV}} j \text{ [p.u.]} \tag{6}$$

$$z_{1NLV} = z_{2NLV} = z_{0NLV} = \frac{S_r}{S_{scLV}} j \text{ [p.u.]} \tag{7}$$

Impedance of the entire model z_1 is calculated with:

$$z_{1HV}' = z_{activHV} + z_{1HVN} + z_{1HV} \text{ [p.u.]} \tag{8}$$

$$z_{1LV}' = z_{activLV} + z_{1NLV} + z_{1LV} \text{ [p.u.]} \tag{9}$$

$$z_1 = z_2 = \left[\left(z_{1HV}' \| z_{1LV}'\right) + z_{1MV}\right] \| \left(z_{activMV} + z_{1NMV}\right) \text{ [p.u.]} \tag{10}$$

Coefficients used to recalculate the positive-sequence current to currents through each winding are as follows:

$$k_{1HV} = \frac{\left(z_{1HV}' \| z_{1LV}'\right)}{z_{1HV}'} = \frac{z_{1LV}'}{z_{1HV}' + z_{1LV}'} \text{ [p.u.]} \tag{11}$$

$$k_{1LV} = \frac{\left(z_{1HV}' \| z_{1LV}'\right)}{z_{1LV}'} = \frac{z_{1HV}'}{z_{1HV}' + z_{1LV}'} \text{ [p.u.]} \tag{12}$$

$$k_{1MV} = \frac{z_1}{\left(z_{1HV}' \| z_{1LV}'\right) + z_{1MV}} \text{ [p.u.]} \tag{13}$$

3.2. Zero-sequence impedance

Zero-sequence model is analog to the positive-sequence model, but influenced by an additional parameter – winding connection. This is presented with impedances Z_{YDHV1}, Z_{YDHV2}, Z_{YDMV1}, Z_{YDMV2}, Z_{YDLV1}, Z_{YDLV2} depicted in Figure 4 which are determined according to the Table II.

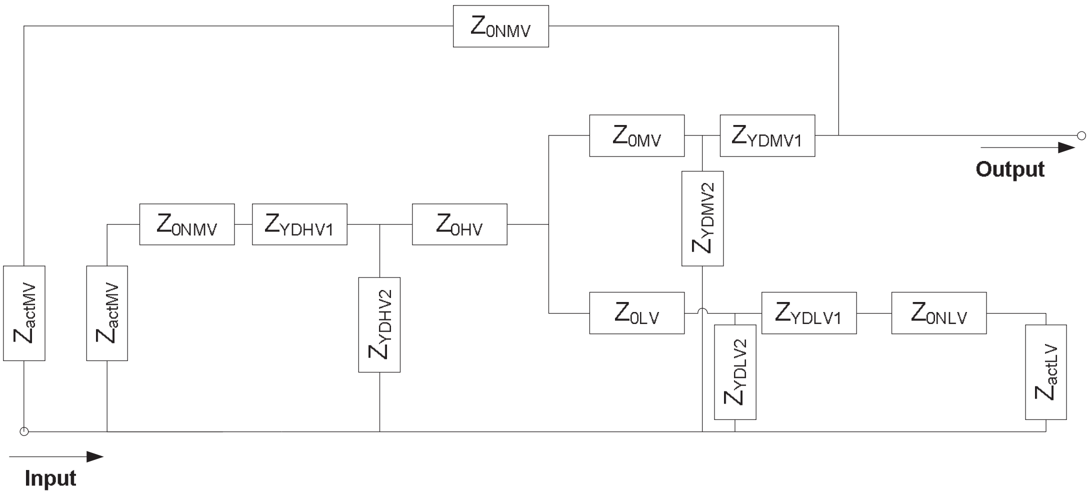

Figure 4 - Extended zero-sequence model

Table II - Winding connection impedances

	Z_{YDHV1}	Z_{YDHV2}	Z_{YDMV1}	Z_{YDMV2}	Z_{YDLV1}	Z_{YDLV2}
Y y y	∞	∞	∞	∞	∞	∞
YN y y	0	0	∞	∞	∞	∞
Y yn y	∞	∞	0	0	∞	∞
Y y yn	∞	∞	∞	∞	0	0
YN yn y	0	∞	0	∞	∞	∞
YN y yn	0	∞	∞	∞	0	∞
Y yn yn	∞	∞	0	∞	0	∞
YN yn yn	0	∞	0	∞	0	∞
Y d y	∞	∞	∞	∞	∞	∞
Y y d	∞	∞	∞	∞	∞	∞
D y y	∞	∞	∞	∞	∞	∞
YN d y	0	∞	∞	0	∞	∞
YN y d	0	∞	∞	∞	∞	0
Y yn d	∞	∞	0	∞	∞	0
Y d yn	∞	∞	∞	0	0	∞
D yn y	∞	0	0	∞	∞	∞
D y yn	∞	0	∞	∞	0	∞
YN d yn	0	∞	∞	0	0	∞
YN yn d	0	∞	0	∞	∞	0
D yn yn	∞	0	0	∞	0	∞
Y d d	∞	∞	∞	∞	∞	∞
D y d	∞	∞	∞	∞	∞	∞
D d y	∞	∞	∞	∞	∞	∞
YN d d	0	∞	∞	0	∞	0
D yn d	∞	0	0	∞	∞	0
D d yn	∞	0	∞	0	0	∞

Impedance of the entire model z_1 is calculated according to equations (14)-(16):

$$z_{0HV}' = \left[\left(z_{activHV} + z_{0NHV} + z_{YDHV1}\right) \| z_{YDHV2}\right] + z_{0HV} \text{ [p.u.]} \quad (14)$$

$$z_{0LV}' = \left[\left(z_{activLV} + z_{0NLV} + z_{YDLV1}\right) \| z_{YDLV2}\right] + z_{0LV} \text{ [p.u.]} \quad (15)$$

$$z_0 = \left[\left(z_{0HV}' \| z_{0LV}' + z_{0MV}\right) \| z_{YDMV2} + z_{YD;V1}\right] \| \left(z_{activMV} + z_{oNMV}\right) \text{ [p.u.]} \quad (16)$$

Coefficients used to recalculate the zero-sequence current to currents through each winding are as follows:

$$k_{0HV} = \frac{\left(z_{0HV}' \| z_{0LV}'\right)}{z_{0HV}'} = \frac{z_{0LV}'}{z_{0HV}' + z_{0LV}'} \text{ [p.u.]} \quad (17)$$

$$k_{0LV} = \frac{\left(z_{0HV}' \| z_{0LV}'\right)}{z_{0LV}'} = \frac{z_{0HV}'}{z_{0HV}' + z_{0LV}'} \text{ [p.u.]} \quad (18)$$

$$k_{0MV} = \frac{z_{activMV} + z_{0NMV}}{\left[\left(z_{0HV}' \| z_{0LV}' + z_{0MV}\right) \| z_{YDMV2} + z_{YDMV1}\right] + z_{activMV} + z_{0NMV}} \cdot \frac{z_{YDMV2}}{z_{0HV}' \| z_{0LV}' + z_{0MV} + z_{YDMV2}} \text{ [p.u.]} \quad (19)$$

4. CASE STUDY

Calculation of short-circuit currents will be performed on a real case transformer, using both methods. The aim is to illustrate how the generic approach simplifies the calculation process, and is also less time consuming. The mesh analysis method requires separated models for each short-circuit case.

Input data for transformer T1 are presented in Table III, where S_r is rated power of the transformer; U_{rHV}, U_{rMV} and U_{rLV} are rated voltages; $u_{scHV/MV}$, $u_{scHV/LV}$ and $u_{scMV/LV}$ are rated short-circuit voltages between windings referred to rated power S_r.

Table III - Input data for transformer T1

S_r [MVA]	Winding connection	U_{rHV} [kV]	U_{rMV} [kV]	U_{rLV} [kV]	$u_{scHV/MV}$ [%]	$u_{scHV/LV}$ [%]	$u_{scMV/LV}$ [%]	S_{scHV} [MVA]	S_{scMV} [MVA]
400	YNynd	400	115	10.57	12.24	86.46	69.95	12000	5000

Tertiary (LV) winding has a function of stabilization so the calculations will be performed with short-circuit on MV side of the transformer. Both, HV and MV side are connected to an active network.

4.1. Mesh Analysis Method

4.1.1. Single-phase to earth short circuit on MV side

Model for single-phase to earth short circuit on MV side is presented in Figure 5, where U_{rHV_U}, U_{rHV_V} and U_{rHV_W} are rated voltages for each phase on HV side of the transformers with corresponding network industance Z_{NHV}. U_{rMV_U}, U_{rMV_V} and U_{rMV_W} are rated voltages for each phase on MV side of the transformers with corresponding network inductance Z_{NMV}.

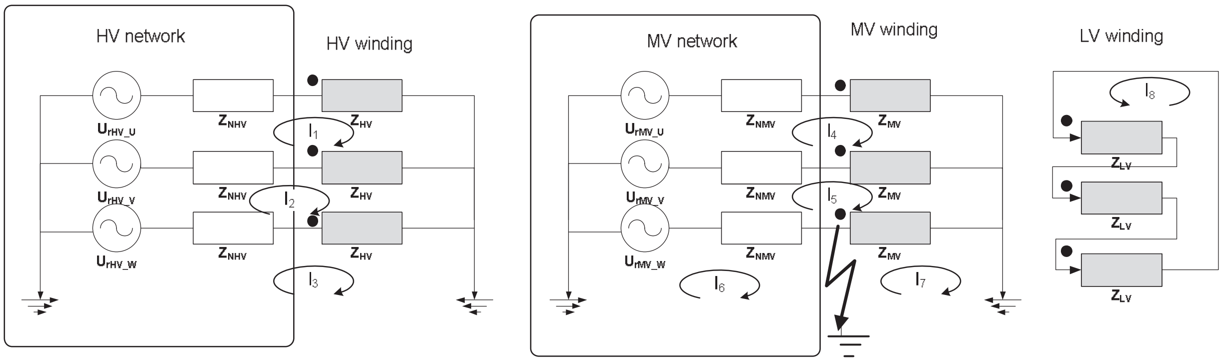

Figure 5 - Model for single-phase to earth short circuit on MV side

Network impedances on Figure 5 are calculated according to the formulas:

$$Z_{NHV} = j\frac{U_{rHV}^2}{S_{scHV}} \tag{20}$$

$$Z_{NMV} = j\frac{U_{rMV}^2}{S_{scMV}} \tag{21}$$

Z_{HV}, Z_{MV} and Z_{LV} are transformer inductances for each winding calculated from the expressions:

$$Z_{HV} = \frac{U_{rHV}^2}{i_0 \cdot S_r} \cdot 100\,, \tag{22}$$

$$Z_{MV} = \frac{U_{rMV}^2}{i_0 \cdot S_r} \cdot 100\,, \tag{23}$$

$$Z_{LV} = \frac{U_{rLV}^2}{i_0 \cdot S_r} \cdot 100\,, \tag{24}$$

where i_0 is the magnetizing current in percent of the rated current.

Mutual inductances between the winding $M_{HV/MV}$, $M_{HV/LV}$ and $M_{MV/LV}$ are not shown in Figure 5 and are calculated from the following expressions:

$$M_{HV/MV} = \sqrt{Z_{MV} \cdot \left(Z_{HV} - \frac{u_{scHV/MV} \cdot U_{rHV}^2}{S_r} \right)}\,, \tag{25}$$

$$M_{MV/LV} = \sqrt{Z_{LV} \cdot \left(Z_{MV} - \frac{u_{scMV/LV} \cdot U_{rMV}^2}{S_r} \right)}\,, \tag{26}$$

$$M_{HV/LV} = \sqrt{Z_{LV} \cdot \left(Z_{HV} - \frac{u_{scHV/LV} \cdot U_{rHV}^2}{S_r} \right)}\,, \tag{27}$$

Kirchhoff's voltage law equations are given in matrix form in (28):

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \\ I_8 \end{bmatrix} = \begin{bmatrix} j(2\cdot Z_{NHV}+2\cdot Z_{HV}) & -j(Z_{NHV}+Z_{HV}) & 0 & j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & 0 & 0 & 0 \\ -j(Z_{NHV}+Z_{HV}) & j(2\cdot Z_{NHV}+2\cdot Z_{HV}) & -j(Z_{NHV}+Z_{HV}) & -j(M_{HV/MV}) & j(2\cdot M_{HV/MV}) & 0 & -j(M_{HV/MV}) & 0 \\ 0 & -j(Z_{NHV}+Z_{HV}) & j(Z_{NHV}+Z_{HV}) & 0 & -j(M_{HV/MV}) & 0 & j(M_{HV/MV}) & j(M_{HV/LV}) \\ j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & 0 & j(2\cdot Z_{NMV}+2\cdot Z_{MV}) & -j(Z_{NMV}+Z_{MV}) & 0 & 0 & 0 \\ -j(M_{HV/MV}) & j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & -j(Z_{NMV}+Z_{MV}) & j(2\cdot Z_{NMV}+2\cdot Z_{MV}) & -j(Z_{NMV}) & -j(Z_{MV}) & 0 \\ 0 & 0 & 0 & 0 & -j(Z_{NMV}) & j(Z_{NMV}) & 0 & 0 \\ 0 & -j(M_{HV/MV}) & j(M_{HV/MV}) & 0 & -j(Z_{MV}) & 0 & j(Z_{MV}) & j(M_{MV/LV}) \\ 0 & 0 & j(M_{HV/LV}) & 0 & 0 & 0 & j(M_{MV/LV}) & j(3\cdot Z_{LV}) \end{bmatrix}^{-1} \times \begin{bmatrix} u_{rHV\_U}-u_{rHV\_V} \\ u_{rHV\_V}-u_{rHV\_W} \\ u_{rHV\_W} \\ u_{rMV\_U}-u_{rMV\_V} \\ u_{rMV\_V}-u_{rMV\_W} \\ u_{rMV\_W} \\ 0 \\ 0 \end{bmatrix} \quad (28)$$

4.1.2. Three-phase short circuit on MV side

Model for three-phase short circuit on MV side of the transformer is presented in Figure 6.

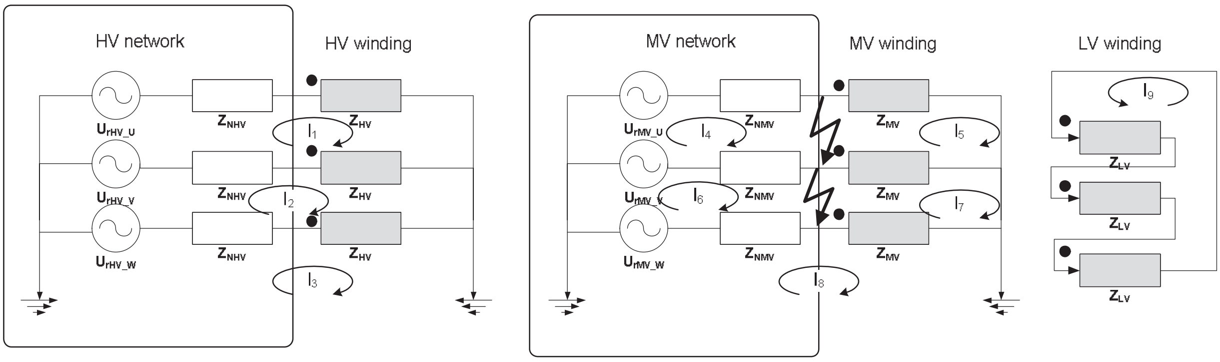

Figure 6 - Model for three-phase short circuit on MV side

Kirchhoff's voltage law equations are given in matrix form in (29).

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \\ I_8 \\ I_9 \end{bmatrix} = \begin{bmatrix} j(2\cdot Z_{NHV}+2\cdot Z_{HV}) & -j(Z_{NHV}+Z_{HV}) & 0 & 0 & j(2\cdot M_{HV/MV}) & 0 & -j(M_{HV/MV}) & 0 & 0 \\ -j(Z_{NHV}+Z_{HV}) & j(2\cdot Z_{NHV}+2\cdot Z_{HV}) & -j(Z_{NHV}+Z_{HV}) & 0 & -j(M_{HV/MV}) & 0 & j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & 0 \\ 0 & -j(Z_{NHV}+Z_{HV}) & j(Z_{NHV}+Z_{HV}) & 0 & 0 & 0 & -j(M_{HV/MV}) & j(M_{HV/MV}) & j(M_{HV/LV}) \\ 0 & 0 & 0 & j(2\cdot Z_{NMV}) & 0 & -j(Z_{NMV}) & 0 & 0 & 0 \\ j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & 0 & 0 & j(2\cdot Z_{MV}) & 0 & -j(Z_{MV}) & 0 & 0 \\ 0 & 0 & 0 & -j(Z_{NMV}) & 0 & j(2\cdot Z_{NMV}) & 0 & -j(Z_{NMV}) & 0 \\ -j(M_{HV/MV}) & j(2\cdot M_{HV/MV}) & -j(M_{HV/MV}) & 0 & -j(Z_{MV}) & 0 & j(2\cdot Z_{MV}) & -j(Z_{MV}) & 0 \\ 0 & -j(M_{HV/MV}) & j(M_{HV/MV}) & 0 & 0 & -j(Z_{NMV}) & -j(Z_{MV}) & j(Z_{NMV}+Z_{MV}) & j(M_{MV/LV}) \\ 0 & 0 & j(M_{HV/LV}) & 0 & 0 & 0 & 0 & j(M_{MV/LV}) & j(3\cdot Z_{LV}) \end{bmatrix}^{-1} \times \begin{bmatrix} u_{rHV\_U}-u_{rHV\_V} \\ u_{rHV\_V}-u_{rHV\_W} \\ u_{rHV\_W} \\ u_{rMV\_U}-u_{rMV\_V} \\ 0 \\ u_{rMV\_V}-u_{rMV\_W} \\ 0 \\ u_{rMV\_W} \\ 0 \end{bmatrix} \quad (29)$$

4.2. Symmetrical Components – Generic Approach

The calculation is performed for single-phase to earth and three-phase short circuit on MV side of the transformer. Both HV and MV side are connected to active network. According to Table I, active impedances for this case are $Z_{activHV} = 0$, $Z_{activMV} = 0$, $Z_{activLV} = \infty$; and according to Table II, winding connection impedances are $Z_{YDHV1} = 0$, $Z_{YDHV2} = \infty$, $Z_{YDMV1} = 0$, $Z_{YDMV2} = \infty$, $Z_{YDLV1} = \infty$, $Z_{YDLV2} = 0$. Hence, formulas (8)-(10) for positive-sequence system are transformed to:

$$z_{1HV}' = z_{1HVN} + z_{1HV} \text{ [p.u.]} \quad (30)$$

$$z_{1LV}' = \infty \text{ [p.u.]} \quad (31)$$

$$z_1 = z_2 = [z_{1HV}' + z_{1MV}] \,\|\, z_{1NMV} \text{ [p.u.]} \quad (32)$$

Coefficients used to recalculate the positive-sequence current to currents through each winding, according to expressions (11)-(13), are as follows:

$$\mathrm{k}_{1\mathrm{HV}} = 1 \text{ [p.u.]} \tag{33}$$

$$\mathrm{k}_{1\mathrm{LV}} = 0 \text{ [p.u.]} \tag{34}$$

$$\mathrm{k}_{1\mathrm{MV}} = \frac{z_1}{z_{1HV}' + z_{1MV}} \text{ [p.u.]} \tag{35}$$

For zero-sequence system, formulas (14)-(16) are transformed to:

$$z_{0HV}' = z_{0NHV} + z_{0HV} \text{ [p.u.]} \tag{36}$$

$$z_{0LV}' = z_{0LV} \text{ [p.u.]} \tag{37}$$

$$z_0 = \left(z_{0HV}' \| z_{0LV}' + z_{0MV}\right) \| z_{oNMV} \text{ [p.u.]} \tag{38}$$

Coefficients used to recalculate the zero-sequence current to currents through each winding, according to expressions (17)-(19), are as follows:

$$\mathrm{k}_{0\mathrm{HV}} = \frac{\left(z_{0HV}' \| z_{0LV}'\right)}{z_{0HV}'} = \frac{z_{0LV}'}{z_{0HV}' + z_{0LV}'} \text{ [p.u.]} \tag{39}$$

$$\mathrm{k}_{0\mathrm{LV}} = \frac{\left(z_{0HV}' \| z_{0LV}'\right)}{z_{0LV}'} = \frac{z_{0HV}'}{z_{0HV}' + z_{0LV}'} \text{ [p.u.]} \tag{40}$$

$$\mathrm{k}_{0\mathrm{MV}} = \frac{z_{0NMV}}{\left(z_{0HV}' \| z_{0LV}' + z_{0MV}\right) + z_{0NMV}} \text{ [p.u.]} \tag{41}$$

4.2.1. Single-phase to earth short circuit on MV side

According to Figure 1 short-circuit current for each system is calculated as:

$$i_1 = i_2 = i_0 = \frac{1}{2z_1 + z_0} \tag{42}$$

Short-circuit currents through each winding are calculated with:

$$i_{HV} = 2i_1 k_{1HV} + i_0 k_{0HV} \tag{43}$$

$$i_{MV} = 2i_1 k_{1MV} + i_0 k_{0MV} \tag{44}$$

$$i_{LV} = 2i_1 k_{1LV} + i_0 k_{0LV} \tag{45}$$

4.2.2. Three-phase short circuit on MV side

According to Figure 1, short-circuit current for each system is calculated as:

$$i_1 = \frac{1}{z_1}; \qquad i_2 = i_0 = 0 \tag{46}$$

Short-circuit currents through each winding are calculated with:

$$i_{HV} = 2i_1 k_{1HV} + i_0 k_{0HV} = i_1 k_{1HV} \tag{47}$$

$$i_{MV} = 2i_1 k_{1MV} + i_0 k_{0MV} = i_1 k_{1MV} \tag{48}$$

$$i_{LV} = 2i_1 k_{1LV} + i_0 k_{0LV} = i_1 k_{1LV} \tag{49}$$

4.3. Comparison and Analysis

Results obtained using both methods for single-phase to earth short circuit are presented and compared in Table IV.

Table IV - Results for single-phase to earth short circuit in W phase

Single-phase to earth SC	HV			MV			LV
	U phase	V phase	W phase	U phase	V phase	W phase	
Inductance Matrix (1)	73.5 A	73.5 A	3748 A	771.5 A	771.5 A	14060 A	6442 A
Symetrical Components (2)	73 A	73 A	3748 A	770 A	770 A	14061 A	6443 A
$\frac{(1)-(2)}{(1)} \cdot 100\%$	0.68%	0.68%	0%	0.19%	0.19%	-0.007%	-0.015%

Results obtained using both methods for three-phase short circuit are presented and compared in Table V.

Table V Results for three-phase short circuit results

Three-phase SC	HV			MV			LV
	U phase	V phase	W phase	U phase	V phase	W phase	
Inductance Matrix (1)	3707 A	3707 A	3707 A	12890 A	12890 A	12890 A	0 A
Symetrical Components (2)	3707 A	3707 A	3707 A	12895 A	12895 A	12895 A	0 A
$\frac{(1)-(2)}{(1)} \cdot 100\%$	0%	0%	0%	-0.039%	-0.039%	-0.039%	0%

5. CONCLUSION

Requirements for short-circuit calculations for power transformer are an essential part of the transformer design process. Short circuit currents are input for the calculation of mechanical forces and stresses, as well as an important part of required transformer documentation.

In this paper, two methods for short circuit currents calculation are presented – mesh analysis method and symmetrical components method, with results compared on a real case transformer. Symmetrical components method is then extended using generic approach in order to obtain a standardized system applicable for all transformer types, all transformer configurations and for all short-circuit faults. Presented generic formula simplifies the calculation process and is less time consuming. Its application enables the automatization of the calculation process and also allows simple upgrading of the calculation system with additional possibilities due to oncoming requirements and requests.

6. REFERENCES

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