IMPEDANCE CORRECTION FACTOR OF THREE-WINDING TRANSFORMERS

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ABSTRACT

This paper focuses to using of impedance correction factor for three-winding transformers which is related to short-circuit voltage on referential power. This correction factor influence on size impedance is shown on the two examples of three-winding transformers and subsequently to the size of short-circuit current. The error of the short-circuit current can be made by conversion of the short-current voltage on another referential power and it can be even 19 %. It is neccesary respect substitution at use computer program for calculation in nominal values.

1 INTRODUCTION

The requirement does not rise exchange relative short-circuit voltage on other power, till rated, which is only one. The label values of the short-circuits voltage of the three-winding transformer can be related even on power, which is not rated for given winding. Problem comes out at calculation according ČSN EN 60909-0, where can be found impedance correction factors, because impedance correction factors are different for the short-circuit voltage related on other power between two sides of the three-winding transformer. The correction factor was not used by the standard IEC 909 from year 1988. In another problem is solved entering of the short-circuit voltage and referantial power into computing program for short-circuit calculation.

2 STUDY

The related short-circuit voltage of transformer u_k is given by equation

$$u_{k12}^{(2)U_{n2}} = \frac{U_{k2}}{U_{n2}} = \frac{\sqrt{3}Z_{12}I_{n2}}{U_{n2}}, \tag{1}$$

where U_{k2} is short-circuit voltage on the secondary side, U_{n2} is secondary nominal voltage, Z_{12} is impedance and I_{n2} is secondary nominal current of the transformer. Index 1 would be signed primary side. The number in the brackets of the superscript signs referential power. This related short-circuit voltage can reached to a referantial power S_{n1} in following consideration rated transformation ratio $t_r \doteq \frac{U_{n1}}{U_{n2}} \doteq \frac{I_{n2}}{I_{n1}}$

$$u_{k12}^{(1)U_{n2}} = \frac{\sqrt{3}Z_{12}I_{n1}U_{n1}^2}{U_{n2}}. \tag{2}$$

It is obtained by subtitution $I_{ni} = \frac{S_{ni}}{\sqrt{3}U_{ni}}$ to equation (2) relation

$$u_{k12}^{(2)U_{n2}} = Z_{12}\frac{S_{n2}}{U_{n2}^2} \tag{3}$$

$$u_{k12}^{(1)U_{n2}} = Z_{12}\frac{S_{n1}}{U_{n2}^2} \tag{4}$$

The recomputation of the short-circuit voltage to other power is evident at same relative voltage

$$\frac{u_{k12}^{(2)U_{n2}}}{u_{k12}^{(1)U_{n2}}} = \frac{S_{n2}}{S_{n1}}. \tag{5}$$

As a consequence of u_k is independent on voltage in calculation of Z, because we always want recalculate impedance on one side of transformer. Further we consider that $Z = X$ for simplify calculation relative reactance x_T, which is then equal to u_k. The recomputation of the three-winding transformer from triangle to star configuration of impedances starts from presumption that the measurement is performed between two windings whereas the last winding is open-circuit.

$$\begin{aligned} X_1 &= \frac{1}{2}\left(X_{12} + X_{31} - X_{23}\right) \\ X_2 &= \frac{1}{2}\left(X_{12} + X_{23} - X_{31}\right) \\ X_3 &= \frac{1}{2}\left(X_{23} + X_{31} - X_{12}\right) \end{aligned} \tag{6}$$

So there is no problem with the recomputation of u_k on other power then the rated one. The reactances are even after recomputation identical.
The impedance correction factor is given for impednace of the transformer according the standard ČSN EN 60909-0

$$K_T = 0{,}95\frac{c_{max}}{1 + 0{,}6x_T}, \tag{7}$$

where x_T is relative reactance

$$x_T = \frac{X_T S_{rT}}{U_{rT}^2} \tag{8}$$

and c_{max} is the voltage factor related to the nominal voltage of the network connected to the low-voltage side of the network transformer, further S_{rT} is rated power and U_{rT} is rated voltage of transformer. Standard [3] shows calculation x_T on instance for referent rated power between windings. The using of the K_T factor is determined by standard, see [2].
The problem comes in case of calculation of K_T using of a program on short-circuit calculation, if we recalculate u_k on other power (for $Z = X$ is $x_T = u_k$), K_T will be changed. The program works with input values we enter. If other input values then rated are filled in, K_T will differs.
Hereafter we presume that u_k is outspread to voltage, on which U_k is measured side of the transformer. The u_k measured from any side should be the same. The K_T should be always of the same value to ensure the recalculated impedances from triangle to star impedances configuration will be identical. Considering, the program computes the K_T with mentioned simplifications as follows

$$K_{T12}^{a} = 0{,}95\frac{c_{max}}{1 + 0{,}6\frac{X_{12}S_{n1}}{U_{n1}^2}} = 0{,}95\frac{c_{max}}{1 + 0{,}6u_{k12}^{(1)U_{n1}}}, \tag{9}$$

when it is substituted other referential power, the K_T will differs

$$K_{T12}^{b} = 0{,}95 \frac{c_{max}}{1 + 0{,}6 \frac{X_{12} S_{n2}}{U_{n2}^{2}}} = 0{,}95 \frac{c_{max}}{1 + 0{,}6 u_{k12}^{(2)U_{n2}}}, \tag{10}$$

because $u_{k12}^{(1)U_{n1}} \neq u_{k12}^{(2)U_{n2}}$. The independent of the K_T on referantial voltage is doing away with implementation x_T, but dependence is discovered on referential power, see relationships (63) and (65) in [2]. Relative reactance, or also short-circuit voltage, is independent on voltage regarding to recomputation on one reference voltage for short-circuit impedances.

3 EXAMPLE

Table 1 shows inaccuracies in resulting reactances and short-currents computed by a program in case of different input u_k values referential powers. The reactances are related to voltage level $400\,kV$ (Transformer 1) and $110\,kV$ (Transformer 2).

	Transformer 1			Transformer 2		
t_{r12} (kV/kV)	400/231	400/231	400/231	110/6,3	110/6,3	110/6,3
t_{r23} (kV/kV)	231/34	231/34	231/34	6,3/6,3	6,3/6,3	6,3/6,3
t_{r31} (kV/kV)	400/34	400/34	400/34	110/6,3	110/6,3	110/6,3
S_{12} (MVA)	167	167	167	20	40	40
S_{23} (MVA)	167	60	60	20	20	40
S_{31} (MVA)	167	167	60	20	20	40
u_{k12} $(-)$	0,1195	0,1195	0,1195	0,1083	0,2166	0,2166
u_{k23} $(-)$	0,4080	0,1466	0,1466	0,2054	0,2054	0,4108
u_{k31} $(-)$	0,5561	0,5561	0,1998	0,1083	0,1083	0,2166
X_{12} (Ω)	114,491	114,491	114,491	65,522	65,522	65,522
X_{23} (Ω)	390,898	390,933	390,933	124,267	124,267	124,267
X_{31} (Ω)	532,790	532,790	532,800	65,522	65,522	65,522
K_{T12} $(-)$	0,975	0,975	0,975	0,981	0,925	0,925
K_{T23} $(-)$	0,839	0,961	0,961	0,930	0,930	0,838
K_{T31} $(-)$	0,784	0,784	0,933	0,981	0,981	0,925
X_1 (Ω)	100,686	76,825	116,522	6,493	4,658	8,540
X_2 (Ω)	10,942	34,804	-4,894	57,784	55,950	52,068
X_3 (Ω)	317,021	340,883	380,580	57,784	59,619	52,068
X_1+X_2 (Ω)	111,628	111,629	111,629	64,277	60,608	60,608
X_2+X_3 (Ω)	327,963	375,687	375,687	115,568	115,569	104,136
X_3+X_1 (Ω)	417,708	417,708	497,102	64,277	64,277	60,608
I''_{k_sek} (kA)	3,753	3,753	3,753	18,073	19,167	19,167
I''_{k_ter} (kA)	6,313	6,313	5,305	18,073	18,073	19,167

Table 1: Comparison of the resultant reactances of the transformers for the different powers

The K_T is derived in [2] using superposition method at steady state before short-circuit and during short-circuit.

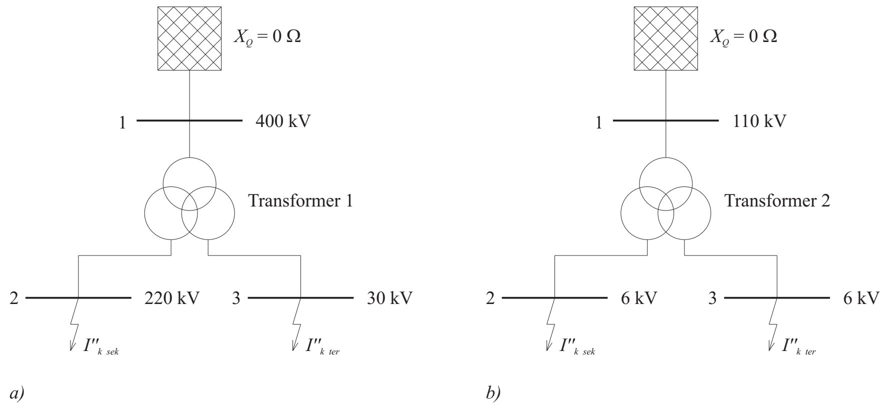

Figure 1: The substitution diagram for the calculation I''_{k_sek} and I''_{k_ter}

The transformer is set by these values:

$$U_{rT1} = 400\,kV \quad U_{rT2} = 231\,kV \quad U_{rT3} = 34\,kV$$
$$S_{rT1} = 167\,MVA \quad S_{rT2} = 167\,MVA \quad S_{rT3} = 60\,MVA$$
$$u_{kr12} = 0{,}1195 \quad u_{kr13} = 0{,}5561 \quad u_{kr23} = 0{,}4080$$

u_{kr} is referred to $167\,MVA$

Table 2: The values from the transformer label

From these values is determined referential power between the particular windings and these are recalculated in relevant rate u_k to power.

index	12	13	23
$S_{rT}\ (MVA)$	167	60	60
$u_{kr}\ (-)$	0,1195	0,1998	0,1466

Table 3: The input values for the computation program

The acceptable values for the transformer 2 are in first column of the table 1. It is obvious that values of short-circuit current obtained by this calculation values are smaller than values obtained from recalculating reached values u_k on other power than rated power between relevant windings.

4 CONCLUSION

Error of the current was at calculation of short-current, on outlets of the transformer at other relative powers for short-circuits voltage using the program, at side 34 kV c. 19 %. u_k is not necessary to be recalculated on other power than rated at two-winding transformer. The relative short-circuit voltages are outspread on the explicit power at three-winding transformers. The problem comes in case of introduction of the correction factor and simultaneously with recalculation u_k to other relative power, because the program substitute relative power for u_k instead of rated power to the relation for x_T. Therefore the determination of u_k would be unified on this account relative to power corresponding with current of the transformator side, at which it was measured. The standard should notice that correction factors would be calculated to rated power and that recomputation to other power than rated is not acceptable, when we use the computer program. ČSN EN 60909-0 presents in equation (10) for the calculation impedances the rated power between sides of the transformer. In these equations it is not important, to which power is u_k related. The standard restricts the calculation for using only rated values.

REFERENCES

[1] ČSN EN 60909-0. *Zkratové proudy v třífázových střídavých soustavách — Část 0: Výpočet proudů*, 2002

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[3] CEI IEC TR 60909-4. *Short-circuit currents in three-phase a.c. systems — Part 4: Examples for the calculation of short-circuit currents*, 2000