Calculating to methodology for short circuit currents in power transformers (PT)

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ABSTRACT

This paper describes a methodology to appropriately calculate short-circuit currents in power transformers using their either actual parameters or their manufacturing specifications. Results considering the are compared ANSI / IEEE C57-12-002006 and IEC 60076-70-5-2006 standards.

Keywords: Power transformer (TP), Short Circuit (SC) and Electric Power Systems (EPS)

1. INTRODUCTION

The development of the power transformer made possible the development of modern systems of power supply. Among the main problems facing the TP and the EPS are all short-circuit currents and their effects cause severe damage to its components, equipment and electrical facilities. For this reason the planning, design and operation of the EPS require detailed studies to evaluate its performance, reliability and security. A typical study in transformers is the short circuit, which is on equipment selection, capability determination as well as protection setting.

Although the TP is a machine designed for a lifecycle of 30 years, It is common in the electric industry to operate reliable machines beyond this limit. To know the state and limit of a transformer, it is important to carry out a large number to detect either a malfunction or an internal failure. The short-circuit test applied to transformers, it is essential to substantiate your capability, they must withstand high currents or overloads, taking into account each parameter to perform such test or by applying different methods according to the rule that will be used.

2. NATURE OF POWER TRANSFORMERS IN SC

A transformer is a static machine that reduces or increases the AC voltage level, through the interaction of a magnetic field. The main elements of the machine are the windings (copper coils wound) and the by ferromangnetic core. To explain the operation of the transformer see Figure 1 where it can be analyzed applying a voltage to the primary winding, a current flows through it, which will induce a magnetic flux in the ferromagnetic core, this circulating flow and make a connection between both windings because of both of them are mounted on the same core. Having such a connection the voltage to increment or decrement depends also on the transformation ratio (turns ratio).

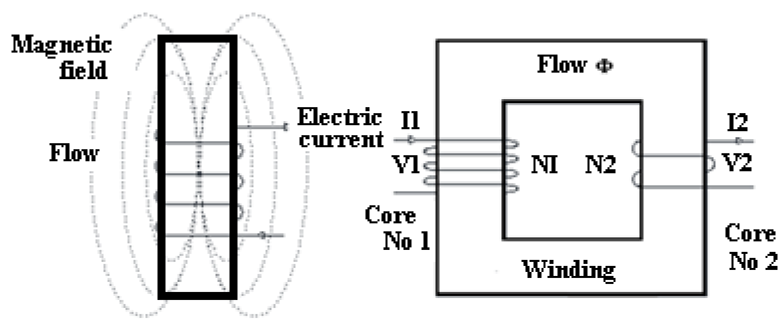

Figure 1: A simple schematic of a transformer.

TPs facilities help to transmit electrical energy from large power plants to residential and industrial users. Typically, the feed voltage and constant frequency, its primary purpose is to adapt the values of voltage and current between the circuits to be connected. Apply in substations, connection or step, power generation and large users. Such machines are classified according to the type of nucleus (columns, battleship and toroidal), the number of phases (single phase, three phase and hexafásicos) and by the power, the power levels as shown in Table 1.

Table 1. Classification by power transformer

CATEGORY	PHASE (KVA)	THREE PHASES (KVA)
I	5 A 500	5 A 500
II	501 A 1667	501 A 5000
III	1668 A 10000	5001 A 30000

The PT constantly present in the copper losses because they are subjected to high temperatures, precisely to reduce these losses on transformer has a cooling system which is the use of oil or air applied either by natural or forced convection, forced convection using a fan or pump.

The main event more severe than occurs in the transformer is SC are disturbances on system generally produce high currents magnitude which cause thermal and mechanical stresses more severe. The SC is a low resistance connection established intentionally or by accident between two points in an electrical circuit. The origin of the short circuit is usually due to deterioration or perforation of the insulation, mechanical problems, due to lightning surges, among others. In three-phase electrical systems can produce different types of faults: symmetrical and asymmetrical fault.

3. . MATHEMATICAL BASIS

Studies of SC in power transformers are used to improve the design of these, and to demonstrate the ability to determine their fault currents.

3.1.1 METHODOLOGY I FOR SHORT CIRCUIT CALCULATION USING ANSI / IEEE C57.12.00.2006.

To calculate the short-circuit current rule provides 4 categories, set out below.

Category I and II

The symmetrical short-circuit current can be calculated by using transformer impedance only.

Category III and IV

The symmetrical SC current is calculated by using transformer impedance plus system impedance specified by the user of the transformer. To obtain the magnitude of the short circuit current is symmetric, uses equation 1.

Symmetrical current.

$$I_{SC} = \frac{I_R}{Z_T - Z_S} \tag{1}$$

Where in:

I_sc is the symmetrical short-circuit current (Arms)

I_r the current ratio is given by the connection of the tap (A rms)

Z_t is the impedance of the transformer in the same base unit that I_r.

Z_s is the impedance of the system or permanently connected devices on the same base unit.

Asymmetrical current.

Now for calculating asymmetrical current used equations 2 and 3.

$$I_{sc\ (Asimetric\ peak,)} = k * I_{sc} \tag{2}$$

$$k = \left\{1 + \left[E^{-\left(\alpha + \frac{\pi}{2}\right)\frac{r}{x}}\right] \sin \alpha\right\} \sqrt{2} \tag{3}$$

Wherein:

ά is the arctan (x / r), (radians)

x/r is the ratio of reactance to resistance, both in ohms, is the total impedance limits the fault current when the short circuit occurs.

3.1.2 METHODOLOGY II FOR CALCULATING CIRCUIT USING IEC 60076-5-2006.

To calculated the symmetrical circuit current using the measured impedance transformer short-circuit coupled to the impedance of the system. For transformer of class I, the contribution of the system impedance is neglected in the calculation of the short circuit current if this impedance is equal to or less than 5% of the short circuit impedance of the transformer. Uses equation 4.

Symmetrical current.

$$I_{SC} = \frac{U_n}{\sqrt{3}\, x\, (Z_t + Z_s)} \quad (4)$$

Where in:

U_n is the nominal system voltage. (kV)

Z_T is the impedance of the transformer;

Z_s is the impedance of the system.

Asymmetric current.

$$i = Ik\sqrt{2} \quad (5)$$

Wherein:

i is the current asymmetrical.

I is the current symmetric.

The factor *K x √2*, or crest factor depends on the ratio *X/R* These values can be obtained from Table 2.

Table 2 Values *f k x √ 2*

X/R	1	2	3	4	5	6	14
K x √2	1,51	1,76	1,95	2,09	2,19	2,27	2,55
NOTE: For other values of X /R between 1 and 14 kx factor √2 can be determined by linear interpolation							

4. ESPERIMENTAL NUMERICAL DATA

The transformer data used for the test case are:

Transformer data.

Power 30MVA

Voltage 115/13.8KV

Category III

4.1.1 METHODOLOGY I FOR THE CALCULATION OF SYMMETRICAL SHORT-CIRCUIT CURRENT USING ANSI /IEEE C57.12.00.2006.

First compute the current given by the connection of the tap, the impedance of the transformer as well as the system impedance. Then we have:

The power system (s_n) is 30MVA.

The impedances as the taps are

Z_sc1=13,158%=13,158

Z_sc3=13,092%=13,092

Z_sc5=13,196%=13,196

The source impedance (Z _s) is given by the following formula.

$$Z_s = \frac{{U_n}^2}{Scc} = \frac{(13.8x10^3)^2}{25100x10^6VA} = \mathbf{0.0076}\Omega$$

The voltage transformer (U_n) is 13.8kV. to obtain the short circuit power of the system uses the table of the short circuit power of the standard for 25100MVA capability. We begin with the calculations and we have the following:

$$I_r = \frac{s_n}{\sqrt{3}\cdot U_n} = \frac{30\text{x}10^6\text{VA}}{\sqrt{3}(13.8\text{x}10^3\text{V})} = \mathbf{1.255x10^3A}$$

The capability of the short circuit current of the transformer is:

$$I_{SC1} = \frac{I_r}{Z_{sc1}} = \frac{1.255\text{x}10^3\text{A}}{.13158} = \mathbf{9538.75}\boldsymbol{A}$$

$$I_{SC3} = \frac{I_r}{Z_{sc3}} = \frac{1.255\text{x}10^3\text{A}}{.13092} = \mathbf{9586.84}\boldsymbol{A}$$

$$I_{SC5} = \frac{I_r}{Z_{sc5}} = \frac{1.255\text{x}10^3\text{A}}{.13196} = \mathbf{9511.29}\boldsymbol{A}$$

The short circuit power of the transformer is:

$$s_{sc1} = \sqrt{3}U_n \cdot I_{sc1} = \sqrt{3}(13.8\text{x}10^3\text{V})(9538.75A) = \mathbf{228}\boldsymbol{MVA}$$

$$s_{sc3} = \sqrt{3}U_n \cdot I_{sc3} = \sqrt{3}(13.8\text{x}10^3\text{V})(9586.84A) = \mathbf{229.15}\boldsymbol{MVA}$$

$$s_{sc5} = \sqrt{3}U_n \cdot I_{sc5} = \sqrt{3}(13.8\text{x}10^3\text{V})(9511.29A) = \mathbf{227.34}\boldsymbol{MVA}$$

The transformer impedance for each tap is:

$$Z_{T1} = \frac{U_n{}^2}{s_{sc1}} = \frac{(13.8\text{x}10^3\text{V})^2}{228x10^6VA} = \mathbf{0.835}\Omega$$

$$Z_{T3} = \frac{U_n{}^2}{s_{sc3}} = \frac{(13.8\text{x}10^3\text{V})^2}{229.15x10^6VA} = \mathbf{0.831}\Omega$$

$$Z_{T5} = \frac{U_n{}^2}{s_{sc5}} = \frac{(13.8\text{x}10^3\text{V})^2}{227.34x10^6VA} = \mathbf{0.838}\Omega$$

The source impedance on PU

$$z_{s1} = \frac{(Z_s \cdot Z_{sc1})}{Z_{T1}} = \frac{(0.0076\Omega)(.13158)}{0.835\Omega} = \mathbf{0.0012}$$

$$z_{s3} = \frac{(Z_s \cdot Z_{sc3})}{Z_{T3}} = \frac{(0.0076\Omega)(.13092)}{0.831\Omega} = \mathbf{0.0012}$$

$$z_{s5} = \frac{(Z_s \cdot Z_{sc5})}{Z_{T5}} = \frac{(0.0076\Omega)(.13196)}{0.838\Omega} = \mathbf{0.0012}$$

Thus concludes with the calculation of symmetrical short-circuit current in accordance with ANSI/IEEE.

$$\boldsymbol{I_{ssc1}} = \frac{I_r}{z_{s1} + Z_{sc1}} = \frac{1.255\text{x}10^3\text{A}}{0.0012 + .13158} = \mathbf{9.45}\boldsymbol{KA}$$

$$\boldsymbol{I_{ssc3}} = \frac{I_r}{z_{s3} + Z_{sc3}} = \frac{1.255\text{x}10^3\text{A}}{0.0012 + .13092} = \mathbf{9.5}\boldsymbol{KA}$$

$$\boldsymbol{I_{ssc5}} = \frac{I_r}{z_{s5} + Z_{sc5}} = \frac{1.255\text{x}10^3\text{A}}{0.0012 + .13196} = \mathbf{9.43}\boldsymbol{KA}$$

4.1.2 CALCULATION OF ASYMMETRICAL SHORT-CIRCUIT CURRENT

For the next calculation takes the following data.

$$I2R1 = 137.955kW$$

$$I2R3 = 141.034kW$$

$$I2R5 = 145.458kW$$

For asymmetric short-circuit current is taken into account in Equation 5. The value k can be taken from Table 2 taking into account the values of *X/R* exists in the norm, but to get exact values can perform the following calculation.

Asymmetric current to TAP 1.

$$\%R1 = \left(\frac{I2R1 \cdot 100}{s_n}\right) = \left(\frac{(137.955kW)(100)}{30MVA}\right) = \mathbf{0.45985}$$

$$R1 = \frac{\%R1 \cdot Z_{T1}}{Z_{sc1} \cdot 100} = \frac{(0.45985)(0.835\Omega)}{(0.13158)(100)} = \mathbf{0.0292}\Omega$$

$$X1 = \sqrt{(Z_{T1})^2 - (R1)^2} = \sqrt{(0.835\Omega)^2 - (0.0292\Omega)^2} = \mathbf{0.835}\Omega$$

According to the following relations are obtained values of *X/R*

$$XR1 = \frac{X1}{R1} = \frac{0.835\Omega}{0.0292\Omega} = \mathbf{28.596}$$

$$RX1 = \frac{R1}{X1} = \frac{0.0292\Omega}{0.835\Omega} = \mathbf{0.035}$$

$$\theta 1 = atan(XR1) = atan(28.596) = \mathbf{1.536}\boldsymbol{rad}$$

$$sen\theta 1 = \sin(1.536) = \mathbf{0.999}$$

$$\boldsymbol{K1} = \left[1 + \left[exp\left[-\left(\theta 1 + \frac{\pi}{2}\right) \cdot RX1\right] \cdot sen\theta 1\right]\right] \cdot \sqrt{2}$$

$$= \left[1 + \left[exp\left[1.536 - \left(+\frac{\pi}{2}\right) \cdot 0.035\right] \cdot 0.999\right]\right] \cdot \sqrt{2} = \mathbf{2.6821}$$

Asymmetrical current to TAP 3.

$$\%R3 = \left(\frac{I2R3 \cdot 100}{s_n}\right) = \left(\frac{(141.034kW)(100)}{30MVA}\right) = \mathbf{0.4701}$$

$$R3 = \frac{\%R3 \cdot Z_{T3}}{Z_{cc3} \cdot 100} = \frac{(0.4701)(0.831\Omega)}{(0.13092)(100)} = \mathbf{0.0298}\Omega$$

$$X3 = \sqrt{(Z_{T3})^2 - (R3)^2} = \sqrt{(0.831\Omega)^2 - (0.0298\Omega)^2} = \mathbf{0.831}\Omega$$

According to the following relations are obtained values of *X/R*

$$XR3 = \frac{X3}{R3} = \frac{0.831\Omega}{0.0298\Omega} = \mathbf{27.831}$$

$$RX3 = \frac{R3}{X3} = \frac{0.0298\Omega}{0.831\Omega} = \mathbf{0.036}$$

$$\theta 3 = atan(XR3) = atan(27.831) = \mathbf{1.535}\boldsymbol{rad}$$

$$sen\theta 3 = \sin(1.535) = \mathbf{0.999}$$

$$\boldsymbol{K3} = \left[1 + \left[exp\left[-\left(\theta 1 + \frac{\pi}{2}\right) \cdot RX3\right] \cdot sen\theta 3\right]\right] \cdot \sqrt{2}$$

$$= \left[1 + \left[exp\left[1.535 - \left(+\frac{\pi}{2}\right) \cdot 0.036\right] \cdot 0.999\right]\right] \cdot \sqrt{2} = \mathbf{2.678}$$

Asymmetrical current to TAP 5.

$$\%R5 = \left(\frac{I2R5 \cdot 100}{s_n}\right) = \left(\frac{(145.458kW)(100)}{30MVA}\right) = \mathbf{0.4849}$$
$$R5 = \frac{\%R5 \cdot Z_{T5}}{Z_{cc5} \cdot 100} = \frac{(0.4849)(0.838\Omega)}{(0.13196)(100)} = \mathbf{0.0308}\Omega$$
$$X5 = \sqrt{(Z_{T5})^2 - (R5)^2} = \sqrt{(0.838\Omega)^2 - (0.0308\Omega)^2} = \mathbf{0.837}\Omega$$

According to the following relations are obtained values of *X/R*

$$XR5 = \frac{X5}{R5} = \frac{0.837\Omega}{0.0308\Omega} = \mathbf{27.198}$$
$$RX5 = \frac{R5}{X5} = \frac{0.0308\Omega}{0.837\Omega} = \mathbf{0.037}$$
$$\theta 1 = atan(XR5) = atan(27.198) = \mathbf{1.534rad}$$
$$sen\theta 5 = \sin(1.534) = \mathbf{0.999}$$
$$\mathbf{K5} = \left[1 + \left[exp\left[-\left(\theta 1 + \frac{\pi}{2}\right) \cdot RX5\right] \cdot sen\theta 5\right]\right] \cdot \sqrt{2}$$
$$= \left[1 + \left[exp\left[1.534 - \left(+\frac{\pi}{2}\right) \cdot 0.037\right]\right] \cdot 0.999\right]\right] \cdot \sqrt{2} = \mathbf{2.675}$$

Obtaining the values of K applied by solving the formula 5 and obtain the asymmetric short-circuit current.

$$I_{asc} = K * I_{sc}$$
$$\boldsymbol{I_{asc1}} = K1 * I_{sc1} = (2.6821)(9.45KA) = \mathbf{25.353kA}$$
$$\boldsymbol{I_{asc3}} = K3 * I_{sc3} = (2.678)(9.5KA) = \mathbf{25.444kA}$$
$$\boldsymbol{I_{asc5}} = K5 * I_{sc5} = (2.675)(9.43KA) = \mathbf{24.036kA}$$

4.1.3 CALCULATION OF SYMMETRICAL SHORT-CIRCUITS CURRENT EMPLOYING IEC.

Corresponding calculation yields the symmetrical short-circuit current.

$$\boldsymbol{I_{ssc1}} = \frac{U_n}{\sqrt{3}(Z_s + Z_{T1})} = \frac{13.8\text{x}10^3\text{V}}{\sqrt{3}(0.0076\Omega + 0.835\Omega)} = \mathbf{9.453KA}$$

$$\boldsymbol{I_{ssc3}} = \frac{U_n}{\sqrt{3}(Z_s + Z_{T3})} = \frac{13.8\text{x}10^3\text{V}}{\sqrt{3}(0.0076\Omega + 0.831\Omega)} = \mathbf{9.5KA}$$

$$\boldsymbol{I_{ssc5}} = \frac{U_n}{\sqrt{3}(Z_s + Z_{T5})} = \frac{13.8\text{x}10^3\text{V}}{\sqrt{3}(0.0076\Omega + 0.838\Omega)} = \mathbf{9.426KA}$$

Calculation of asymmetrical short-circuits current, now for the factor K using the elements to the standard. And you get the following.

$$K1 = 2.55$$

$$K3 = 2.55$$

$$K5 = 2.55$$

$$I_{asc} = I_{sc} * k$$

$$\boldsymbol{I_{asc1}} = I_{sc1} * k1 = (9.453KA)(2.55) = \boldsymbol{24.1kA}$$

$$\boldsymbol{I_{asc3}} = I_{sc3} * k3 = (9.5KA)(2.55) = \boldsymbol{24.23kA}$$

$$\boldsymbol{I_{asc5}} = I_{sc5} * k5 = (9.426KA)(2.55) = \boldsymbol{24.04kA}$$

5. Results

ANSI/IEEE C57.12.00.2006 **IEC 60076-5-2006**

Symmetrical short-circuit currents

ANSI/IEEE C57.12.00.2006	IEC 60076-5-2006
$\boldsymbol{I_{ssc1} = 9.45K}$	$\boldsymbol{I_{ssc1} = 9.453KA}$
$\boldsymbol{I_{ssc3} = 9.50KA}$	$\boldsymbol{I_{ssc3} = 9.50KA}$
$\boldsymbol{I_{ssc5} = 9.43KA}$	$\boldsymbol{I_{ssc5} = 9.426KA}$

Asymmetrical short-circuit currents.

ANSI/IEEE C57.12.00.2006	IEC 60076-5-2006
$\boldsymbol{I_{asc1} = 25.353kA}$	$\boldsymbol{I_{asc1} = 24.1kA}$
$\boldsymbol{I_{asc3} = 25.444kA}$	$\boldsymbol{I_{asc3} = 24.23kA}$
$\boldsymbol{I_{asc} = 24.036kA}$	$\boldsymbol{I_{asc5} = 24.04kA}$

It is clear that there is not a significant difference between the two standards. A notable difference in the ANSI/IEEE regarding the IEC is that the units used per unit (pu).

5.1.1 Using to ANSI/IEEE C57.12.00.2006

Duration of short circuit test.

The duration of the test for the category can be determined by the following equation (6) and for the other categories are shown in Table 3.

$$t = \frac{1250}{I^2} \tag{6}$$

Table 3 Duration of the test circuit.

CATEGORY	LONG TIME
II	1.0 Sec
III	0.5 Sec

5.1.2 USING TO STANDARD IEC 60076-5-2006.

Duration of short circuit test.

For transformer of category I and II are recommended. The duration of each test

- 0.5 s for transformers of Class I
- 0.25s for transformers of categories II and III

With a tolerance of ± 10%

Number of tests that can be done to the transformer.

- For single-phase transformers, three;
- For three-phase transformers: nine.

6. CONCLUSIONS

The use of standards IEC60076 ANSI/IEEEC57.12.00.2006 5-2006 in the study of the short circuit to transformers and other devices is of great importance given the complexity of testing such devices are subjected, studies of SC demonstrate the importance of bringing a team to test aimed to offer in a market that team once the team has left the whole train successful gone all the test train, it is noteworthy that the SC test is the more stringent particularly for transformers, second criterion of these two rules is such as to the bearing capacity symmetrical flows having a small variation in the results of asymmetric currents are however very feasible to use.

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