Numerical Prediction of Maximum Magnetizing Inrush Current in Power Transformers Based on Design Parameters

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***Abstract* – This paper presents an analytical method to predict the maximum inrush current for three phase power transformer. The calculation of transformer design parameters and the method for calculation of peak inrush current is proposed. The magnitude of maximum inrush current by analytical method and the results obtained from simulation in PSCAD/EMTDC are in agreement with one another. This method is very useful to estimate the maximum inrush current before manufacturing of the power transformer.**

***Keywords:-* Power transformers, Magnetizing inrush currents, Measurements, Design parameters, PSCAD/EMTDC simulation.**

I. INTRODUCTION

The reliability of power transformers directly determines whether the power system works safely or not. According to the statistical reports, most of power transformer faults are internal faults. At present, the main protection scheme of internal faults of the power transformer is the differential protection. The sum of the differential circuit currents equals to the exciting current of the power transformer. When the unloaded power transformer is connected to the power system or the power transformer is reconnected to the power system after the fault cleared, it will usually produce magnetizing inrush current, which often causes the differential relay acting wrongly. Therefore the precise simulation of the magnetizing inrush current is essential for designing differential protection relay and setting operating range correctly.

II. INRUSH CURRENT

Transformer energization at no load may result in a very high inrush current as the peak value of the inrush current is a function of the switching instant of the terminal voltage, the characteristics of the magnetization curve(residual and saturation fluxes), the primary winding resistance and the inherent primary winding air core inductance. Inrush currents are originated by the high saturation of the iron core during switching in.

The driving force of the inrush current is the voltage applied to the primary of the transformer. The voltage may drive the flux to build up to a maximum theoretical value of twice the steady state flux plus any residual flux. This super-saturation of the core may lead to an inrush current hundreds of times larger than the normal excitation current and many times larger than the rated current.

Following are the adverse effects of the magnetizing inrush currents of the transformer:

1. The protective devices for overloads and internal faults may falsely operate and may disconnect the transformer.
2. The windings are exposed to mechanical stresses that can damage the transformer[12]-[14].
3. Power quality problems may arise; high resonant over voltages[15] and voltage sags[16].
4. Special problem occurs if large number of transformers are being switched on grid after break in electric energy supply because of appearance of higher harmonics.
5. Mutual effect occurs if transformer is being switched on bus where other transformers are already switched. Disturbances caused

by switched transformer are transferred to other transformers and consumers in the area.

III. INRUSH CURRENT CALCULATION

In this regard, some numerical and analytical methods have been proposed in the literatures. Analytical expressions for the magnetic fluxes of no-load power transformers are presented that can be used for inrush current calculation. In this paper, an analytical method to predict the maximum inrush current for power transformers is presented. The magnitude of maximum inrush current by analytical method and the results obtained from simulation in PSCAD/EMTDC are compared.

Table 1 : Technical Specification of 10 MVA power transformer

KVA capacity	:	10000
HV voltage	:	66000
LV voltage	:	11000
Vector Group	:	Yd1
Et	:	42.35
Net area	:	1238.45
Core diameter	:	420.6
HV turns	:	1356

LV turns : 150

Table 2 : Transformer Coil Dimensions

	LV Coils	HV Coils
Coil I.D.	442.6 mm ø	595.6 mm ø
Radial	45.5	82
Coil O.D.	533.6 mm ø	759.6 mm ø
Axial Height	1376 mm	1250 mm

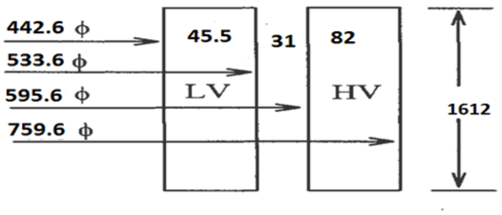

Fig 1 : Dimension of 10 MVA power transformer

IV. ANALYTICAL CALCULATION

Spect , Holcomb , Bertangoli have derived analytical formulae for inrush current measurement.ABB also have given rigorous formula to estimate Inrush current in a transformer.

Here, we have used following two formulae to calculate inrush current.

First formula finds the inrush peak for the first cycle as:

$$i_{o\max} = \frac{K_2 V\sqrt{2}}{X_s}(1 - \cos\theta)$$

Where V = rms value of the applied voltage

K_2=correction factor for the peak value=1.15

θ = saturation angle which corresponds to the instant at which the core saturates,

$$\theta = K_1 \cos^{-1}\left(\frac{B_s - B_{mp} - B_r}{B_{mp}}\right)$$

Here, B_s = saturation flux density,

B_{mp} = peak value of designed steady state flux density in the core.

B_r = residual flux density.

Another formula utilized is :

$$i_{o\max} = \frac{(2B_{mp} + B_r - 2.03)A_c H_w}{\mu_o A_w N_1}$$

Where , A_c = Area of core

A_w = area inside the mean turn of excited winding

H_w = height of energized winding.

V. Simulation

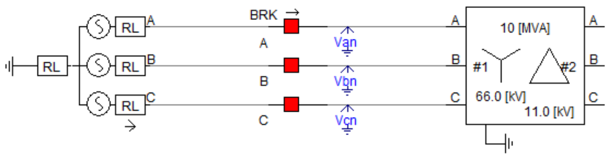

Fig 2 : Modelling circuit of transformer on NO Load in PSCAD/EMTDC

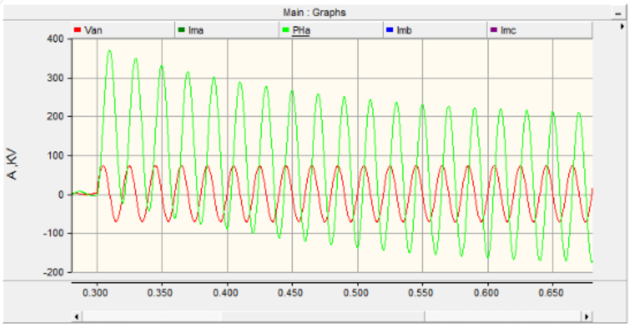

Fig 3: Flux wave form along with the voltage when switched on at energization angle 0°

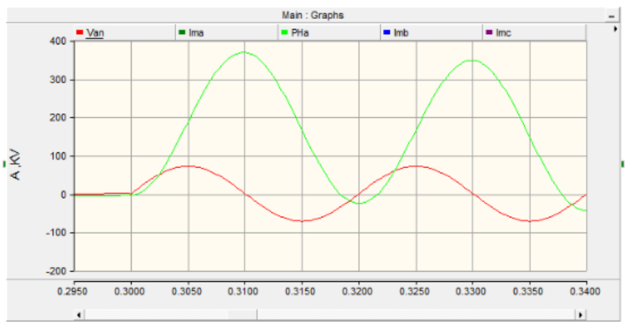

Fig 4: Magnitude of the flux wave form is almost double or more when the voltage is switched on at energization

angle 0^o.

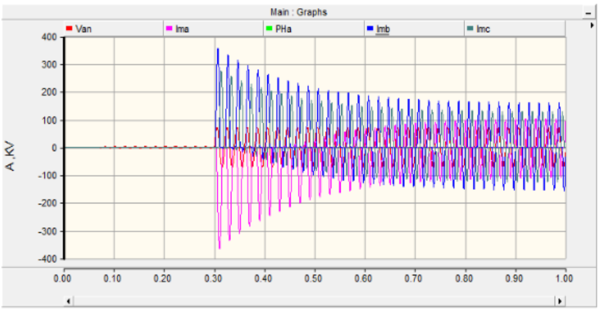

Fig 5: Magnetization Inrush current in all the three phases of 10 MVA power transformer.

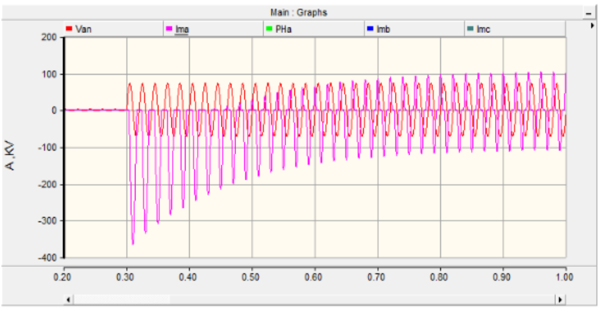

Fig 6: Inrush current in A – Phase of 10 MVA power transformer.

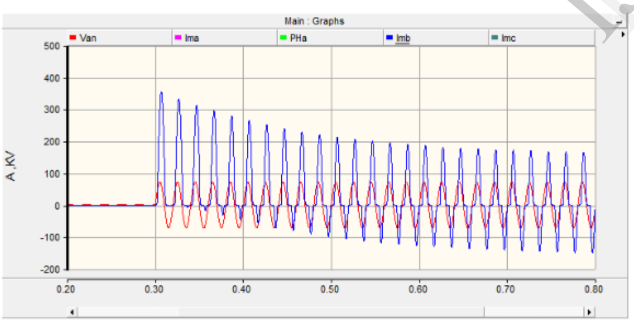

Fig 7: Inrush current in B – Phase of 10 MVA power tansformer.

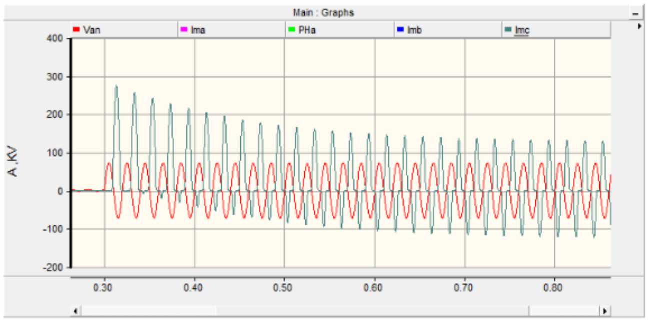

Fig 8: Inrush current in C – Phase of 10 MVA power tansformer.

VI. RESULTS AND DISCUSSION

Inrush currents are computed in this paper with time-domain simulations using the PSCAD/EMTDC software. The switching angle was selected to be at 0^o so that flux builds in the direction of the residual flux. Therefore, we always obtain twice the normal flux plus any residual flux on the leg.

Table 3 : Comparison of Results

Analytical Results	First formula	358.66 A
	Second Formula	364 A
Simulation Results	A Phase	-366.29 A
	B Phase	355.65 A
	C Phase	274.47 A

Table 4 : Comparison of Maximum Inrush Currents

Analytical Results	First formula	358.66 A
	Second Formula	364 A
Simulation Results	Maximum |x| = 366.29 A	

As shown in figure 9, we have used CSMF (continuous system model function) control component to find maximum inrush current out of the three phases of the power transformer.

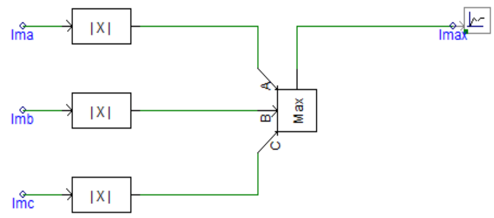

Fig 9: Use of CSMF control Block to find maximum Inrush current in 10 MVA power tansformer.

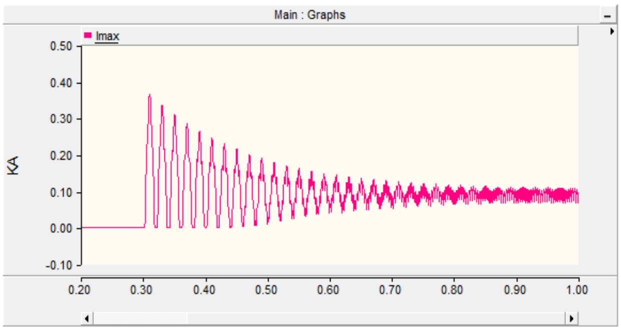

Fig 10: Simulation of Maximum Inrush current in 10 MVA power tansformer.

The differences between the analytical approach and simulation are as follows:

1. Here, residual flux were omitted, since we are concerned with first time energization without any residual flux.
2. Positive leakage inductance were introduced to prevent numerical instabilities with non-linear inductors.
3. The formulae of analytical approach are for single phase transformers. Hence, they are converted to three-phase considering the type of transformer connections. The inrush current value is divided by √3 for the star connected primary and multiplied with 0.557 for delta connected primary.

VII. CONCLUSION

This study enabled the numerical prediction of maximum magnetizing inrush current of single phase and three phase transformers on the basis of design parameters available from the manufacturer.

The magnitude of maximum inrush current by analytical method and the results obtained from simulation in PSCAD/EMTDC are in agreement with each other. This method is very useful to estimate the maximum inrush current before manufacturing of the power transformer.

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