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CALCULATION OF MAGNETIZING INRUSH CURRENT IN TRANSFORMER

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ABSTRACT

When transformer is energized its current reaches very high value generally approximately 10 to 20 times greater than its rated current. This paper deals with study of calculation of inrush current in transformer. Different methods are available to calculate inrush current in transformer. Different methods to calculate inrush current in transformer which depends on operating conditions and type of transformer; which are explained in this paper.The calculation of inrush current is necessary is necessary to predefine the protective system adapted to power transformer.

KEYWORDS: Inrush current, and Calculation methods.

1. INTRODUCTION:

At the time of switching on the transformer its switching current becomes very high for particular cycles of alternating current, which is simply called inrush current of transformer. Its magnitude is normally 10 to 15 times greater than its rated current. This causes the failure of equipments as well as protective system; sometimes causeselectrical accidents. It is necessary in case of power transformer to predict, control and calculates inrush current in transformer. In case of small transformer it is neglected because of low magnitude of working current. At generating station or power station wide use of power transformer having large rating.

The phenomenon of inrush current has been described in different publications as a theoretical and experimental study point of view. The value inrush current depends on parameters of transformer, impedance, instantaneous core magnetization and voltage. The steady state current of transformer is only 1-2 % of rated current. This current in transformer may be due to switching unloaded transformer, external fault, and voltage recovery after fault and out of phase synchronizing of connected generator. Most of the inrush current results are verified in simulation method firstly and then practically. During re-energizing the residual flux will also affect on peak value of transformer. Inrush current can lead the system to undesirable effect like triggering of protection devices alsoresonant voltages. The presence of residual magnetism can also increase the inrush current.

2.THE VARIOUS METHODS TO CONTROL THE INRUSH CURRENT ARE ENLISTED SHORTLY AS BELOW,

- A resistor in series with line.
- By using inrush current limiter.
- Using NTC thermister.
- By using backup transformer.
- Harmonics restrain methods.
- Voltage and flux restraints.
- Inductance based method.
- Pattern Recognition.
- Using Surge-Guard inrush current limiters.
- PTC thermister for inrush current protection.
- By series compensator.
- By reducing residual flux with an ultra low frequency power source.
- By step voltage method.

3. METHODS FOR CALCULATION OF INRUSH CURRENT IN TRANSFORMER

A) FLUX DENSITY EQUATIONS: The following analysis is valid for the cases where each phase can be considered electrically and magnetically independent from the other two phases. This is the case for primaries connected in either solidly earthed star or delta, irrespective of the secondary connection.

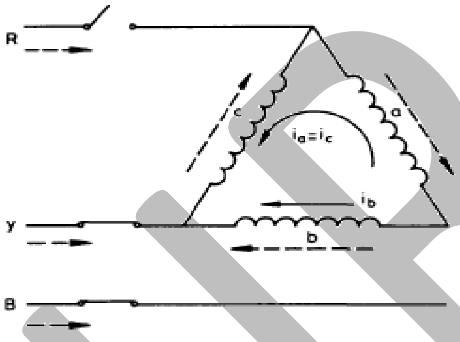
$$B_a(t) = B_{max}[\cos(\alpha) - \cos(\omega t + \alpha)]$$

$$B_b(t) = B_{max}\left[\cos\left(\alpha - \frac{2\pi}{3}\right) - \cos\left(\omega t + \alpha - \frac{2\pi}{3}\right)\right]$$

$$B_c(t) = B_{max}\left[\cos\left(\alpha - \frac{4\pi}{3}\right) - \cos\left(\omega t + \alpha - \frac{4\pi}{3}\right)\right]$$

B) REMNANT FLUX IN 3-PHASE TRANSFORMERS

One of the main difficulties encountered in presenting accurate analytical solution of the inrush current, is the estimation of the remnant flux densities left in the magnetic cores after tripping the circuit-breaker. It is a well known fact that the electrical circuit can be interrupted only when its instantaneous current value is zero or forced to zero (no current chopping). In 3-phase systems one of the circuit-breaker poles interrupts its circuit at a current angle equal to zero or 180°. The other two poles disconnect their circuits simultaneously at some time later (assuming a 3-wire system without earth fault). The currents in the latter two lines are equal in magnitude and opposite in sign because one line represents the return Path of the other. For the 3-phase star connection, when the current is zero, the remnant flux is approximately defined. For the primary delta connection, however, after the first line interrupts, the flux will change in all cores. If the first circuit-breaker pole has opened, in say, line *R,* the line voltage remains across the parallel connection of one winding and the other two windings connected in series asshown in This means that current continues to flow in all three windings and will result in a further change inthe flux in all limbs.An accurate analysis of the final flux value attainedafter the disconnection of lines *Y* and *B* is impossible.Under the assumption of sudden saturation at certain fluxlevel *(f)s*(i.e. *fir—*co* for 0 <</>s and *fir* = 1 for </> ^ 0S) andassuming no energy change between the transformer beingswitched off and the other parallel transformers in thesystem, Reference 15 estimated an approximate final valueof the fluxes of 0, *+ (f>max* and — *<f)max* for the deltaconnected primary of a loaded transformer. These fluxesare instantaneous at the interruption of lines *Y* and *B* andwill decay to the remnant flux value according to thedecay of the small load current, which is still not zero atthe instant of final disconnection of the primary windings.It is again important to allocate suitable values for theremnant fluxes after the decay of the load currents.The same reference suggests that remnant fluxes of 0,+ 0.5 *^)max*and —0.5 *<\>max* are compatible with the inrush currents measured in 11 kV rural systems.



C) THE CALCULATION OF THE INRUSH CURRENT PEAK VALUE OF SUPERCONDUCTING TRANSFORMERS

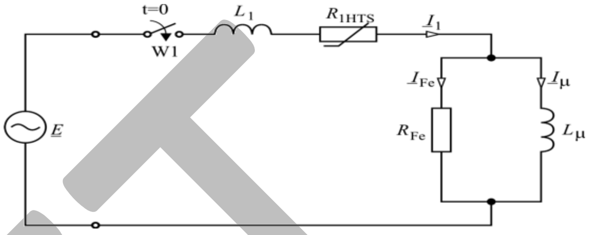


Fig .Intervals for determination of unidirectional current

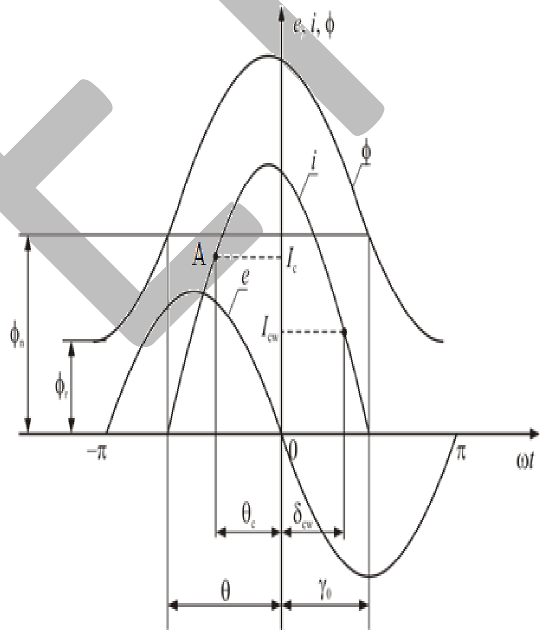


Fig. Equivalent circuit diagram of a no-load HTS transformer

The source of the transformer inrush current is a transient state in the electrical circuit coupled with the magnetic circuit .This state occurs each time voltage on transformer terminals suddenly changes. It is a result of a shift in energy value in the magnetic and electric field of the whole circuit. The equivalent circuit diagram is shown in Figure

If the active current compensating for iron losses (RFe=∞) is excluded and the following is assumed:

$L = L + L1$

the basic equation for transformer operation can be formulated as follows:

$e = -2E\sin\omega t = Ri + L\, di/dt$

$$\cos\theta = \frac{B_n - B_m - B_r}{B_m}$$

$$i = -\frac{\sqrt{2}EX}{Z^2}\left(\begin{array}{l}\frac{R}{X}\sin\omega t - \cos\omega t \\ +\left(\frac{R}{X}\sin\theta + \cos\theta\right)e^{-\frac{R}{X}(\omega t+\theta)}\end{array}\right)$$

$$X = \omega L$$

$$Z = \sqrt{R^2 + X^2}$$

$$\tan\beta_c = \frac{A}{B}$$

$$A = \frac{R}{X}e^{\frac{R}{X}\lambda_c} - \frac{R^2}{X^2}\sin\lambda_c - \frac{R}{X}\cos\lambda_c$$
$$+ I_c\frac{R}{X}\frac{Z^2}{\sqrt{2}EX\cos(\theta_c - \lambda_c)}$$

$$B = e^{\frac{R}{X}\lambda_c} - \frac{R}{X}\sin\lambda_c + \frac{R^2}{X^2}\cos\lambda_c$$

d) The Study of Inrush Current Phenomenon Using Operational Matrices-In this method inrush current can be calculated by Hartley Series and Hartley Matrix of Integration

In this paper the methodology is applied to inrush currentcalculation. The method assumes that the overall inrush transients part of a periodic train of transients. Fig. 1 illustrates thebasic idea behind this concept, where the transient phenomenonhas a time duration of , and a given harmonic has a period, which corresponds to the system fundamental frequency in steady state.

$$I_{inr} = (V_s + I_\psi \mathbf{Z}_1 - V_{init})(\mathbf{Z}_1 + \mathbf{Z}_2)^{-1}$$
$$\Psi = V\mathbf{P}$$

where

$$\mathbf{Z}_1 = r_1\mathbf{U}_I + l_1\mathbf{P}^{-1}$$
$$\mathbf{Z}_2 = r_{mag}\mathbf{U}_I$$
$$V_{init} = V_s(0)\mathbf{P}^{-1} + r_{mag}I_\psi(0) - (r_1 + r_{mag})I_{inr}(0)\mathbf{P}^{-1}$$
$$V = V_s - I_{inr}\mathbf{Z}_1$$

$\mathbf{U}_I$ is the identity matrix.

4. CONCLUSION

By using different methods we can calculate the inrush current in transformer which are explained shortly as above. For calculating inrush current operating condition of transformer, loading conditions ,switching conditions. Different methods are used for different application of transformer .After calculation of inrush current magnitude we can adopt the inrush current controlling methods for that system. The maximum times the experimental results are verified in MATLAB firstly and then implemented. High magnitude of inrush current impact on power system operation .

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