Reetima Mary Sah, Jyoti Srivastava / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 3, May-Jun 2013, pp.984-987

# Modelling And Simulation Of Distribution Transformer For Analysing The Transformer Losses Using Analytical And Simulation Method

[1]Reetima Mary Sah, [2]Jyoti Srivastava
Sam Higginbottom Institute Of Agriculture,Technology & Sciences Allahabad, India

## Abstract

**In this paper, losses due to linear load has been calculated using analytical and simulation method and also losses due to harmonic load current has been calculated by analytical method .Transformer is basic component of power system and it is usually constructed and basically designed to work at rated frequency and perfect sinusoidal load current .Now days use of non linear load has increased a lot ,so losses due to harmonic current has increased .This in turn detoriates the insulation of the winding and life of transformer due to heating .In this paper a 200 KVA 3 phase distribution transformer is taken and losses has been calculated under linear load ,using two methods . i.e computational method and simulation method .Also losses due to harmonic current has been calculated analytically and has been compared with losses of linear load. For simulation method ,a SIMULINK model of transformer is designed and finally both the method has been compared.**

**Keywords:** Transformer losses ,non linear loads ,harmonic current, KVA rating ,Eddy current

## INTRODUCTION

Transformer is most important electrical machine of power system and it is interfaces between consumer and supplies. With increasing demand of electrical energy, number of distribution transformer to be installed is increasing .Efficiency of transformer is usually 97% to 99% as we all know but because of increase in total number of transformer in power system network ,losses has increased. Now days use power electronics device has increased .Because of use of non linear device, has detoriated and reduced the life of transformer .There are many reason that detoriates the insulation of transformer. Harmonic also effect overall performance of a transformer ,which in turn reduces the life of a transformer ,which may also called aging of transformer .The major effects of harmonic distortion is to increase both load and no load losses. Most important losses due to eddy current losses occurring in winding. Increase of eddy current loss because of harmonics increases the temperature of transformer and as mentioned above reduces life of transformer.

In this paper we have used MATLAB software and designed a SIMULINK model and calculated losses due to linear load by simulation method and finally we have compared this simulation method with our analytical method. Also we have calculated losses and rated output under harmonic current analytically and has compared with analytical method used for calculating losses due to linear load.

## LOSSES IN TRANSFORMER

Two types of losses occur in transformer (1) no load losses or core losses (2) load losses

Total loss =no load loss +load loss

$P_{TOTALLOSS}=P_{NOLOADLOSS}+P_{LOADLOSS}$ (1)

Load losses = copper losses +eddy current losses in winding+ other stray losses

$P_{LOADLOSSES}=P_{DC}+P_{EDDYCURRENT}+P_{OTHERSTRAYLOSSES}$ (2)

## NO LOAD LOSSES:

The No load losses or core losses arises in transformer because of the voltage which is induced in core. As we know that the number of distribution transformer is high in power system network and they are always in service. So no load losses is high but it is merely constant. These losses occur because of eddy current and hysteresis phenomenon in the core. Load losses which consist of (a) $I^2R$ LOSSES (b) EDDY CURRENT LOSSES (c) OTHER STRAY LOSSES.

$P_{DC}$ is calculated by knowing the value of resistance and square of load current

$P_{DC}=I^2R$

## III .EDDY CURRENT LOSSES IN WINDING

Two effect is responsible for eddy current losses in winding

(1) SKIN EFFECT (2) PROXIMITY EFFECT

The eddy current losses occurring in winding in power frequency spectrum is directly proportional to $f^2$ and $I^{2,}$ where f and I are frequency and load current. The effect of low order harmonics on skin effect is usually taken negligible in windings of transformer.

**PROXIMITY EFFECT**: In the given figure because of charging current, the hv winding produces a flux density. The core and LV winding cuts the flux density and hence eddy current which is also called circulating current is produced. We call this effect proximity effect. This effect is caused by magnetic field or current carrying conductors that induce currents in other conductors in close proximity to the other current carrying or magnetic fields. Power loss $P_{ec}$ will occur due eddy currents.

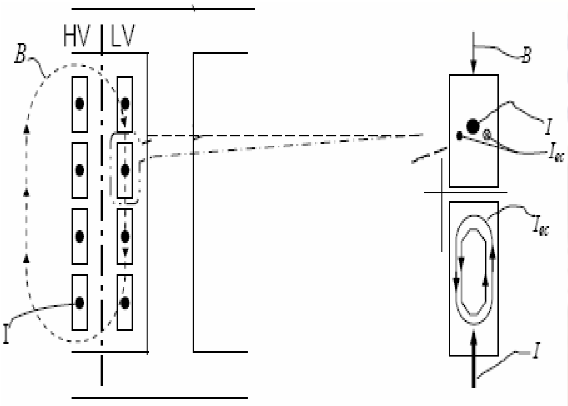


Fig 1. Forming eddy current by proximity effect

The proximity effect loss is given by

$$P_{PE}=\frac{\mu^2 N \omega^2 I^2 n d^4}{128\rho l} G_r. \qquad (3)$$

where n is number of conductor, d is strand diameter, and I is maximum current. $G_r$ is proximity factor and by considering $\delta = \sqrt{\frac{1}{\omega\mu\sigma}}$

**Other stray losses in transformer**

Total stray losses=sum of eddy current losses+ other stray losses (4)

With the help of above equation, we can calculate other stray losses. As we have studied earlier, whenever a conductor is linked by electromagnetic flux. Because of this a voltage is induced in the conductor. Hence eddy current is produced. The losses which takes place in structural parts of transformer for example like clamps, tanks ,walls of enclosure are known as other stray losses. The other stray losses are the part of eddy current loss which takes place in structural part of transformer. Many experiments have been done to determine the effect of frequencies on other stray loss value.

At low frequency (0-360) Hz

$$R_{OSL}=1.29\left(\frac{f_h}{f_1}\right)^{.8} m\Omega \qquad (5)$$

At high frequency (420-1200) Hz

$$R_{OSL}=9.29-.59\left(\frac{f_h}{f_1}\right)^{.9} m\Omega \qquad (6)$$

Hence $P_{OSL}$ is proportional to (i) $I^2$ i.e square of load current (ii) $f^{.8}$

Where f is frequency

**HARMONIC EFFECT ON NO LOAD LOSSES**

As we know by Faraday's law that the voltage at the terminal determines the transformer flux level

$$N\frac{d\phi}{dt}=v\ (t) \qquad (7)$$

We transfer the above equation in frequency domain

$$N\ j\ (h\omega)=V_h \qquad (8)$$

So from above equation it is clear that, the magnitude of flux is directly proportional to harmonic voltage and is inversely proportional to harmonic order h. Also in most power systems, the total harmonic distortion THD of the system voltage is below 5%. The harmonic component of voltage is small if compared to fundamental component. So by neglecting the effect of harmonic voltage and hence considering that the no load losses which occured by the fundamental voltage component will give rise to an insignificant error. But in case $THD_V$ is not negligible then the losses which occurs under distorted voltages calculated with following equation based on ANSI-C.27-1920 standard.

$$P=P_M\ [P_h+P_{ec}(\frac{V_{hrms}}{V_{rms}})^2]. \qquad (9)$$

$V_{h\,r\,ms}$ and V r ms are the r ms values of distorted and sinusoidal voltages, $P_M$ and P are no-load Losses under distorted and sinusoidal voltages, $P_H$ and $P_{EC}$ are hysteresis and eddy current losses.

**HARMONIC EFFECT ON NO LOAD LOSSES EFFECT OF HARMONIC CURRENT ON OHMIC LOSSES**

The $I^2R$ losses occur due to distorted primary and secondary current flowing through primary and secondary winding of transformer. The $I^2R$ loss occurring in winding of transformer under effect of harmonic condition is given by.

$$P_{DC}=R_{DC}*I^2=R_{DC}*(\sum_{h=1}^{h=max} I^2_{h,rms})\ \text{watt} \qquad (10)$$

**EFFECT OF HARMONIC CURRENT ON EDDY CURRENT LOSSES IN WINDING**

The eddy current losses varies by the square of $I^2_{RMS}$ and $f^2$.where f is frequency and $I_{RMS}$ is rm s value of current.

$$P_{ec}=P_{ec}.\sum_{h=1}^{h=max} h^2 \left[\frac{I_h}{I_R}\right]^2 watt \qquad (11)$$

$$F_{HL}=\frac{\sum_{h=1}^{h=max} h^2 I_h^2}{\sum_{h=1}^{h=max} I_h^2}=\frac{\sum_{h=1}^{h=max} h^2\left[\frac{I_h}{I_1}\right]^2}{\sum_{h=1}^{h=max}\left[\frac{I_h}{I_1}\right]^2} \qquad (12)$$

$I_h$ &$I_1$ is harmonic current and fundamental current and $I_R$ is rated load current

So, it is important to multiply eddy current losses occurring in winding by harmonic loss factor $F_{HL}$.

According to IEEEC57.110 standards, amount of rated eddy current loss of windings is about 33% of total stray loss for oil-filled transformers

## EFFECT OF HARMONIC CURRENT ON OTHER STRAY LOSSES

We know that other stray losses is proportional to the square of $I_{RMS}$ and $f^{.8}$,where $I_{RMS}$ is rms current and f is frequency.

$P_{OSL}$ is given by following formula

$$P_{OS}=P_{OSL-R}\sum_{h=1}^{h=max} h^{0.8}\left(\frac{I_h}{I_R}\right)^2 \quad (13)$$

The harmonic loss factor for $P_{OSL}$ is given by following expression

$$F_{HL-STR}=\frac{P_{OSL}}{P_{OSL-R}}=\frac{\sum_{h=1}^{h=max}\left[\frac{I_h}{I}\right]^2 h^{0.8}}{\sum_{h=1}^{h=max}\left[\frac{I_h}{I}\right]^2}=\frac{\sum_{h=1}^{h=max}\left[\frac{I_h}{I_1}\right]^2 h^{.8}}{\sum_{h=1}^{h=max}\left[\frac{I_h}{I_1}\right]^2}$$

(14)

So , it is very important that $P_{OSL}$ should be multiplied by $F_{HL-STR}$ under harmonic losses factor, where $F_{HL-STR}$.

**TRANSFORMER MODEL** In above figure.2 is shown that the proximity effect loss is represented as potential difference defined as the second derivative of load current and other stray losses is represented as a resistor in series with leakage inductance and dc resistance.[2]

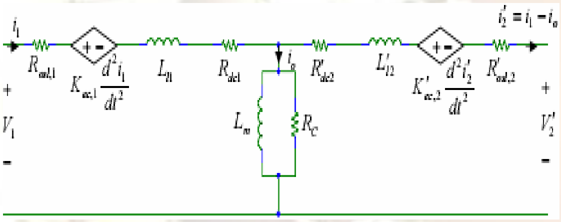

Fig2 PROPOSED EQUIVALENT TRANSFORMER MODEL REFEERED TO PRIMARYSIDE

## CALCULATION AND RESULT

Losses is calculated using two methods (1) ANALYTICAL METHOD (2) SIMULATION METHOD.

ANALYTICAL METHOD A 200 KVA transformer parameters are given below [7]

| $V_1$(V) | $V_2$(V) | $I_1$(A) | $I_2$(A) | $P_O$(W) | $P_{SC}$(W) |
|---|---|---|---|---|---|
| 11KV | 433 | 10.5 | 266.7 | 500 | 3000 |

| $R_1$ | $R_2$ | $L_1$ | $L_2$ | $R_C$ | $X_m$ |
|---|---|---|---|---|---|
| 3.27 Ω | .0041 Ω | .003 H | .067m H | 728K Ω | 32105 H |

To calculate $P_{TSL}$ is calculated below

$P_{TSL}=P_{SC}-P_{DC}=3000-3(10.5^2*3.27 +266.7*.00413)=1043.57$Watt

$P_{EC}=.33*1043.57=3443.7$watt

$P_{OSL}=P_{TSL}-P_{EC}=699.2$watt

## HARMONIC LOAD SPECIFICATION IS GIVEN BELOW

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 5 | 7 | 11 | 13 | 17 | 19 |
| .966 | .208 | .093 | .069 | .045 | .031 | .023 |

## EFFECT OF HARMONIC ON THE CAPACITY OF TRANSFORMER DUE TO NON LINEAR LOAD

When a transformer supplies a non linear load losses are increased, as a result the rated power decreases. To determine the capacity of a transformer under harmonic load, we use following equation and per unit basis is used.

$$P_{LL-R(PU)}=1+P_{EC-R(PU)}+P_{OSL-R(PU)} \quad (F)$$

Now ,if we have non sinusoidal load current

$$P_{LL-R(PU)}=I_{PU}^{2}[1+F_{HL}P_{EC-R(PU)}+F_{HL-STR}P_{OSL-R(PU)}]$$

(15)

The maximum permissible load current of transformer is given by following equation

$$I_{PU}=\left[\frac{P_{LL-R(PU)}}{[1+FHL\ PEC-R(PU)+FHL-STR\ POSL-R(PU)]}\right]^{0.5}$$

(16)

$S_h=S*I_{max(pu)}$

Where,

$P_{LL-R}$=Rated load loss of transformer, $P_{EC-R}$=Eddy current loss winding at rated load.1 is per unit amount of $P_{dc}$ loss, S=Transformer rated capacity, $S_h$=Transformer capacity under non sinusoidal load.

Also $P_{EC-R(PU)}=\frac{P_{EC-RATED}}{I^2R_{RATED}}$, $P_{OSL(PU)}=\frac{P_{OSL-RATED}}{I^2R_{RATED}}$.[6]

With the help of above formula, we can calculate maximum permissible load current of a transformer and reduction of transformer capacity under non-sinusoidal current.

So, $I_{PU}=\left[\frac{1+.17+.34}{[1+3.843*.17+1.193*.34]}\right]^{.5}=(.736)^{.5}=.858$ pu

Current=.858*266.7=228.8A

Equivalent KVA=.858*200 =171.6KVA

## LOSSES UNDER RATED LOAD CURRENT AND HARMONIC LOAD CURRENT BY ANALYTICAL METHOD

| Types of losses | Rated losses (W) | Losses under harmonic load current (W) | Harmonic losses factor | Corrected losses under harmonic load (W) |
|---|---|---|---|---|
| No load | 500 | 500 | ------------ | 500 |
| Dc | 1956.43 | 1989.72 | ------------ | 1989.72 |

| | | | | |
|---|---|---|---|---|
| Winding eddy current | 344.37 | 365.03 | 3.843 | 1402.8 |
| Other stray losses | 699.2 | 741.15 | 1.193 | 884.19 |
| Total | 3499.97 | 3595.9 | | 4776.71 |

| OUTPUT KVA under RATED CURRENT(KVA) | OUTPUT KVA UNDER HARMONIC CURRENT(KVA) |
|---|---|
| 200 | 171.6 |

**SIMULATION METHOD:** With the help of simulation method we will calculate losses under linear load and compare the losses under linear load obtained from analytical method. For this we will design SIMULINK model for no load test, short circuit test, and load test. Finally we will obtain losses by simulation method.

**COMPARISON OF LOSSES UNDER RATED CURRENT BY ANALYTICAL METHOD AND SIMULATION METHOD**

| RATED LOSSES(Watt) | ANALYTICAL METHOD | SIMULATION METHOD |
|---|---|---|
| NO LOAD | 500 | 498.6 |
| D.C | 1956.43 | 727.36 |
| WINDING EDDY CURRENT | 344.37 | 309.02 |
| OTHER STRAY LOSSES | 699.2 | 627.42 |
| TOTAL | 3500 | 2162.64 |

## CONCLUSION

In this paper transformer losses i.e,$I^2R$ losses, winding eddy current losses, stray losses have been calculated by analytical method and simulation method. These calculation determines the transformer equivalent KVA, when it is supplying non linear load. From above calculation, we conclude that losses increase when transformer is supplying non linear load because of harmonic component and hence rated capacity get decreased under harmonic current. Also we conclude that whenever there is change in harmonic current, there is change in harmonic loss factor and definitely change occur in losses and capacity of transformer**.** Also we conclude that by simulation method, losses are less and hence we conclude that simulation method is more accurate than analytical method **.**So in power system network it is important to monitor voltage and current, so that to reach the useful capacity of transformer based on available standard and proposed model if harmonic component is existing.

## REFERENCE

[1] IEEE Std C57.110-1998, "IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non sinusoidal Load Currents"

[2] SAFET AYASUN,1 CHIKA O.NWANKPA "*Transformer Tests Using MATLAB/SIMULINK and their Integration into Undergratuade Electric Machnery Courses.*IEEETRANS EDU,2005 .

[3]. S.B.Sadati, A.Tahani, M.Jafari, M.Dargahi, *Derating of transformers under Nonsinusoidal Loads*, Proc. of the 11th International Conference on Optimization of Electrical andElectronic Equipment OPTIM 2008, Brasov, Romania.

[4]. Sadati, S.B., A. Tahani, B. Darvishi, M. Dargahi and H. Yousefi, 2008. *Comparison of Distribution Transformer Losses and Capacity under Linear and Harmonic Loads.* In the proceedings of the IEEE 2nd International Power and Energy Conference, 2008, PP: 1265-1269.

[5] M.Yazadani-Asrami,M.mirzaie and A.Shayegani Akmal. *Calculation of transformer losses under non sinusoidal currents using analytic methods and finite element analysis* .World applied journal.Vol. II, IMECS 2011, March 16-18, 2011, Hong Kong

[6]. Amit Gupta,Ranjana Singh. *Comparison of transformer losses under the effect of non sinusoidal load currents*, An International Journal,vol.2,No.6,November 2011.

[7]. Mohammed k,Edan. *Non Sinusoidal Loading Effect On Oil Immersed Power Transformers* .Eng & Tech Journal ,Vol 29,No 12,2011

[8]. A.H. Al-badi, A. Elmoudi, I. Metwally. *Losses reduction in distribution transformers*, Proceedings of the International Multi Conference of Engineers and Computer Scientists 2011 VOL II IMECS 2011,MARCH 16-18.2011,HONG KONG

[9] H.I.Zynal, Ala'a a.Yass.*The Effect of Harmonic Distortion on a Three Phase Transformer losses*. Canadian Journal of Electrical and Electronics Engineering Vol.3,no .5,May 2012.